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The effect of stationary and sweeping frequency AC electric fields on frost crystal removal on a cold plate

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Abstract

The effect of stationary and sweeping frequency AC electric fields on frost crystals growth and frost control/removal on a cold plate was studied for the first time in this paper. The main results of this study showed that the presence of AC electric fields can greatly affect both the frost crystals growth pattern and mass accumulation on cold surfaces. The ice surface electrical properties and basic electrostatics were used to explain the main findings in this paper. Up to 46% frost reduction was obtained when the electric field frequency spanned 370 Hz to 7.5 kHz while the applied voltage was 14.5 kV. Two different sets of environmental conditions were tested, which showed that the plate temperature placed an important effect on frost crystals growth under electric fields. An optimum application time of the AC electric fields was found based on least frost mass accumulation on the cold plate.

Keywords: Research; Experiment; Growth; Crystal; Frost; Defrosting; Modelling; Plate; Electric field; Alternating current

Elimination des cristaux de givre sur une plaque froide: effets des fréquences stationnaires et de balayage des champs électriques

Mots clés: Recherche; Expérimentation; Croissance; Cristal; Givre; Dégivrage; Modélisation; Plaque; Champ électrique; Courant alternatif

1. Introduction

An investigation of the effect of AC electric fields on frost crystal growth with direct potential applications in refrigeration systems is discussed in the present study. Frost control using the EHD technique is a relatively new and promising area, with broad research needs aimed at understanding the phenomena involved. The particular behavior of frost crystals under electric fields makes such a technique desirable for refrigeration applications where frost formation creates reduced heat transfer on the cold surface and increased pressure drop across the fins/coils of a heat exchanger due to blockage of air passing through the coil.

The growth and destruction of frost crystals in electric fields poses interesting and challenging questions regarding the physics involved in these processes. The creation of long and thin ice needles that grow quickly in the direction of

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Nomenclature

E	electric field ($V\ m^{-1}$)	R	frost mass reduction
EHD	electro-hydrodynamics	Re	Reynolds number
f	frequency (Hz)	RH	relative humidity (%)
G	electrode gap (mm)	S	ice/frost crystal surface (m^2)
m_{ef}	frost mass formed under electric fields	V	voltage (V)
m_{wef}	frost mass formed without electric fields	λ_s	surface charge ($C\ m^{-2}$)
PID	proportional, integral, derivative		

he electric field lines has intrigued many authors ever since [1–3,6,9,10,14,15]. The ways in which the frost crystals are affected by the presence of the electric fields depend on several factors, such as the electrical field strength and type (AC or DC), ice surface electrical properties and the thermodynamic characteristics of frost growth.

The effect of AC electric fields on frost crystals has been little studied and is far from fully understood. No previous study besides our previous experimental work [16,17] appears to have reported any observations on frost breakage and removal from a cold plate using AC electric fields. Bartlett [1] is the only reference in the open literature that conducted limited experiments using 50 Hz-AC electric fields and bare wire electrodes. However, in his experiments, Bartlett did not notice any effect of the AC electric fields on neither frost crystal nor ice needle formation, as for the case of DC fields.

In the present study it is demonstrated that the frost crystals formed on a flat plate could be easily removed by application of a sudden or continuous AC electric field. Effects of both constant and sweeping AC frequency (0 Hz to 7.5 kHz) electric fields were experimentally quantified.

One of the major requirements for an EHD technique for practical purposes is low power consumption. For this reason insulated wire electrodes [2] were used in this study. The benefit of dielectric insulation was to prevent current leakage/sparking, and reduce power consumption.

Controlling frost growth (both mass and height) through an EHD active technique could have drastic improvements in the performance of selected refrigeration systems such as those employed in the supermarket refrigeration industry.

2. Background

The unique electrical properties of ice are believed to be one of the major factors in the observed phenomena. Ice, is one of the few materials that acts as a ‘protonic’ semiconductor [4,5,13].

At the ice surface a significant fraction of molecules is oriented with their dipole moments (i.e. protons) pointing outwards, as opposed to the bulk where molecules are oriented randomly. This results in the buildup of a large positive polarization charge at the surface (λ_s), which gradually decays with distance into the bulk of ice (Fig. 1).

If a DC electric field is applied, the net resultant force acting on an entire ice crystal can be expressed as follows [8]:

$$F = \frac{1}{2}\int_S \lambda_s E\, dS \qquad (1)$$

Eq. (1) indicates that the force acting on an ice crystal placed in an electric field will vary proportionally to the electric field strength. In order to better exemplify the above considerations, the behavior of the frost crystals grown without electric fields and then suddenly subjected to an electric field with oscillating polarity is schematically presented in Fig. 2(a) and (b). The electric force acting on the frost crystals will pull on the crystals regardless of the polarity of the applied voltage. This is in agreement with our previously reported visualization results [16,17] in which fallen crystals were pulled towards the grounded plate, while the ones on the top (Fig. 2(a) and (b)) were pulled downwards. Similar results are reported in the open literature [1,7,11].

In an oscillating electric field, a net force will pull the crystals with a frequency corresponding to that of the electric field. Theoretically, if the applied frequency matches the natural frequency of the crystal, then complete removal of the crystal from the cold surface can be achieved. Because the frost crystals shape, height and thickness distribution is very complex and not uniform on the surface of the cold plate, one cannot remove all frost crystals using a constant frequency wave. It can be assumed that the application of an electric

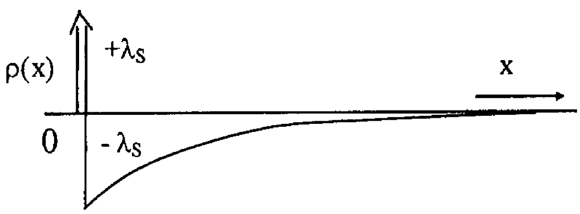

Fig. 1. Ice crystals’ surface properties: (a) the ice liquid-like layer [6]; (b) the surface charge distribution [13].