# MATHEMATICAL MODELING OF THERMAL PROCESSING OF MEAT PRODUCTS

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## Background

Heat treatment is an operation which takes part in most of manufacturing processes of meat products (cooked meats, cooked meat products, cooked cured meat products, etc.). This operation not only controls microorganism growth but also affects taste, flavor, color and texture of end products, allowing for sensorial features required by consumers. For instance, in cooked emulsion sausage manufacture, heat treatment is a critical operation that ensures emulsion stability. According to Carciofi et al. (2002), meat cooking promotes coagulation and denaturation of proteins, changing their solubility and stabilizing emulsion.

The objective of meat industry is to guarantee hygienic safety and shelf-life of products with minimum thermal exposure in order to prevent degradation of sensorial attributes (ZANONI et al., 1997). Through mathematical modeling, it is possible to determine optimum exposure time, predict thermal distribution, calculate process lethality and evaluate yield losses under different process conditions. Numerical simulation was initially used as an analysis tool in scientific research. Nowadays, it has became a powerful tool in the solution of important applied engineering problems. According to Maliska (1995), simulation will play a major role in project quality and cost, used together with practical experimentation. The easy application of numerical methods even in complex problems allied to the broad dissemination of computer were the key points to the advances observed in this area .

In the planning of heat treatment process of meat products, it is advisable to take into account factors which influence the heating rate, such as geometry and thermophysical properties of the product (FORREST et al.,1979). These properties may be experimentally determined or predicted through mathematical models which take into account effects of chemical composition and temperature.

## Objectives

The proposition of this paper is to present works which were performed in the last ten years, concerning mathematical modeling of thermal processing of meat products. It focuses on the contributions for the meat industry.

## Methods

Conventional methods of heat treatment involve conduction, convection and radiation heat transfer. For example, heat transfer from the surface to the center of a solid piece of meat is done exclusively by conduction. Transient conduction problems, like heat transfer in meat product cooking, is described by Equation 1.

$$\frac{\partial T}{\partial t} = \alpha \ \nabla^2 T \qquad (1)$$

In the equation, $\alpha$ is the thermal diffusivity of the product, $\partial \mathbf{T}/\partial \mathbf{t}$ is the rate of change of temperature and $\nabla^2\mathbf{T}$ is the temperature laplacian. Thermal diffusivity is a thermophysical property of great importance since it permits to establish how fast heat penetrates in the product and to understand the dependence degree between temperature and time. By resolving Equation 1, it is possible to plot transient temperature curves, which represent temperature variation in terms of position and time.

In order to solve heat transfer problems, three techniques are mainly available: analytical methods, numerical methods and laboratory experimentation (MALISKA, 1995). The former two methods are theoretical methods since they directly attack the solution of differential equations, although with different approaches. Analytical methods allow for exact solutions but are only applicable to problems with simple geometry and boundary conditions. Numerical methods (numerical simulation), on the other hand, usually do not present restrictions, permitting the solution of problems with complicated boundary conditions in different geometries, allowing for fast results to be achieved.

Resolution of a physical problems need ability to develop a corresponding mathematical model which can be solved in non prohibitive computational time, whose results can represent correctly the phenomenon studied. Numerical method task is to solve one or more differential equations, substituting derivatives existing in the equation for algebraic expressions. A differential equation is numerically approximated for a fixed number of points. Its approximate solution closely represents exact solution when the number of points is increased (MALISKA, 1995), although with an also increased computational effort. In other words, analytical methods permit exact solutions while numerical methods can only achieve approximate solutions in some points (INCROPERA & DEWITT, 1992).

Laboratory experimentation deals with the real problem though with higher costs. It may not be possible to implement due to instrumentation concerns. Nevertheless, its usage is obligatory in the absence of reliable mathematical models or with extremely complex geometries.

## Results and Discussions

In the last years, some researchers have developed mathematical models for thermal processing of meat products, namely Zorrilla & Singh, (2003), Obuz, Powell & Dikeman (2002), Carciofi et al. (2002) e Pan & Singh (2001), Pan, Singh & Rumsey (2000), Chen, Marks & Murphy (1999), Zanoni et al (1997), Huang & Mittal (1995), Ghazala et al. (1995). These researchers solved heat transfer problem using numerical methods, mainly the finite difference method. Problem solution using finite difference starts with the division of the area under analysis into small regions identified with a central referential point. Each point or node represents a average temperature of the respective region. The numerical determination of temperature distributions demands suitable equations for each node to be solved simultaneously. (INCROPERA & DEWITT, 1992).

Zorrilla & Singh (2003) developed a heat transfer mathematical model in two dimensions, considering a cylindrical geometry in double-sided cooking of meat patties. The proposed model showed no significant difference to predict geometric central temperature when it was compared with one-dimensional model. However, it was able to provide a good description of temperature in regions close to the circumferential edge of the patty, which is not possible with the one-dimensional model. Chen, Marks & Murphy (1999) also proposed a heat and mass transfer mathematical model in two dimensions for patties, working with convection cooking of chicken patties in this case. They achieved good results in temperature and moisture prediction using the finite element method.

Obuz, Powell & Dikeman (2002) developed a heat and mass transfer mathematical model for cooking of cylindrical beef roasts in a forced-air-convection oven which was considered suitable for predicting cooking times. Huang & Mittal (1995) proposed a heat and mass transfer mathematical model for different processes of meatball cooking. According to them, the good agreement between the observed and predict results demonstrated feasibility of the model for predicting cooking time and moisture loss during cooking.

Some papers present mathematical modeling adding predictive food microbiological models to the heat and transfer equations. Through this approach, Pan, Singh & Rumsey (2000) developed a model to the contact-heating process of cooking hamburger patties. A good agreement between predicted and experimental results was achieved, permitting to investigate the effects of process conditions on yield, crust thickness, geometric central temperature and destruction of *Escherichia coli* O157:H7, using the model.

Zanoni et al (1997) proposed and validated experimentally a heat and mass transfer model of bologna sausage cooking, including two thermal inactivation models for the *Enterococcus faecium*: the first order kinectic model and the Whiting and Buchanan model. It was observed in this paper that the former method, which is traditionally used to predict thermal inactivation, is unreliable and risky; while the latter was considered suitable. Ghazala et al. (1995) also used a mathematical model involving heat transfer and thermal inactivation of *E. faecium*. They made simulations with a three-dimensional heat conduction equation for *sous vide* processing (pasteurization and under vacuum packaging ) of fish and meat foods, showing good agreement with experimental results.

In the presented papers, thermophysical properties of food were experimentally measured or obtained through prediction equations. Thermophysical properties are important parameters in food process simulation and design. Saravacos & Kostaropoulos (1996) emphasized the need of accuracy and reliability of data in processes dealing with safety and sensory quality. Carciofi et al. (2002) e Pan & Singh (2001) also stated the importance of thermophysical properties on modeling of food processes. Becker & Fricke (1999) presented some thermophisical property models, such as thermal conductivity and specific heat, and evaluate their performance by comparing their results with experimental data.

## Conclusions

Papers studying mathematical modeling are of great importance in meat product technology and food industry as a whole. These studies contribute to a better understanding of processes, help development of techniques to measure internal temperature and allow for process controlling and optimization. In addition, numerical simulation permits to obtain information with a minimum number of experiments, reducing investigation costs.

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