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Review

Ohmic heating in dairy processing: Relevant aspects for safety and quality

L.P. Cappato [a], M.V.S. Ferreira [a], J.T. Guimaraes [b], J.B. Portela [c], A.L.R. Costa [d], M.Q. Freitas [b], R.L. Cunha [d], C.A.F. Oliveira [e], G.D. Mercali [f], L.D.F. Marzack [g], A.G. Cruz [c, *]

[a] *Universidade Federal Rural do Rio de Janeiro (UFRRJ), Departamento de Tecnologia de Alimentos, 23890-000, Seropédica, Rio de Janeiro, Brazil*
[b] *Universidade Federal Fluminense (UFF), Faculdade de Medicina Veterinária, 24230-340, Niterói, Rio de Janeiro, Brazil*
[c] *Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ), Departamento de Alimentos, 20270-021, Rio de Janeiro, Brazil*
[d] *Universidade de Campinas (UNICAMP), Faculdade de Engenharia de Alimentos (FEA), 13083862, Campinas, São Paulo, Brazil*
[e] *Universidade de São Paulo(USP), Faculdade de Zootecnia e Engenharia de Alimentos (FZEA), Av. Duque de Caxias Norte, 225, 13635-900, Pirassununga, SP, Brazil*
[f] *Universidade Federal do Rio Grande do Sul, Instituto de Ciência e Tecnologia dos Alimentos, Av. Bento Gonçalves, 9500, Campus do Vale, Prédio 43.212, 91501970, Porto Alegre, RS, Brazil*
[g] *Universidade Federal do Rio Grande do Sul (UFRGS), Departamento de Engenharia Química, Rua Luiz Englert s/n, 90040-040, Porto Alegre, RS, Brazil*

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A B S T R A C T

Background: Ohmic Heating (OH) technology is a heating process wherein electric current is passed through the food acting as an electrical resistor, converting the electrical energy into thermal energy. This fact results in shorter heating times compared to the conventional process, which promotes some advantages, such as, the maintenance highest levels of nutritional compounds, the uniformness in heating system and the reduction in fouling formation. The success of the process depends on the parameters related to the food and process itself, such as, frequency, electrical field strength, residence time and electrical conductivity.
Scope and approach: This review aims to describe the main factors and parameters involved in this technology, highlighting its effects on quality, microbial inactivation, and fouling during processing of dairy products.
Key findings and conclusions: Due to the more rapid and uniform heating, the OH technology has advantages over the conventional processes, such as maintenance of nutritional compounds and reduction of fouling, which are important factors in the dairy products processing. In addition, there are additional effects of electroporation on microbial cells, which promotes further microorganisms inactivation which are problematic for safety of dairy foods.

1. Introduction

The conventional thermal processing (HTST pasteurization and UHT sterilization) stands out as the most used technique to ensure microbiological safety of processed foods (Goullieux & Pain, 2005). However, due to the heat transfer mechanisms involved (conduction and convection), such processes have certain disadvantages, including overheating, loss of nutritional compounds, and sensory changes; moreover, the combustion of fossil fuels to generate heat causes economic and energy losses (Sakr & Liu, 2014). These drawbacks can be avoided with emerging technologies, such Ohmic Heating (OH) (Goullieux & Pain, 2005; Kaur & Singh, 2016; Sudhir, 2004; Varghese, Pandey, Radhakrishna, & Bawa, 2014).

Despite being considered a new thermal technology, the concept of OH applied to foods is known since the 19th century, being first applied to milk pasteurization (De Alwis & Fryer, 1990). The process fell into disuse because of the high cost of the electricity, lack of suitable inert materials to make the electrodes and difficulties to control the process parameters (Allali, Marchal, & Vorobiev, 2008; Fryer, De Alwis, Koury, Stapley, & Zhang, 1993). However, over the years this technology has been studied by many scientists, and lots of improvements were made. Nowadays, it is applied in different fields, including blanching, evaporation,

* Corresponding author.
E-mail address: food@globo.com (A.G. Cruz).

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dehydration, fermentation, extraction, thawing foods, sterilization and pasteurization (Duygu & Ümit, 2015; Guida et al., 2013; Stancl & Zitny, 2010; Varghese et al., 2014).

OH is defined as a process wherein electric current is passed through materials with the primary purpose of heating them through the conversion of electrical into thermal energy, resulting generally in a rapid and uniform temperature increase within the food (Leizerson & Shimoni, 2005; Mercali, Schwartz, Marczak, Tessaro, & Sastry, 2014). This phenomenon is the greatest advantage of this technique as it allows the development of faster and more effective processes, ensuring greater nutrient retention capacity and sensory attributes (Guida et al., 2013; Pereira, Martins, & Vicente, 2008; Pereira et al., 2015).

The knowledge of the mechanisms during OH is an important factor for the correct application of this technology for thermal processing (Pellegrino, De Noni, & Resmini, 1995). Although the main mechanism involved in the OH microbial inactivation is based on thermal effects, several studies reported the existence of an additional non-thermal effect, which consists of pore formation in the microorganism cell membrane (Jaeger et al., 2016). This phenomenon, known as electroporation, changes the cell permeability and can disrupt the membrane, leading to cell death (Loghavi, Sastry, & Yousef, 2009; Park & Kang, 2013; USA-FDA, 2000; Yoon, Yung, Lee, & Lee, 2002). However, electroporation is still not fully understood and more research is necessary to elucidate it.

Few studies have reported the effect of OH on the intrinsic quality parameters and microbiological stability in dairy products. Jermann, Kuchma, Margas, Leadley, & Ros-Polski (2015) have reported the trends of using emerging technologies for food processing, involving researchers and CEOs (Chief Executive Officer) of large companies, and found that the OH is a promising technology for the dairy sector, with great commercial interest in the next five years. In this context, this paper aims to describe the main factors and parameters necessary for the application of this technology during processing of dairy products, considering its effects on products quality, microbial inactivation and fouling.

2. Fundamentals and process parameters

The basic principle of OH is given by the passage of alternating electric current (AC) via two electrodes inserted in the food, as shown in Fig. 1. The electrical energy conducted through the food is converted into thermal energy due to the electrical resistance of the food (phenomenon known as Joule effect), leading to a volumetric and instantaneous heating. Power generation is directly proportional to the square of the electric field applied (E, V/cm) and the electrical conductivity of the food (σ, S/m) (Ruan, Ye, Chen, Doona, & Taub, 2001).

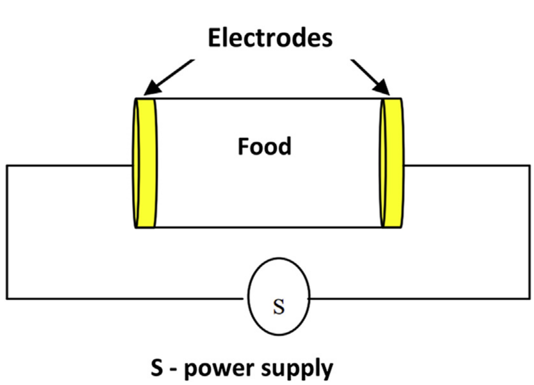

Fig. 1. Basic scheme of ohmic heating.

Table 1 shows the main parameters of the OH concerning the variables inherent of the process, equipment, and product. The most important processing variables are the intensity of the electric field, which vary according to the voltage applied, and the electrical conductivity, which depends on temperature, ionic dissociation, viscosity, texture, solid content, cell structure and the presence of non-conductive components, such as fat, sugar and gases (Sarang, Sastry, & Knipe, 2008). Among them, temperature is the most significant factor because it affects ions mobility in the product (Zareifard, Ramaswamy, Marcotte, & Karimi, 2014a). Alike the conventional heating treatment, the main parameter during the OH to be controlled is the temperature-time profile (USA-FDA, 2000). The effectiveness of the process is strictly related to OH rate, which depends on the electric field and the electrical conductivity of the product. The electrical conductivity measures the material ability to conduct electricity through a unit of area, per unit of potential gradient and time (Goullieux & Pain, 2005) and has units of Siemens per meter (S/m), being determined generally by Equation (I) (Zell, Lyng, Morgan, & Cronin, 2009):

$$\sigma = \frac{L}{A} \times \frac{I}{V} \tag{I}$$

where, A is the cross sectional area perpendicular to the passage of electric current (m^2), L is the distance between the electrodes (m), I is the alternating electric current (A) and V is the voltage applied (V).

Electrical conductivity (EC) is a key parameter in the OH heating, which allows determining the best parameters to be adopted as well as the intensity of process (Goullieux & Pain, 2005; Kaur & Singh, 2016). It is not present constant values and dependent on the material temperature, increasing in a proportional manner with the former (Sark & Liu, 2014). Electrical conductivities between 0.01 and 10 S/m at 25° C are considered suitable for OH process (Mercali et al., 2014). Table 2 shows the electrical conductivity values of dairy products at different temperatures. As can be seen, these values are in the range of those appropriate for OH processing. In food systems with distinct phases, liquid and solid, the this process has major advantages over the conventional heat treatment, since it allows heating both phases in the same rate if they have similar electrical conductivities (Chen, Li, Zhao, & Zheng, 2010; Sastry & Palaniappan, 1992). Studies have reported a linear relationship between the electrical conductivity and the process temperature (Icier & Ilicali, 2005; Sarang et al., 2008), expressed by Equation (II) (Palaniappan & Sastry, 1991).

Table 1
Important parameters of the ohmic heating process.

Parameters	Factors
Processing parameters	Electric field strength
	Time
	Temperature
	Frequency of the electric current
Product parameters	Electrical conductivity
	Viscosity
	Density
	Specific heat
	Homogeneous or solid-liquid systems
	Fouling formation tendency
Equipment parameters	Size of the ohmic cell
	Size and shape of the electrodes
	Electrode composition
	Bath or continuous configuration

*Adapted from: Chen et al., 2010; Crattelet et al., 2013; Fillaudeau et al., 2006; Varghese, Pandey, Radhakrishna, & Bawa, 2014.