Optimization and automation of the thermal process

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INTRODUCTION

The cooking stage is the final phase of an elaborate technological process for obtaining a good cooked meat product. This phase is a very critical part of the process because one small error can destroy all the work done in the previous phases. And yet, surprisingly, the techniques used have hardly evolved at all since the beginning of the meat industry. Temperature processes and regimes have continued adapting to products over the years, but the equipment used has remained practically the same.

During cooking a series of changes are produced in the product’s internal structure, such as coagulation and breakdown of proteins, which improve the meat’s palatability by intensifying its flavor, destruction of many microorganisms, inactivation of the proteolytic enzymes, stabilization of the meat’s pink cured color, etc.

All these changes directly affect the end product’s appearance, taste, texture and quality, and take place simply by the transference of heat from an ambience (water or steam) to the product’s interior, followed by cooling at a safe temperature by means of similar methods (water, air).

The traditional water cooking process consists of a series of water boilers in which the product is immersed in baskets, which in most cases are still loaded and unloaded manually. There is no specific monitoring or detailed recording of the process, and the last step of the process is usually carried out in a period of time pre-established in tests conducted beforehand, without regard for the product’s final temperature. Over time temperature monitoring of the water, and in some cases of the product, has continued to improve, but even in the most up-to-date water cooking systems, this monitoring tends to fade away when it comes to the cooling phase, which is the most neglected stage of the process. It is rarely taken into account that if cooling is not done properly, problems can result in regard to flavor/texture or weight loss due to overcooking, as well as problems of recontamination caused by decreasing the temperature too slowly.

This mode of operation has been (and continues to be) valid for a certain type of production. But as soon as product traceability is required, with recording of all steps, conventional processes can no longer meet the needs of today’s industry. In order to carry out such monitoring the cooking and cooling phases must be automated, integrating them in a single phase with the transition from one phase to the other performed automatically, without the loss of time that usually results from lack of basket transport capacity or insufficient manpower.

Moreover, since market competition demands uniform and reliable product quality, companies cannot afford to have a segment of the process left unmonitored, without knowing what is happening inside a cooking boiler or a cooling chamber, without the assurance that all pieces have undergone the same process so that the resulting product quality/safety will be homogeneous.

Another important point to be analyzed is the amount of manpower required for the transition between processing phases: loading and unloading of the boilers/ovens, transport of the mold baskets from stuffing to cooking, subsequent transport to cooling and, finally, transfer to the demolding zone. If all these steps are added up, it becomes clear that the number of hours employed in work that contributes no value whatsoever to the product is sufficient justification for automating the system and diverting what is saved in the cost of labor to other more productive work.

And it must not be forgotten that food safety is an issue that, unfortunately, has become a household topic, due to episodes of substandard manufacturing practices that have led to outbreaks of food poisoning. Today it is of utmost importance to be able to ensure proper microbiological quality
of products to be sold to the consumer. And to this end, it is indispensable to have full assurance that the thermal process has been carried out correctly.

This article analyzes an innovative automated FORCED AND DIFFUSE CONVECTION cooking system (FDCC) that eliminates all the above-mentioned shortcomings by means of equipment that provides comprehensive monitoring, product safety and quality, and automation of the process.

What is Forced and Diffuse Convection Cooking (FDCC)?

Before detailing the advantages offered by this system, a brief description of its components will be given. The equipment involved in this process is made up of a boiler divided into two levels by a plate equipped with various holes that allow the passage of water flow from the volume defined in the upper level (chamber 1) and the volume defined in the lower level (chamber 2) to facilitate complete emptying of the boiler. The fundamental advantage of this division lies in the fact that it provides better control and channeling of the water flow inside the boiler and guarantees its circulation through the molds. This modification results in a faster and more uniform flow through the molds, and also provides a more efficient and homogenous thermal transfer.

To intensify recirculation of the fluid, the system is equipped with two water inlets in the upper chamber and, on the opposite surface of the same chamber, two outlets that also constitute the inlets to the lower chamber, repeating the same scheme of inlets and outlets, but running crosswise. Figure 1 shows this arrangement. At each water inlet point there is a distributor formed by a perforated metal plate, which creates a pre-chamber to collect the water coming through the inlet pipe and distribute it to the corresponding boiler chamber as the water flows through its holes.

The system is also provided with outlet distributors, which have the same characteristics as the inlet distributors described above, except that the holes are of a slightly larger diameter. This guarantees a linear flow, in the transverse direction of each chamber, at high velocity (approx. 7 m/s at the outlet of the holes), which uniformly bathes all surfaces of the molds and heats them to the desired temperature as quickly and efficiently as possible.

Each level is equipped with a steam injection system. The upper and lower chambers have a single launch installed on the side nearest the water outlet and near the lower molds, to prevent the formation of steam pockets that are detrimental to the cooking process. From the standpoint of heating energy, this represents a 100% utilization of Steam Energy, since it is mixed directly by means of injection with the cooking water, thereby avoiding the corresponding losses that usually occur in heat transfer between steam-water heat exchange in operating equipment and long pipelines.
Before proceeding to conduct tests using a machine equipped with the above-mentioned elements, the objectives to be achieved were analyzed, in order to determine if it really succeeds in overcoming the deficiencies described regarding systems currently in use:

- **Increase** thermal efficiency of the system and standardization of the process by means of cooking temperature homogenization and process regularity, with the goal of obtaining uniform product quality.

- **Reduce** time-consuming processes and costly manual routines by performing cooking and cooling of the product in a single location, thereby eliminating unnecessary transport procedures.

- **Reduce labor costs** involved in mold loading and unloading phases by automating this step of the process, thereby cutting down on manpower and freeing operators for other tasks.

- **Obtain processing information** easily and precisely with the generation of recorded data.

- **Versatility of formats**: utilization of all mold types available in the plant, without having to replace equipment that is already in use.

**Energy efficiency and regularity in temperature distribution**

In traditional water cooking systems (TC) heat transfer to the product basically takes place by thermal conduction. Only minimal heat transfer occurs through the more efficient method of thermal convection, brought about by simple natural convection due to differences in water temperature and to replacement of hot water to maintain the temperature. This generates thermal pockets and preferential circuits that minimize heat transfer, giving rise to irregular temperature distribution inside the water boiler.

In contrast, the design of the *forced and diffuse convection cooking* (FDCC) system significantly increases recirculation velocity and temperature distribution, maximizing heat transfer with the same energy consumption.

In order to demonstrate the differences between the two cooking systems, a study was conducted of the water flow inside a boiler of each system, and the differences were analyzed using numerical models based on fluid-dynamic simulations (FDS).

The study focused on the distribution of fluid velocities (water) inside the boiler during the recirculation phase. The Figures below show the results obtained from the simulation starting with traditional cooking boilers and traditional molds (Figure 2) and with forced and diffuse convection boilers (Figure 3):

As can be observed in Figure 3, the velocities of temperature recirculation and distribution have been significantly increased, while all fluid-dynamic and thermal bottlenecks have been eliminated inside the boiler (which can be created by the system itself), thereby maximizing heat transfer and notably increasing efficiency of the cooking and cooling process. Since thermal regularity inside the boiler is increased, standardization of the process is
ensured, guaranteeing quality and microbiological safety of the end product.

Automatic control and process recording

The FDCC system incorporates a highly automated cooking/cooling boiler that provides total process control by obtaining recorded data of all steps necessary for product traceability, such as monitoring the product’s temperature during cooking/cooling, eliminating the risk of overcooking. An unmonitored cooking process like the one usually used in the traditional system can result in high losses of water, which can be detrimental for the consumer (sensory aspects) as well as for the product (economic losses).

Figure 4 shows the record of the complete thermal treatment (cooking and cooling) of a product processed by the FDCC system vs. a traditional system:

In the case of the FDCC thermal treatment, it can be observed that once the temperature setpoint has been reached and the cooking phase completed, tempering of the product with water at 15ºC automatically stops, and shortly thereafter cooling of the product with water at 2ºC begins. When the product reaches its final temperature setpoint (4-7ºC in the center of the product) the cooking/cooling process comes to an end. All these changes

▲ Figure 3: Velocity map of the frontal section in the upper level of a FDCC boiler.

▲ Figure 4: FDCC cooking and cooling vs. traditional system.
are performed automatically, without any operator intervention or time wasted.

It can also be observed that the cooking/cooling temperature curve in the traditional system can vary a good deal depending on the method used after cooking. Depending on the duration of pre-cooling with water before entering the chamber (if this is done), the necessary cooling time for the product to reach the desired temperature may vary from 20% to 40%.

In contrast, with automatic cooking, the cooling time is practically equal to product cooking time, and never varies at all. From the standpoint of food safety, this provides an additional guarantee of the end product’s quality.

A central system control computer generates on-line recording of the water temperature and product temperature in each of the boilers being monitored, with graphic display of data and stored records of pasteurization values and process history, resulting in total traceability.

**Automation of transition between phases**

For the system to be truly efficient and productive, it is imperative that all operations that are usually done manually, such as loading/unloading of the boilers and transfer of the mold baskets to the chambers, be performed automatically. Automation not only cuts down on manpower required to complete these tasks, but also eliminates accumulated losses of time due to inattention of operators or not having the necessary transport equipment available.

To prevent such losses of productivity, the FDCC system is equipped with a robot that performs all these tasks, which are programmed in the system’s software. This robot receives the multi-molds or cooking baskets for individual molds at a loading station, where the loading cycle is activated.
The robot picks up the multi-mold/basket and automatically takes it to the selected cooking unit, where it then loads the boiler as indicated in the daily programmed schedule (Fig 5).

Once the cooking and cooling cycle has been completed, the process is repeated in reverse, this time with the multi-molds or baskets transported to an unloading station located at the opposite end of the robot's displacement track.

This automated system provides for an accurate calculation of the plant's production capacity. Since all operations are performed automatically, the exact time spent in each of the stages can be calculated.

**CONCLUSIONS**

As has been explained in this article, it is possible to “modernize” one of the most neglected phases of cooked ham processing. The weak points that currently exist in the cooking/cooling phases, including energy efficiency, monitoring and data recording, and excessive labor, can be overcome with the new technologies available in the market today. The Forced and Diffuse Convection cooking/cooling system offers a totally integrated processing system that provides product standardization and traceability, complete automation and great versatility, compatible with all mold types and without extra investment.

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