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Applications of High Voltage Electric Field in Food Thawing: A Review

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ABSTRACT

High voltage electric field (HVEF), as a novel technique, has recently been known in food industry because of its low thermal damage, being free of chemicals, low energy consumption, non-mechanical design, simplicity and rapid control. High voltage electric field thawing, as a quick method, has been paid a lot of attention in recent years. In this technology, an electrical wind is produced by the corona discharge, air is ionized and ions produced in a small area around the needle electrodes, are then accelerated by an electric field and the resulting momentum is transferred from the air ions to the neutral air molecules to move the bulk fluid towards the surface. Different electrode configurations such as point-ring, needle-ring, needle-plane and wire-plane are commonly used for preparing electric field. As review of studies suggests the thawed food under HVEF showed better quality characteristics than the one thawed under conventional thawing such as still air method. However, high electric field strengths may have adverse effects on the structure and physical properties of the product. Decrease in thawing time and energy consumption has been reported, too. However, achieving the best quality of HVEF thawed products depends on the electric field condition like electrode distances, electrode spacing between the two neighboring needles, voltage and electric field strength. This paper describes and deals with the HVEF technique and its applications in thawing of food.

Keywords: High voltage electric field, Thawing, Corona discharge, Electrode distance, Voltage

INTRODUCTION

Today, non-thermal techniques have been noticed in order to overcome the problems caused by conventional thermal processes and their associated long process times. High voltage electric field (HVEF) is one of the recent non-thermal technologies. In this method, air is ionized in a needle-plate electrode system by a corona discharge. One of the effects of the corona discharge is the generation of an electric field-induced flow or secondary electrohydrodynamic flow (EHD) which is produced by transferring momentum from high speed drifting ions to surrounding air molecules [1]. HVEF is advantageous for its low energy consumption, non-mechanical design, simplicity and rapid control. HVEF has been mostly applied for the drying of foods [2,3], preserving food freshness through increasing its shelf-life [4-6]. It also controls ice nucleation [7-9] and inhibits microbial growth [10,11]. Recent studies have been conducted towards the use of electric field in thawing, described below.

HVEF process mechanism

HVEF process is based on the production of an electrical wind by corona discharge. Corona discharge involves the partial electrical breakdown of the gaseous medium between at least two electrodes: a sharp electrode with very small radius of curvature which is called the corona electrode or emitter electrode and could be wires, pins and needle and a blunt electrode with much larger radius of curvature which is grounded (grounded electrode). Different electrode configurations such as point-ring, needle-ring, needle-plate and wire-plate are commonly used for preparing electric field. The ions produced in a small area around the needle electrodes are then accelerated by an electric field and the resulting momentum is transferred from the air ions to the

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neutral air molecules to move the fluid bulk to the surface. In this case, the fluid bulk collides with the surface and causes turbulence on the boundary layer formed on the surface. Ultimately, this leads to the enhancement of heat transfer coefficient [12]. A general schematic of experimental apparatus for the HVEF system (needle-plate electrodes) is shown in **Figure 1**.

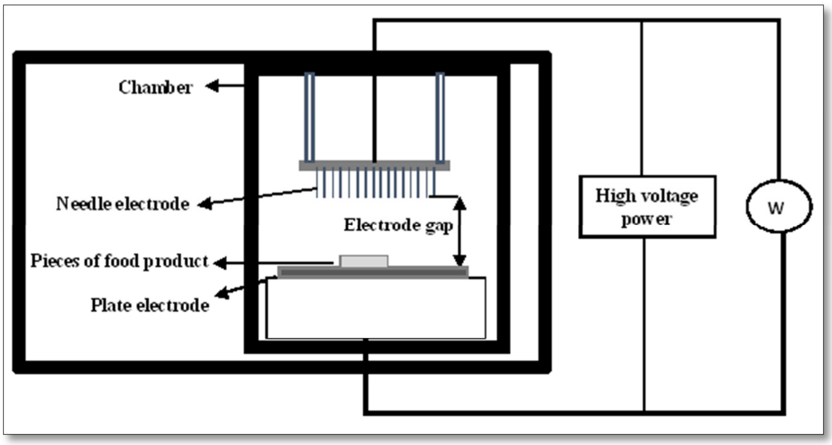

Figure 1. Schematic of HVEF thawing apparatus.

Application of HVEF in thawing

Thawing generally occurs more slowly than freezing; therefore, there is a possibility of further damage to the product following chemical and physical changes [13]. On the other hand, increasing surface temperature results in possible microbial growth on the product surface [14]. Leaching of soluble nutrients, particularly proteins, and large quantities of loaded waste-water are also other disadvantages of conventional thawing [15]. Thus, it seems by applying non-thermal and fast techniques, these problems can be overcome. One of the new applications of HVEF involves thawing of food. Recent studies have shown that thawing of food by HVEF reduces damages occurring during the process because of the reduction of the process time and the antimicrobial effects of HVEF thawing [11,16-18]. Basically, the initial temperature in the thawing process of a frozen material changes very fast up to a temperature of –5°C. However, the rise in temperature up to 0°C accounts for the longest thawing time. The temperature range between –5 to 0°C is often considered to be the maximum ice formation zone in food freezing and HVEF has its greatest impact on this temperature range [13].

Bai et al. [19] investigated the optimal parameters involved in thawing with an electrical field. They estimated the effects of the distance between the two neighboring needles, the electrode spacing and different thawing voltages on the thawing rate and energy consumption.

Their results showed that 9 cm electrode spacing fewer than 6 cm distances between the two neighboring needles at the voltage of 45 kV yielded the maximum thawing rate and little electrical energy. Moreover, they indicated that energy consumption and thawing rate increased sharply when voltage exceeded 25 kV. Finally, they concluded 45 kV was the optimum thawing voltage due to its largest thawing rate and relatively low energy consumption [19]. Hesie et al. [11] studied the effect of thawing by HVEF on the qualitative properties of frozen chicken. They applied 20 kV on 16 negative needle electrodes at an electrode gaps of 20 cm. Thawing was accomplished in the temperature range of –3°C to 4°C and reduced the thawing time up to 0.66 and 0.75 of a traditional thawing. Microbial counts, total volatile basic nitrogen and weight losses decreased compared with the control, but water holding capacity of the protein of the HVEF-thawed chicken was greater. Another study investigated the effect of HVEF treatment on the thawing characteristics and post-thawing quality of frozen pork tenderloin meat. In this study, 16 needle electrodes, 0.001 mm in diameter, were used and voltages of 4, 6, 8 and 10 kV were applied at a temperature of 20°C for meet thawing. The thawing times recorded were 52, 46, and 40 min for the voltages of 6, 8 and 10 kV, respectively. The time taken for thawing of the control sample [still air thawing] was 64 min, while the 4 kV treatments recorded a longer thawing time than that of the control. Furthermore, it was found out that HVEF led to a reduction in microbial counts and total volatile nitrogen compared to the control. Nevertheless, high voltage treatment led to a greater weight loss and cooking loss due to thawing [16].

He et al. [20] examined the factors affecting the thawing characteristics and energy consumption of frozen pork tenderloin meat using high-voltage electrostatic field. The thawing time of the frozen pork was shortened by increasing the voltage and decreasing the electrode distance, but this shortening was limited above a certain voltage under a particular distance. On the other hand, the energy consumption for HVEF thawing was very low compared with microwave, hot- and cold-water thawing methods which means HVEF-thawing is an energy-efficient and cost-saving method.

Mousakhani-Ganjeh et al. [17] investigated the impact of high voltage electric field -thawing on frozen tuna fish quality. Their results demonstrated that thawing rate increased with increasing the voltage and reducing the electrode gap. The authors also declared that volatile nitrogen produced by microorganism was reduced; however, color, texture and protein solubility of HVEF thawed changed after thawing. Moreover, they verified the thawing of frozen tuna fish using still air combined with a high voltage electric field. The results showed increasing the applied voltage and decreasing the electrode gap significantly elevated specific energy consumption in the combined method, but decreased it in the electric field method. In addition, electric wind velocity had a more pronounced effect on the energy consumption [21]. Another study was done to investigate the effect of high voltage electrostatic field thawing on the lipid oxidation of frozen tuna fish [22]. The result showed that lipid oxidation during storage was more intense with increasing voltage as a result of reducing the electrode gap. However, lipid oxidation decreased by increasing the electrode gap at a constant voltage. They concluded that the production and release of the negative ions of air (NIA) and ozone during the process could lead to the oxidation of the sample surface and to the degradation of food flavor. Rahbari et al. [18] investigated the parameters associated with the quality of protein during high-voltage electric field thawing of frozen chicken breast. Results showed higher myofibrillar protein solubility and water holding capacity were observed at the starting voltage of corona and maximized at 2.25 kV/cm electric field strength. Differential scanning calorimetry thermograms revealed the HVEF-treated samples at 2.25 kV/cm electric field strength showed less protein denaturation than the air-thawed sample. Nonetheless, by giving rise to the electrical strength up to 3 kV/cm, protein denaturation increased. Additionally, Jia et al. [23] conducted a study on high-voltage electrostatic field thawing of frozen rabbit meat and claimed that this method retained a higher Water Holding Capacity (WHC) and a better texture quality than still air thawing, and the degree of denaturation for myofibrillar proteins and some sarcoplasmic proteins was decreased which led to a better WHC. In another study, a higher abundance of proteins extracted from -10 kV HVEF thawed pork tenderloin was found compared with the air-thawed samples. Furthermore, air thawing led to the lowest total sulfhydryl content and highest carbonyl content compared to the HVEF method [23]. Li et al. [24] determined the changes in water loss and degradation of adenosine triphosphate and the microbial community of lightly-salted common carp after HVEF thawing, and compared this with conventional thawing using still air or running tap water. They concluded that thawing under 12 kV HVEF at 4 cm electrode distance, reduced microorganisms significantly (0.5-1 log CFU/g), enhanced adenosine monophosphate deaminase activity, reduced acid phosphotase activity, and delayed the degradation of inosine monophosphate compared to the other methods. In addition, thawing under 12 kV HVEF decreased the water loss of fish cubes (**Table 1**).

Table 1. Applications of HVEF thawing to different food matrix.

Food matrix	Thawing condition	Main findings	References
Chicken tight meat	Multiple point to plate electrode system; voltage=20 kV, electrode gap=20 cm; temperature=-3 to 4°C	Thawing time under HVEF reduced up to 0.66 and 0.75 of a traditional thawing. Microbial counts, total volatile basic nitrogen and weight losses decreased compared with the control and water holding capacity was greater.	Hsieh et al. [11]
Ice	Multiple point to plate electrode system	9 cm electrode spacing under 6 cm distance between the two neighboring needles at the voltage of 45 kV yielded the maximum thawing rate and little electrical energy	Bai et al. [19]
Pork tenderloin meat	Multiple point to plate electrode system; voltage=4, 6, 8, 10 kV, electrode gap=5 cm, temperature=20°C	HVEF led to a reduction in microbial counts and total volatile nitrogen compared to the control. But, a greater weight loss and cooking loss due to thawing were observed. At electric field strength more than 2 kV/cm, thawing time decreased significantly	He et al. [16]
Pork tenderloin meat	Multiple point to plate electrode system; voltage=8, 10, 12, 14 kV, electrode gap=3, 4, 5, 6, 8, 10 cm; temperature=12°C	The thawing time of the frozen pork was shortened by increasing the voltage and decreasing the electrode distance; The energy consumption for HVEF thawing was very low compared with microwave, hot- and cold-water thawing methods	He et al. [20]

Tuna Fish (*Thunnus albacares*)	DC power supply, a multiple points to-plate Electrode. EHD+ Electric field strength=1.25-3.5 kV/cm	Thawing rate increased with increasing the voltage and reducing the electrode gap; however, color, texture and protein solubility of HVEF thawed samples changed. Lipid oxidation during storage was more intense at high electric field strengths	Mousakhani-Ganjeh et al. [17]
Rabbit meat	DC voltage generator, a multiple point-to-plate electrode; voltage=5, 10, 15, 20, 25 kV; electrode gap=5 cm	Higher abundance of proteins extracted from -10 kV HVEF-thawed pork tenderloin was found compared with the air-thawed samples. Air thawing led to the lowest total sulfhydryl content and highest carbonyl content compared to the HVEF method	Jia et al. [23]
Carp (*Cyprinus carpio*)	Multiple point-to-plate electrode; voltage=6, 12 kV; electrode gap=4 cm	HVEF thawing at 3 kV/cm kV electric field strength, reduced microorganisms significantly (0.5-1 log CFU/g), enhanced adenosine monophosphate deaminase activity, reduced acid phosphatase activity, and delayed the degradation of inosine monophosphate compared to the still air and running tap water methods.	Li et al. [24]
Chicken breast	Multiple points to-plate electrode. EHD+ Electric field strength=1.5-3 kV/cm	Higher myofibrillar protein solubility and water holding capacity were observed at the starting voltage of corona and minimized at 3 kV/cm electric field strength	Rahbari et al. [18]

CONCLUSION

The studies reviewed in this article revealed that high voltage electric field has a great potential for use in the thawing of food. Corrosive products, especially meat, subjected to HVEF thawing retain higher qualities than those subjected to conventional methods. In conclusion, by developing optimum voltages and electrode gaps to create an electric field, the advantages of this process, as a novel thawing method, will be achieved.

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