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Review

Opinion on the use of ohmic heating for the treatment of foods

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A B S T R A C T

Background: The working group "Food Technology and Safety" of the DFG Senate Commission on Food Safety (SKLM) deals with new technologies which are being developed or used to treat foods. Ohmic heating is a new process for heating food by means of direct application of current to the food. Compared to conventional heating methods, this process can achieve shorter heating times while avoiding hot surfaces and can reduce temperature gradients. The electrical, thermophysical and rheological properties of the products play an important role in achieving uniform heating. In addition to the product parameters, process parameters such as the current frequency used, the electrode material and the geometry of the treatment chamber are also relevant.
Scope and approach: On June 22nd 2015, the SKLM issued an assessment of the process for Ohmic heating of food in German. The English version was issued on December 14th, 2015. The objective of this statement was to describe the state of the research, to draw attention to critical points in the application and science-based further development of the process, and to define the need for research.
Key findings and conclusions: As with conventional heating, the effectiveness of ohmic heating as a preservation process depends on reaching and maintaining a certain temperature at each point of the food for a sufficient period of time to inactivate microorganisms. The physicochemical product properties are extremely important for achieving heating conditions that are as uniform as possible. Because the electric field strengths applied are low, mainly thermal effects come into play. However, some studies discuss potential additional synergistic or non-thermal inactivation effects of the electric field. As with other processing methods, the structure and concentration of ingredients and contaminants in foods may be altered during ohmic heating. Besides the thermal effects of ohmic heating, it is also necessary to pay attention to potential electrochemical reactions at the contact surface between electrodes and food as well as potential non-thermal effects of the electric field, depending on the process conditions. Therefore, process control becomes particularly important to prevent such effects, which are sometimes undesirable.
Compared to conventional heating methods, the primary requirement in evaluating ohmic heating is a standardised means of acquiring the process control parameters. This includes, first and foremost, a space- and time-resolved temperature measurement that takes into account the product and electric field properties. It is absolutely necessary to carry out systematic studies while paying attention to the comparability with respect to product and process parameters as well as the system design. Consequently, the existing gaps in the data records are in part due to the insufficient comparability of the available studies.

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Moreover, it is necessary to analyze thermal and non-thermal as well as additional process-induced changes in the food and its ingredients. This applies particularly to the effect on the potential allergenicity of the food components.
Thermal and non-thermal effects can be studied in a differentiated manner in simulation models. This is regarded as a promising approach for providing a model-like description of combination processes and for optimising process conditions as well.

1. Introduction

Conventional thermal methods for pasteurising and sterilising food are based on heat transfer, whereby the heat transfer and thermal conductivity are limiting factors for the quick heating of the product. Particularly in the case of viscous and particulate food, this results in a lengthening of the heating times with a possible overprocessing of individual product fractions and an associated loss of quality. Additionally, in the case of indirect heating methods, heat transfer via hot surfaces can lead to unwanted temperature peaks in the product (Goullieux & Pain, 2005). There is growing interest in alternative thermal methods of pasteurising and sterilising which avoid long heating times, overprocessing and unwanted temperature peaks; the use of ohmic heating in particular is among these methods (Goullieux & Pain, 2005; Ruan, Ye, Chen, Doona, & Taub, 2001; Yildiz-Turp, Sengun, Kendirci, & Icier, 2013; Zareifard, Ramaswamy, Trigui, & Marcotte, 2003).

Research on the preservation of food through the direct application of electric current began as early as at the end of the 19th century, when electricity became commercially available (Jones, 1897). The first industrial applications of ohmic heating for thermal treatment began in 1920 with the 'Electropure' process (Anderson & Finkelstein, 1919; Fellows, 2000; Toepfl, Heinz, & Knorr, 2007). This involved heating milk in a continuous process while using carbon electrodes and an alternating current of 220 V with a frequency of 60 Hz. This process was approved for pasteurising milk in six US states, and by 1950 it was used in 50 plants that supplied milk for approximately 50,000 consumers. At an early stage, additional methods of ohmic heating were patented, such as one for the direct electric heating of sausages (Kohn, 1933; McConnell & Oisson, 1938), and in the mid-20th century a method for blanching vegetables (Schade, 1951). Increasing costs for electricity and the development of alternative thermal processes for preservation, such as UHT-treatment, later led to the reduced usage of ohmic heating (Kessler, 1996). As a result, ohmic heating was essentially further developed for the sole purpose of thawing food (Naveh, Kopelman, & Mizrahi, 1983).

In the 1980s in Europe, interest in ohmic heating for the preservation of food was renewed, and industrial systems came into use (Skudder, 1988). Currently, ohmic heating is used as a thermal method to preheat, to blanch and to pasteurise and sterilise vegetable products, fruit preparations and meat products (Knirsch, dos Santos, Vicente, & Pennaa, 2010; Marcotte, Ramaswamy, & Sastry, 2014). The process is based on using the electrical resistance of the food being treated. Dissipation of the electrical energy when an electric current flows through food causes heat to be released (Joule effect). The amount of dissipated heat is directly related to the applied voltage and the electrical conductivity of the product or of individual product fractions (Ohm's law) (Kessler, 1996; Varghese, Pandey, Radhakrishna, & Bawa, 2014).

In earlier applications, the use of low alternating current frequencies in the range of 50–60 Hz was found to be disadvantageous, as this led to increased electrochemical reactions and electrode erosion, particularly in conjunction with metallic electrodes (Ruan et al., 2001). Direct contact of the food with the electrodes is regarded as a critical aspect of the application. The subsequent technical improvements of the process with respect to the electrode materials being used (such as titanium) and optimised alternating current frequencies in the kilohertz range led to a wider distribution of the technology (Pataro et al., 2014; Samaranayake & Sastry, 2005; Samaranayake, Sastry, & Zhang, 2005).

The advantages of ohmic heating lie in the heating of the product volume, which, ideally, should be uniform (Ruan et al., 2001). Depending on the conductivity of individual product fractions, the configuration of the treatment chamber and the flow characteristics of the food, it could be heated at relatively low temperature gradients. Since heating times are substantially shortened, the cooking load of food (C value), along with the process-dependent change in quality, is reduced while maintaining the same sterilisation effect (Fo value) (Baysal & Icier, 2010; Leizerson & Shimoni, 2005b).

Another advantage is that the food does not come into contact with hot surfaces. It is also possible to largely prevent the formation of unwanted layers of biological, organic or inorganic composition (fouling) by suitably designing the electrode configuration (Ayadi, Benezech, Chopard, & Berthou, 2008; Goullieux & Pain, 2005).

The growing interest in the industrial use of ohmic heating makes it necessary to consider the critical aspects of the method to ensure that it is harmless to health. Although the effect of ohmic heating on the product is primarily classified as thermal, additional electrical effects, which also influence the quality and safety of the food being treated, can not be excluded.

Concepts for the application of ohmic heating to packaged food are in development (Ito, Fukuoka, & Hamada-Sato, 2014; Jun & Sastry, 2005; Somavat, Kamonpatana, Mohamed, & Sastry, 2012) but are not part of this statement.

2. Procedural principles and technical aspects

During ohmic heating there is a **conversion of electrical energy into thermal energy**. Food with an electrical conductivity in the range of 0.1–10 S/m can always be heated by means of ohmic heating. The products to be heated are subjected to an electric field within an arrangement of two or more electrodes. They are in direct contact with the electrodes or are coupled to them via an electrically conductive medium. The treatment can be performed as an intermittent batch process or in a continuous flow system. A current flow develops as a function of the field strength, electrode configuration and conductivity of the products. Based on Ohm's law, this current flow leads to energy input, which is characterised by nearly complete conversion of the electrical energy into heat, high energy density and short heating times. The voltages used lie between 400 and 4000 V. Field strengths in the range of 20–400 V/cm result when electrode gaps of 10–50 cm are used. The achieved **heating rates** depend on the output of the power supply, the