Innovative Food Science and Emerging Technologies 34 (2016) 135–140

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Effect of corona wind, current, electric field and energy consumption on the reduction of the thawing time during the high-voltage electrostatic-field (HVEF) treatment process

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ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form 3 January 2016
Accepted 4 January 2016
Available online 27 January 2016

Keywords:
High-voltage electrostatic field (HVEF)
Thawing time
Corona wind
Current
Electric field
Energy consumption

ABSTRACT

Electric energy plays an important role in reducing the thawing time and accelerating the entire thawing process. Corona wind speed was increased by increasing the applied voltage and current, which were 0.87 ± 0.19, 1.22 ± 0.19, 1.49 ± 0.13 m/s under 8, 10, 12 kV with 3, 5, 10 μA; 1.01 ± 0.12, 1.24 ± 0.17, 1.49 ± 0.10 m/s under −8, −10, −12 kV with 5, 9, 14.5 μA. The models T1, T2, and T3 were designed to study the effects of current, corona wind and electric field on thawing, respectively. T1: a thin stainless-steel sheet covered the top of stainless-steel box with 10 g frozen distilled water; T2: a plastic sheet was placed under the stainless-steel box; T3: a plastic sheet covered the top of plastic box. Electric field alone cannot affect thawing time, which could be maximally reduced by 1/2 compared to that of air thawing.

Industrial relevance: We have studied HVEF thawing for several years because of its many advantages, such as the quick thawing of frozen meat with little energy consumption and good post-thawing quality. The mechanism of HVEF thawing and the reduction of the thawing time, which are important for the industrial application of new technology from principle to design, must be clarified. Meanwhile, this emerging technology will be beneficial for the food-thawing field.

1. Introduction

Asakawa first reported the high-voltage electrostatic field (HVEF) effect in 1976 regarding the promotion and retardation of heat transfer by electric fields. Since then, many researchers have applied this new technology to different food fields such as fresh keeping (Bajgai, Hashinaga, Isobe, Raghavan, & Ngadi, 2006), drying (Esehaghbeygi & Basiry, 2011), and thawing (Hsieh, Lai, Ho, Huang, & Ko, 2010). The HVEF effect has obvious advantages, such as improving the content of the effective components (Shivashankara, Isobe, Al-Haq, Takenaka, & Shiina, 2004; Zhao, Hao, Xue, Liu, & Li, 2011), reducing the drying and thawing time with little energy consumption (Cao, Nishiyama, & Koide, 2004) and guaranteeing the food quality (Hsieh & Ko, 2008).

We have studied the effect of HVEF treatment on the thawing of frozen pork tenderloin meat for several years, including post-thawing qualities such as protein denaturation and lipid oxidation after thawing and factors that affect the thawing characteristics and energy consumption of the electric field. We have obtained a comprehensive understanding of HVEF thawing treatment. The results show that HVEF treatment can maximally reduce thawing time by 1/2 compared with that of air thawing without affecting the post-thawing quality and can reduce the microbial growth by log 0.5–1, improving the shelf life during the refrigerator storage process (He, Liu, Nirasawa, Zheng, & Liu, 2013). Parameters such as voltage, distance, and electric field strength were studied to determine the relationships and factors that affect HVEF treatment (He, Liu, Tatsumi, Nirasawa, & Liu, 2014). However, the reasons HVEF can reduce the thawing time and how the energy is consumed during the process has not been well explained. Other researchers in the field concentrated on the optimum parameters of high-voltage electrostatic-field thawing (Bai, Sun, Li, & Kang, 2011). Many researchers paid attention to the electrodynamic (EHD)-enhanced drying system (Goodenough, Goodenough, & Goodenough, 2007), which has a similar principle to that of HVEF thawing. Both systems use an inhomogeneous electric field to produce corona wind, which is the movement of uncharged air particles to produce collisions with ionized air particles in an electrostatic field. The electric field in the form of corona wind significantly enhances the drying rate of wet materials, which has been shown in many studies (Lai, 2010).

For a more in-depth investigation, we studied the mechanism of the EHD-enhanced system to investigate the mechanism of the HVEF thawing process based on the relationships among corona wind speed, current, applied voltage, energy consumption and thawing time. We determined the main factors that affect the thawing process and illustrated the principle of HVEF thawing and the reduction in thawing time. The experiment used a sample of ice instead of pork

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http://dx.doi.org/10.1016/j.ifset.2016.01.006
1466-8564/

tenderloin meat to accurately calculate the energy consumption and conveniently study different relationships. We used different simulation models to investigate the effects of corona wind, current and electric field.

2. Materials and methods

2.1. Materials

Distilled water was used to make the samples by storing the water in stainless-steel round boxes and plastic round boxes in a refrigerator at −20 °C for 12 h. The diameters of the stainless-steel and plastic round boxes were 5.4 cm.

2.2. Experimental apparatus

The experimental setup for HVEF thawing is shown in Fig. 1. The setup mainly consisted of two point-to-plate electrode systems, two treatment chambers, a temperature-controlled operating space, and negative and positive high-voltage power supplies. The sharp points of the needles (0.001 mm in diameter), which were connected to the negative and positive poles, formed the corona discharge electrodes. Both the negative and positive high-voltage electric field apparatuses were adjusted using a controller to output high voltages from 0 to 30 kV. The grounded plane electrode was a 20 × 30 cm stainless-steel plate. Voltmeters and ampere-meters were used to measure the voltage across and the current through the circuit, respectively. For the control treatment, the output voltage was zero. The two treatment chambers were placed in the operating space to control the temperature. The distance (discharge gap) between the corona electrode and the plate electrode was set with the adjustable pole.

2.3. Sample preparation

Two models were used to compare the effect of high-voltage electrostatic thawing. Model 1: 10 g distilled water was placed in a stainless-steel round box and stored in a refrigerator at −20 °C for 12 h. Model 2: 10 g distilled water was placed in a plastic round box (polyethylene, PE) and stored in a refrigerator at −20 °C for 12 h.

In Model 1, the sample allowed for a current through the circle, whereas in Model 2, the sample was electrically insulated, which showed the situation without the effect of a current. With these different samples, we could study the relationship among the current, corona wind, electric field and thawing time.

To separately study the effect of the current, corona wind and electric field, we developed three different treatments. In treatment T1, the negative voltage was 8 kV with a discharge gap of 2.7 cm, and a thin stainless-steel sheet covered the top of the Model 1 sample to investigate the situation without the effect of corona wind (Fig. 2). In treatment T2, a plastic sheet (polypropylene, PP) was placed under the Model 1 sample to investigate the condition without the effect of the current (Fig. 3). In treatment T3, a plastic sheet covered the top of the Model 2 sample to investigate the effect of only the electric field (Fig. 4).

2.4. Thawing experiment

The experiment was divided into two parts. In the first part, the corona wind velocity was measured using an instrument (Testo 405-V1, Germany) in the absence of the samples under different negative and positive high voltages; the variations of the corona wind velocity over 1 min and the current changes were recorded. The experiment was performed with different negative and positive voltages of 8, 9, 10, 11, 12 and 13 kV at an electrode distance of 2.7 cm and a room temperature of 20 °C to test the corona wind velocity. In the second part, the thawing time and current in the presence of the samples were measured at negative voltages of 8, 9, 10, 11, 12 and 13 kV at an electrode distance of 2.7 cm and a room temperature of 20 °C. In the presence of Model 1 samples, besides the basic measurements, T1 had a thin stainless-steel sheet on top of the sample under an applied voltage of −8 kV; T2 had a plastic sheet under the sample with an applied voltage of −8 kV. Both T1 and T2 treatments were measured by the thawing time and current under an electrode distance of 2.7 cm at room temperature of 20 °C. In the presence of Model 2 samples, except for the measurements at voltages of −8, −9, −10, −11, −12 and −13 kV, treatment T3 had a plastic sheet on top of the Model 2 sample, which was measured under the applied voltage of −8 kV and the electrode distance of 2.7 cm at room temperature (20 °C).

Thawing was considered complete when the temperature reached 0 °C, as determined by the temperature sensor with a high accuracy of 0.5 °C in the range from −20 to 100 °C (Testo 826-T4, Germany). All measurements were repeated three times.

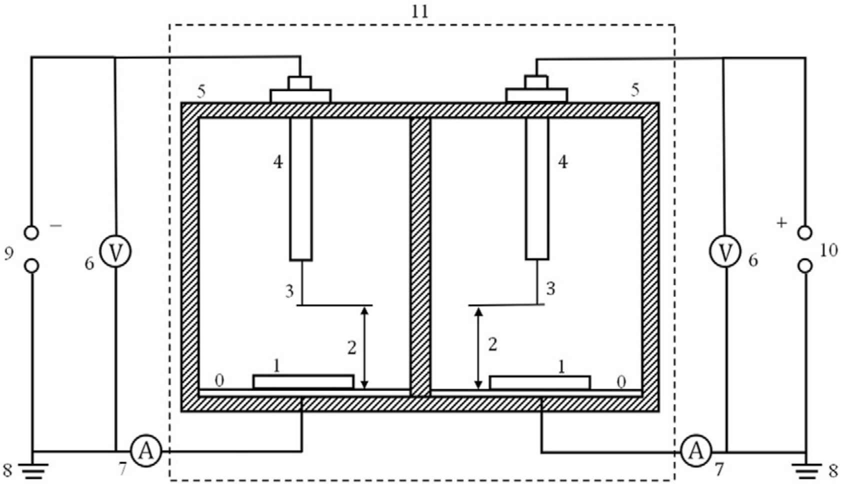

Fig. 1. Schematic diagram of the experimental HVEF thawing system; (0) stainless steel plate; (1) sample; (2) discharge gap; (3) corona electrode; (4) adjustable pole; (5) wooden shelves; (6) voltage meter; (7) microampere meter; (8) ground; (9) negative high voltage power; (10) positive high voltage power; and (11) temperature controlled operating space.