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# Continuous ohmic heating system for the pasteurization of fermented red pepper paste

Won-Il Cho[a], Eun-Jung Kim[b], Hee-Jeong Hwang[b], Yun-Hwan Cha[c], Hee Soon Cheon[d], Jun-Bong Choi[e], Myong-Soo Chung[b,*]

[a] CJ Foods R & D, CJCheiljedang Corp., Gyeonggi-do 16495, Republic of Korea
[b] Dept. of Food Science and Engineering, Ewha Womans University, Seoul 03766, Republic of Korea
[c] Dept. of Food and Nutrition, SoongEui Women's College, Seoul 04628, Republic of Korea
[d] R & D center, Seoul Perfumery Corporation, Seoul 06533, Republic of Korea
[e] Graduate School of Hotel & Tourism, The University of Suwon, Gyeonggi-do 18323, Republic of Korea

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ABSTRACT

Ohmic heating (OH) is a processing in which heat is generated inside foods by the passage of electric current. This study aimed to determine the optimal conditions for pasteurizing the *Gochujang* Korean-style fermented food containing hot pepper paste using a continuous OH system. The effective conditions for OH involved three pairs of electrodes connected diagonally and excitation over the voltage range of 50–100 V. The selected conditions provided heating above 100 °C without scale buildup. A microbial inactivation with a 2 log reduction was achieved by the OH, with the processing time being shorter than for conventional heating (CH). OH was available for 57 cycles during 1 cycle of CH, and it could process 104.4 kilotonnes of product. The consistency index related to thickening properties was markedly higher for OH than for CH. This study has confirmed that continuous OH is suitable for the heat-based sterilization of highly viscous foods.

Industrial relevance

Ohmic heating (OH) is a food processing technique in which heat is generated inside food products by the passage of alternating electric current. This study aimed to determine the optimal conditions for pasteurizing the *Gochujang* Korean-style fermented food containing hot pepper paste using a self-designed continuous OH system.

The effective conditions for OH involved three pairs of electrodes connected diagonally and excitation over the voltage range of 50–100 V. The selected conditions provided heating above 100 °C without scale buildup.

The rapid and uniform OH produced a microbial inactivation effect of a 2 log reduction despite the shorter processing time than for batch-type conventional heating (CH).

OH was available for 57 cycles during 1 cycle of CH, and it could process 104.4 kilotonnes of food products. And the continuous OH is suitable for the heat-based sterilization of highly viscous foods and could result in better energy efficiency and be suitable for implementation in industrial applications.

## 1. Introduction

The heat-based sterilization of viscous foods by conventional methods using steam or boiling water can lead to undesirable deteriorations in quality, including changes in color, destruction of nutrients, and decreased flavor. Such deteriorations are associated with the long time required to increase the temperature at the coldest point, which is normally the center of the largest particle, since this may result in overheating of the remaining particles and the surrounding liquid.

Ohmic heating (OH), which is also referred to as Joule heating, electrical resistance heating, and electroconductive heating, is an innovative heating method used in the food industry for processing a broad range of food products (Samaramyake, Sastry, & Zhang, 2005; Sastry, 2008). OH of food products involves passing alternating current through them, which generates internal heat as a result of their intrinsic electrical resistance. The amount of heat released is proportional to the square of the current, which is known as Joule's first law (Sarang, Sastry, & Knipe, 2008). Systems for implementing OH usually involve electrodes being placed inside the food, with electricity passed through it using various voltage and current combinations, and the food being heated by the resulting dissipation of electrical energy. Most foods contain ionic components such as salts and acids that allow the food to

* Corresponding author at: Department of Food Science and Engineering, Ewha Womans University, 52 Ewhayeodae-gil, Seodaemun-gu, Seoul 03766, Republic of Korea.
*E-mail address:* mschung@ewha.ac.kr (M.-S. Chung).

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conduct electric current and thereby rapidly and evenly generate ohmic heat (Sarang et al., 2008).

In contrast to conventional heating (CH), where the heat of a hot surface is conducted from the outside of the food to its inside, OH induces heat within the entire mass of the food uniformly (Leizerson & Shimoni, 2005a, 2005b; Sarang et al., 2008). The success of OH depends on the rate of heat generation of the system, the electrical conductivity of the food, and the method by which the food flows through the system (Leizerson & Shimoni, 2005a).

OH has several advantages over CH, one of which is providing uniform heating without a temperature gradient, with the absence of a cold spots making it possible to rapidly heat an entire sample. OH makes it possible to heat both the solid particles and the liquid in a two-phase food material extremely rapidly and uniformly, resulting in less thermal damage than when using CH, which inherently relies on heat transfer (Icier & Bozkurt, 2011). In addition, the absence of a hot surface in OH reduces fouling problems and thermal damage to the product, and results in the rapid production of a high-quality product with minimal structural, nutritional, or organoleptic changes (Leizerson & Shimoni, 2005b).

These advantages mean that OH is considered suitable for high-viscosity foods and multiphase foods (Samaramyake et al., 2005; Sastry, 2008). *Gochujang* is a Korean traditional fermented food containing red pepper paste with high viscosity that may support many microorganisms including heat-resistant spores of *Bacillus* strains. The application of an effective sterilization process is therefore necessary for the commercial production of safe processed *Gochujang*. Various studies have investigated methods for extending the storage period of *Gochujang*, including by adding garlic, alcohol, chitosan, K-sorbate, and mustard to the matured paste, and pasteurization, retorting, and OH (Kim & Kwon, 2001). It was found out that the heat treatment conditions that produced adequate microbial inactivation when *Gochujang* was placed inside a 15-mm thick retort pouch were 85, 45, and 35 min at 110 °C, 115 °C, and 120 °C, respectively. And the extra-high-pressure treatment (a nonthermal treatment method) at 680 MPa and 49–73 °C for 30 min resulted in 0–3 log reductions of microbes *Gochujang* (Lim, Kim, Kim, Mok, & Park, 2001).

The heat sterilization of highly viscous paste foods such as *Gochujang* is difficult using CH due to their low thermal conductivity and the resulting long heating time required to deliver heat to the center of a food sample. The excessive external heating caused the destruction of nutritional components and resulted in a burnt smell, discoloration, and tissue degradation (Cho, Kim, Kim, & Pyun, 1994). OH has been recognized as a promising alternative to traditional food thermal processing particularly due to the shorter treatment time, which is critical for maintaining the quality of high-viscosity food as *Gochujang* (Kim, Kim, Park, Cho, & Han, 1996; Shynkaryk & Sastry, 2012).

The objectives of this study were (1) to determine the pasteurization conditions of *Gochujang* utilizing a continuous OH system and (2) to characterize the rheological properties, color values, and microbial inactivation that can be achieved by OH.

## 2. Materials and methods

### 2.1. Sample preparation

*Gochujang* that had been manufactured by the Sunchang Food Company (Sunchang-gun, Jeollabuk-do, Korea) was obtained from a local market. This type of *Gochujang* contained red pepper powder, chopped garlic and onion, starch syrup, gelatinized rice flours, salt, water, and L-monosodium glutamate. All samples were stored at room temperature in a sealed state before being subjected to OH processing.

### 2.2. Continuous ohmic heating system

The continuous ohmic heating system consisted of a monoplunger pump, a product tank, a power supply with voltage generator (DLC-10 K300, Daelimec Co., Paju, Gyeonggi-Do, Korea), a heating cell, a data logger, and a computer (Fig. 1). To implement a continuous system, the monoplunger pump (KRH 20–1, Kraft Precision Industry Co., Seoul, Korea) was used to move the sample from the product tank to the collection container. The monoplunger pump operates at a pressure of 6 $kg_f/cm^2$ with a correspondingly high head and it is suitable for viscous liquids and paste foods. The products are conveyed by a screw inside the stator and driven into the outlet pipe by a helical rotor. After the sample was in the heating cell, the heating process was started by turning on the power supplier (capacity: 30 kVA) to the voltage generator connected to the electrodes attached to the heating cell. The supplied power was a sine-wave alternating current at 60 Hz, and the voltage was controlled by a variable transformer over a range of 0–300 V. The sample was moving while being heated inside the cell installed with several carbon electrodes, and a data logger (Hydra 2625A, Fluke, Everett, WA, USA) linked to a computer recorded essential data such as the voltage, current, and temperature during the processing. A thermocouple (T type, Shinhan, Seoul, Korea) inside the heating cell was used to measure the temperature of the heated sample. In order to observe effects of each electrode, thermocouples were located at inlet, outlet, and in-between of the electrodes as shown in Fig. 1(E). The temperature was measured continuously and recorded at 5 s intervals by data logger linked to a computer.

The heating cell with electrodes is one of the important parts of the ohmic heater because it is an electrical source for heating. The cell was made with polyether ether ketone (PEEK) as it is thermoplastic to resist for impact and abrasion, and has high mechanical strength over a wide temperature range. As shown in Figs.1, 2 rectangular-shaped short cells (cell size: 300 × 100 × 100 mm, W × L × H) with 2 electrodes (electrode size: 150 × 30 × 10 mm) and 1 rectangular-shaped long cell (cell size: 600 × 100 × 100 mm) with 4 electrodes (electrode size: 150 × 30 × 10 mm) that can be attached or detached were used for this study. Electrodes made with carbon have excellent electrical conductivity and resistant against acid and base component.

### 2.3. Experimental design for ohmic heating

Several OH conditions were selected by adjusting the following factors in a statistical factorial design: heating-cell combination, electrode length, voltage change, and the speed of flow. First, two types of heating cell were used: two short cells containing a pair of electrodes, and one long cell containing two pairs of electrodes. This provided the following cell combinations: short cell, short–short cell, short–long cell, short–short–long cell, and long cell. Second, the effect of electrode length was investigated in the long cell. This cell had two pairs of electrodes, which were connected either diagonally (/ type) or in a straight line (I type). Third, voltages of 30, 50, 70, and 100 V were applied. The temperature history of the heating system was measured for each of the cell combination. The input energy was calculated using the following equation:

$$\text{Energy (J)} = \text{Voltage (V)} \times \text{Current (A)} \times \text{Heating time (sec)} \quad (1)$$

The obtained data were used to select the conditions that increased the temperature to over 100 °C with the lowest energy consumption. Selected conditions for treatments of primary ohmic heating as cell combinations, voltage, heating time and temperature, and heating rate were shown in detail in Table 1. Based on preliminary studies on stability of sample flow in our continuous ohmic heating system, pump flow rate was fixed as 1.3 cm/s by controlling pump speed. As shown in Table 1, the heating time for each condition was calculated by considering total lengths (60 cm for OH3, OH5 and OH7, and 45 cm for OH9) of sample passing the electrode as following equation: