



## A review on effect of DC voltage on crystallization process in food systems



Piyush Kumar Jha<sup>a</sup>, Mathieu Sadot<sup>a</sup>, S. Ajay Vino<sup>a,b</sup>, Vanessa Jury<sup>a</sup>, Sébastien Curet-Ploquin<sup>a</sup>, Olivier Rouaud<sup>a</sup>, Michel Havet<sup>a</sup>, Alain Le-Bail<sup>a,\*</sup>

<sup>a</sup> ONIRIS - GEPEA (UMR CNRS 6144), Site de la Géraudière CS 82225, 44322 Nantes cedex 3, France

<sup>b</sup> Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India

### ARTICLE INFO

#### Keywords:

Crystallization  
Freezing  
DC voltage  
Supercooling  
Nucleation  
Food refrigeration

### ABSTRACT

Crystallization of water and food systems may be affected by electric and magnetic fields. In this review paper, the crystallization of water and food systems assisted by DC voltage (DC-V) is compiled based on existing literature. Two ways of applying DC-V during electrocrystallization can be identified, namely charge flow (CF) conditions with electrical charges flowing through the matrix and static electric field (SEF) conditions. Both processes have shown to interact with nucleation mechanism by reducing supercooling and favouring a higher nucleation rate. The theoretical calculations show that the application of SEF can modify the free energy of formation of ice nuclei in the water phase. Moreover, SEF application can also enhance heat and mass transfer during crystallization process. Various molecular simulations and experimental studies have shown that SEF aligns the water molecules in its direction by the phenomenon of dielectric polarization, and thus, reduces the degree of supercooling ( $\Delta T$ ). The freezing process under SEF produces smaller ice crystals in the food products, resulting in less freeze damage; it is thus expected to minimize cell disruption, to reduce the drip loss, to lessen the protein denaturation, and finally to preserve the texture of the fresh food after thawing. Furthermore, freezing under SEF may help to use less energy intensive freezing conditions (higher set point temperature, low air velocity). As a conclusion, the use of DC-V in the case of crystallization of food systems (especially freezing) offers a new perspective to the food industry.

### 1. Introduction

Freezing is a commonly and extensively used method for food preservation (Alizadeh, Chapleau, de Lamballerie, & Le-Bail, 2007; Orłowska, Havet, & Le-Bail, 2009). Frozen storage of food products reduces its water activity and protects it against microbial growth, enzymatic reactions and chemical degradation reactions (Fellows, 2000; Singh & Heldman, 2009). The quality of frozen foods is influenced by the freezing process and frozen-storage conditions (Singh & Heldman, 2009). In general terms, rapid freezing techniques ensure formation of smaller ice crystals within the product structure with minimal damage to its texture. Whereas, the slow freezing process produces larger crystals and increases the damage to food products, such as: mechanical damage to food tissues, destabilization of emulsions, syneresis in gels, precipitation of proteins from solutions and drip loss during thawing (Orłowska et al., 2009; Otero, Martino, Zaritzky, Solas, & Sanz, 2000; Singh & Heldman, 2009). Rapid freezing is thus preferred since it promotes higher nucleation rate resulting in numerous smaller ice crystals in food products (Delgado & Sun, 2011; Otero et al., 2000).

Controlling ice crystal size during freezing becomes a critical

parameter to achieve high quality frozen product (Otero & Sanz, 2011). The size of ice crystals formed throughout the product depends mostly on the rate of ice nucleation and its subsequent growth. Ice nucleation is an activated process driven by supercooling. The greater the extent of supercooling, the larger is the rate of ice nucleation and the number of nuclei created. For several decades, strategies such as lowering the refrigerating medium temperature, enhancing surface heat transfer coefficients, or reducing the size of the products (i.e. individual quick freezing or IQF) to be frozen have been used to enhance ice nucleation (Otero & Sanz, 2011). But in recent years, several new approaches have been successfully used to manipulate the size of the ice crystals. These include crystallization assisted by: high-pressure shift; ultrasound waves; DC voltage; magnetic field; electromagnetic waves, etc. (Anese et al., 2012; Koch, Seyderhelm, Wille, Kalichevsky, & Knorr, 1996; Sun & Li, 2003; Xanthakis, Havet, Chevallier, Abadie, & Le-Bail, 2013; Xanthakis, Le-Bail, & Ramaswamy, 2014). Some acronyms for these methods are proposed in the abbreviation table.

This review paper aims to establish a report on the impact of DC-V on the crystallization process of water and food systems. A focus is done to present the fundamentals of crystallization under DC-V.

\* Corresponding author.

E-mail address: [alain.lebail@oniris-nantes.fr](mailto:alain.lebail@oniris-nantes.fr) (A. Le-Bail).

## 2. Mechanism of crystallization

Crystallization involves three stages, namely supercooling, nucleation, and crystal growth (Woo & Mujumdar, 2010). In the first stage, the specimen (i.e. water or aqueous solution for freezing) is cooled down at a certain cooling rate below the initial solidification point. Due to rapid cooling, the sensible heat is removed; this causes the specimen to surpass its phase change temperature and reach into a supercooled state. The negative difference in temperature, when compared to the solidification point, denotes the degree of supercooling ( $\Delta T$ ). At a particular  $\Delta T$ , the second stage begins, i.e. nucleation or the formation of a minuscule crystalline lattice structure in the solution. The second stage occurs instantaneously, and it is accompanied by a sudden increase in temperature known as the release of latent heat of crystallization. After the initial nucleation is achieved, crystallization proceeds into the next stage, which corresponds to a subsequent growth of the existing nuclei plus secondary nucleation until the final temperature imposed by the ambience is reached. All these stages of crystallization are responsible for the final crystalline structure. In the past, use of DC-V (especially SEF) have proven to affect all three stages of crystallization of water, and hence DC-V can play an important role in controlling frozen food product quality (Bartlett, Van Den Hueval, & Mason, 1963; Dalvi-Isfahan, Hamdami, & Le-Bail, 2016; Jia, He, Nirasawa, Tatsumi, & Liu, 2017; Orłowska et al., 2009; Xanthakis et al., 2013; Yan & Patey, 2011, 2012).

### 3. Crystallization assisted by DC voltage (CA-DC-V)

The ability of DC-V to assist crystallization of supercooled water has been studied from a long time. Dufour seems to be the first scientist who studied crystallization assisted by static electric field (CA-SEF) of supercooled water (Dufour, 1861). Since then, many experimental studies related to CA-DC-V have been performed by others. Their key observations varied from one another. Some reported that DC-V have an effect on freezing (Choi, Yoon, Lee, & Kang, 2005; Hozumi, Saito, Okawa, & Eshita, 2005; Hozumi, Saito, Okawa, & Kazuharu, 2003; Shichiri & Nagata, 1981; Sun, Chen, & Huang, 2006; Xanthakis, Le-bail, & Havet, 2014; Xanthakis et al., 2013) while others have reported no effect (Doolittle & Vali, 1975; Roulleau, Evans, & Fukuta, 1971; Wilson, Osterday, & Haymet, 2009).

Till date, two approaches of CA-DC-V for water have been encountered in the literature. In the first approach, crystallization assisted by charge flow (CA-CF) was investigated (Braslavsky & Lipson, 1998; Hozumi et al., 2005, 2003; Shichiri & Nagata, 1981). While in the second approach, the crystallization assisted by static electric field (DC electric field) (CA-SEF) has been studied (Orłowska et al., 2009; Rau, 1951; Salt, 1961; Stan, Tang, Bishop, & Whitesides, 2011; Svishchev & Kusalik, 1994, 1996; Wei, Xiaobin, Hong, & Chuanxiang, 2008; Yan, Neve, & Collins, 1997). The DC voltage can be used in two forms; one is low voltage (< 1200 V DC) and the other is high voltage (> 1200 V DC) (Abdel-Salam, Anis, El-Morshedy, & Radwan, 2000).

#### 3.1. Crystallization assisted by charge flow (CA-CF)

Many studies on this perspective were conducted by applying a DC-V between two electrodes which were in direct contact with the sample (liquid sample; e.g. water and other aqueous solutions) (Braslavsky & Lipson, 1998; Hozumi et al., 2005, 2003; Shichiri & Nagata, 1981). The experimental setup used for this method mainly consists of: a sample holder; two electrodes separated at a certain distance from each other (one of the electrodes act as an anode (positive terminal) and other plays role of the cathode (negative terminal)); a cooling system; DC voltage generator; and thermocouples (Th) (Fig. 1). In the literature, two approaches related to DC-V application during this method have been discussed: (i) use of continuous DC-V supply, and (ii) use of pulsed DC-V supply. The

application of DC-V between the electrodes cause two phenomena to occur: one is production of the electric field (Braslavsky & Lipson, 1998; Petersen, Schneider, Rau, & Glasmacher, 2006), and other is the electric current flow through the solution (Shichiri & Nagata, 1981). The CA-CF experimental setup works on electrolysis principle. Electrolysis is the oxidation-reduction reaction of electrolyte that occurs when the potential difference is applied across the electrolyte system. The electrolyte decomposes in two ions, cation with a positive charge and anion with a negative charge, respectively. These ions move freely in the solution. When DC-V is applied between the electrodes, an electric field is produced in the solution from the anode towards the cathode. Thus, the cations move towards the cathode and the anions move towards the anode. The movement of cations (positive charge) towards the cathode and anions (negative charge) towards the anode makes the current flow through the electrolyte. The ions give up their charges at the electrodes and the substance making up the ions is liberated. The liberated substance may get deposited on the electrodes or may take part in some secondary chemical reaction. In short, when DC-V is supplied to the system, the electrons enter through the cathode and come out through the anode. The current enters through the anode and leaves the solution through the cathode. Thus, when a current passes through an electrolyte, chemical changes occur in the electrolyte and substances are liberated at the electrodes.

On applying the DC-V to the supercooled water through narrowly spaced immersed electrodes, the nucleation temperature ( $T_n$ ) raises to higher value compared to the spontaneous nucleation temperature ( $T_{sp}$ ). Furthermore, when DC-V is supplied, the nucleation of ice crystals occurs at one of the electrodes, whereas in its absence, spontaneous nucleation takes place at the vessel wall (Shichiri & Nagata, 1981). Intensity of applied electric current, electrode properties (such as: electrode type, ionization tendency, passivity stability of the electrodes, polarity, surface roughness, and shape of the electrode materials) and sample composition have a significant effect on the nucleation process during CA-CF conditions (Hozumi et al., 2005, 2003; Petersen, Schneider, et al., 2006; Shichiri & Nagata, 1981).

##### 3.1.1. Intensity of applied electric current

Shichiri and Nagata (1981) applied a DC-V (0–1000 V) for a short time (< 1 s) at every 0.5 °C descent of water temperature below 0 °C, and measured the electric current simultaneously. The temperature at which the nucleation was observed at the moment of voltage supply was assumed to be the nucleation temperature ( $T_n$ ). They observed higher  $T_n$  in the case of the current being applied (> 0.1 mA) than no current case. Furthermore, they found that  $T_n$  became constant for higher values of electric current. Later, Hozumi et al. (2005, 2003) proposed that electric current between 5 and 7  $\mu$ A can initiate nucleation at a small supercooling between 1 and 2 °C. The applied current affects the nucleation by increasing the cation concentration on the electrodes (Shichiri & Nagata, 1981).

##### 3.1.2. Properties of the electrode materials

**3.1.2.1. Electrode type.** Hozumi et al. (2003) studied the effect of various electrode materials (Al, Cu, Ag, Au, Pt, and C) on the nucleation of supercooled water. The probability of freezing was found to be dependent on the type of electrode being used, and the order of the probability of freezing for different electrode was represented as Al = Cu > Ag > Au > Pt > C. Ionization tendency and passivity stability of electrodes influences the probability of freezing (Hozumi et al., 2003).

**3.1.2.2. Ionization tendency.** If the electrodes with a small ionization tendency are used, the nucleation is spotted at the cathode. Meanwhile, for the higher ionization tendency, the nucleation is observed at the anode (Hozumi et al., 2003; Shichiri & Nagata, 1981). The mechanisms of the nucleation in the both cases are discussed below:

Download English Version:

<https://daneshyari.com/en/article/5521735>

Download Persian Version:

<https://daneshyari.com/article/5521735>

[Daneshyari.com](https://daneshyari.com)