Food Research International 89 (2016) 48–62

Contents lists available at ScienceDirect

Food Research International

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

Review

# The principles of high voltage electric field and its application in food processing: A review

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ARTICLE INFO

*Article history:*
Received 23 June 2016
Received in revised form 19 August 2016
Accepted 1 September 2016
Available online 3 September 2016

*Keywords:*
High voltage electric field
High electrostatic field
High voltage electrical discharge
Food processing

ABSTRACT

Food processing is a major part of the modern global industry and it will certainly be an important sector of the industry in the future. Several processes for different purposes are involved in food processing aiming at the development of new products by combining and/or transforming raw materials, to the extension of food shelf-life, recovery, exploitation and further use of valuable compounds and many others. During the last century several new food processes have arisen and most of the traditional ones have evolved. The future food factory will require innovative approaches food processing which can combine increased sustainability, efficiency and quality. Herein, the objective of this review is to explore the multiple applications of high voltage electric field (HVEF) and its potentials within the food industry. These applications include processes such as drying, refrigeration, freezing, thawing, extending food shelf- life, and extraction of biocompounds. In addition, the principles, mechanism of action and influence of specific parameters have been discussed comprehensively.



**Contents**



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http://dx.doi.org/10.1016/j.foodres.2016.09.002
0963-9969/

**Nomenclature**

| | |
|---|---|
| $a$ | radius of the discharge electrode, m |
| $C_p$ | specific heat of the medium, J kg$^{-1}$ K$^{-1}$ |
| $d$ | distance between the electrodes, m |
| $D$ | plate diameter, m |
| E | electric field vector, V m$^{-1}$ |
| $f$ | surface roughness of the electrode |
| F | electrohydrodynamic force, Nm$^{-3}$ |
| $h_m$ | mass transfer coefficient, kg m$^{-2}$ s$^{-1}$ |
| $h_H$ | heat transfer coefficient, W m$^{-2}$ K$^{-1}$ |
| i | ion current, A |
| I | corona current, A |
| $j$ | magnitude of current distribution |
| $j_0$ | peak value of current density distribution |
| $k$ | dielectric constant of the fluid |
| $k_t$ | thermal conductivity, W m$^{-1}$ K$^{-1}$ |
| m | Warburg's parametric index for the cosine power law |
| $P$ | actual atmospheric pressure, kPa |
| $P_0$ | reference atmospheric pressure, kPa |
| $T_a$ | actual temperature of the air, K |
| $T_0$ | reference temperature, K |
| $V_I$ | corona inception voltage, kV |
| $V$ | applied voltage, kV |
| $V_V$ | visual critical voltage kV m$^{-1}$ |
| $V_0$ | disruptive critical voltage, kV m$^{-1}$ |
| X | distance between two neighbored electrode, m |
| $\rho_e$ | electric charge density, C m$^{-3}$ |
| $\varepsilon_0$ | permittivity of free space, F m$^{-1}$ |
| $\rho_g$ | fluid (air) mass density kg m$^{-3}$ |
| $\mu$ | ion mobility, m$^2$ V$^{-1}$ s$^{-1}$ |
| $\rho$ | charge density, C m$^{-3}$ |
| $\delta$ | relative density of the air |
| $\theta$ | semi-vertical cone angle of discharge |

## 1. Introduction

Nonthermal food processing techniques have been receiving considerable attention lately. They have the potential to maintain the quality of the processed product while ensuring the food safety. Application of high voltage electric field (HVEF) is an important nonthermal processing technology and considerable research has been carried out in the development of new applications (Kempkes & Tokuşoğlu, 2014; Muthukumaran, Orsat, Bajgai, & Raghavan, 2009). A major advantage of this technique is that there is no significant change in temperature of food during processing. Hence, this method can be successfully applied to any temperature sensitive food matrix such as fruits and vegetables (Muthukumaran et al., 2009). Furthermore, the ability of this method to enhance heat and mass transfer could play an important role in food processing. The thermal and refrigeration processes in the food sector often involve transferring energy between the product being treated and the air. These convective processes such as drying or freezing require large air volumes, high air velocity and low or high ambient temperature which can increase energy demands and consumption. The enhancement of the heat transfer at fluid-solid interfaces remains one of the crucial issues of these processes. For that purpose, the application of high voltage electric field appears a promising approach (Ahmedou & Havet, 2009).

### *1.1. High voltage electric field (HVEF)*

High voltage electric field technologies can be divided into two main groups: 1) high electrostatic field (HEF) and 2) high voltage electrical discharge (HVED). Fig. 1 shows the classification of high voltage electric field in food processing. The aim of this paper is to explore the effects of HVEF on food drying, thawing, extending the shelf-life of a food product, freezing, enhancing the extraction of biocompounds by applying HVEF. The mechanisms that make HVEF processing highly effective in improving the process and retaining the quality of products during food processing will be described.

### *1.2. High electrostatic field (HEF)*

Electrostatic means that no currents or varying voltages occur during the experiment. To create a uniform electric field, parallel plate electrodes are usually used. The electric field between the two electrodes is equal excluding the edge of the electrode due to fields' enhancement. This process has been used as an assisting method to improve frozen food quality or food refrigeration and increase shelf- life of fruits and vegetables (Dalvi-Isfahan, Hamdami, & Le-Bail, 2016).

### *1.3. High voltage electrical discharge (HVED)*

High voltage electrical discharge is a process by which a current flows from an electrode with a high potential into a neutral fluid, by ionizing that fluid a region of plasma around the electrode is being created. HVED could be happen in partial or complete breakdown and both of them are used in the food industry. Several types of partial discharges in gaseous medium have been known such as glow discharge, dielectric barrier discharge and corona discharge but among them the corona discharge has drawn more attention in food industry than others.

One of the effects of the corona discharge is the generation of an electric field induced flows or secondary electrohydrodynamic flow (EHD), which is produced by transferring of momentum from high speed drifting ions to surrounding air molecules (see Section 1.4) (Laohalertdecha, Naphon, & Wongwises, 2007).

In recent years, there has been a surge of interest in the application of EHD technique in food industry. Because it has many advantages including 1) its ability to enhance heat and mass transfer; 2) rapid and smart control of heat and mass transfer that can be achieved by varying the applied voltage; 3) it is non-mechanical and simple in design; 4) it is suitable for different environments (space); 5) it is applicable to single phase and multiphase flows; and 6) energy consumption is minimal. Although this technique could be applied for both single phase and double phase, most of the research in food processing has been focused on applications with single phase heat transfer (Seyed-Yagoobi & Bryan, 1999; Taghian Dinani, Hamdami, Shahedi, Havet, & Queveau, 2015). Its application to food processing is involved in many areas of food processing such as drying, thawing and increasing fruits and vegetables shelf-life. It can comply well with high product quality and low energy consumption during processing (Singh, Orsat, & Raghavan, 2012).

High voltage electrical discharge in liquid (electrohydraulic discharge) is an emerging technology with a wide variety of applications in the food processing. It has been applied to the chemical removal of organic impurities present in water, oil extraction and other high added value compounds from plants. Electrohydraulic discharge can be divided in two types: corona discharge and complete breakdown or arcing which differ primarily by the amount of energy deposited in the system (see Section 7) (Koubaa et al., 2015; Locke, Sato, Sunka, Hoffmann, & Chang, 2006).

Generally, in the case of high voltage electrical discharge (HVED), the configuration is consisted on a needle electrode and a grounded one (normally flat geometry) or wire-plane.

It is worth noting that however, pulsed electric field also utilize moderate to high voltage electric field (0.1–20 kV/cm) for valuable compounds recovery from food wastes and by-products, but there are some differences between them in the electrode geometry, shape of pulses and mode of actions (Puértolas, Koubaa, & Barba, 2016).