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Phase change material for the thermal protection of ice cream during storage and transportation

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ABSTRACT

Ice cream is a very temperature sensitive product and temperature variations during the storage and distribution steps may result in a reduction of quality. It is possible to improve the ice cream storage and transportation conditions by using an additional packaging with a low thermal diffusivity. This paper studies a phase change material (PCM) packaging and compares its performance to a polystyrene packaging configuration. The impact on temperature fluctuations and ice crystal size distribution was characterized experimentally during long term storage and temperature abuse. The results show that the use of an additional PCM packaging has a significant impact on the final quality of the product by keeping ice cream temperature stable and close to the phase change temperature of the PCM material. These results were compared with the insulation material results and discussed, showing that a material with a buffering heat capacity can be more efficient to reduce temperature fluctuations than a low conductivity material, and that the same results can be usually obtained with a much thinner layer of material.

Matériau à changement de phase pour la protection thermique de crème glacée pendant l'entreposage et le transport

Mots clés : Transfert de chaleur ; Crème glacée ; Protection thermique ; Dimension des cristaux de glace ; Matériau à changement de phase (PCM)

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Nomenclature

a	Diffusivity $m^2\ s^{-1}$
A	Area, m^2
C_p	Heat capacity, $J\ kg^{-1}\ K^{-1}$
e	Plate thickness, m
L	Length, m
Lv	Enthalpy of phase change, $kJ\ kg^{-1}$
t	Time, s
T	Temperature, °C
z	Distance, m

Subscripts

$_a$	air
$_I$	Value at $t = 0$
l	Liquid state
0	Value at $z = 0$
m	Melting
max	Maximum
w	Wall

Greek symbols

α	Heat transfer coefficient, $W\ m^{-2}\ K^{-1}$
λ	Thermal conductivity, $W\ m^{-1}\ K^{-1}$
ψ	Length density function
ω	Angular frequency, $rad\ s^{-1}$

1. Introduction

Temperature fluctuations during storage and distribution stages affect frozen food products such as vegetables or ice cream, inducing physical and chemical changes. Ice cream has especially been a subject of investigations regarding the storage conditions and particularly the changes in ice crystal size due to the recrystallization phenomenon. An excessive increase of the mean ice crystal size results in a reduction in ice cream quality and a shortening of its shelf life. The ability of stabilizers to exert a cryoprotective effect in ice cream by retarding ice recrystallization phenomena has been proven (Flores and Goff, 1999; Hagiwara and Hartel, 1996). But the influence of storage time/temperature remains predominant: fluctuating temperatures help to promote recrystallization phenomena, but it occurs even when temperature is kept constant for long term storage. There are several recrystallization mechanisms according to the storage conditions and the ice phase volume in the ice cream (migratory, isommas, accretive, melt-refreeze). Migratory recrystallization, also called Ostwald ripening, is characterized by the increase of large crystals at the expense of small crystals due to energy instabilities. The principles of Ostwald ripening is often used to describe the inherent instability of small crystals and serve as theoretical basis for other recrystallization mechanisms (Hartel, 1998). When recrystallization occurs, ice crystal size can increase beyond the critical ice crystal size (around 50 μm) at which coarse and grainy mouthfeel becomes perceptible, even with the presence of stabilizers (Eisner et al., 2005; Marshall et al., 2003). The influence of temperature on ice recrystallization stored under typical bulk and accelerated storage conditions has been experimentally investigated (Donhowe and Hartel, 1996a, b) for ice cream. The mean ice crystal size increased as a function of $time^{1/3}$, with kinetic parameters dependent on the temperature. Moreover, the recrystallization rate was much higher for ice cream subjected to oscillating storage temperature (from 0.01 to 2 °C, 10 min to 2 h) than for constant temperature. Similar results were recently published by (Ndoye and Alvarez, 2014).

Flores and Goff (1999) have shown that if the frequency and duration of temperature cycles (3–8 h) is increased, the smaller crystals tend to disappear. Microscope images of ice cream after temperature fluctuations also show a tremendous increase in crystal size that occurred in the product after heat shock.

During storage, ice cream is submitted to temperature fluctuations due to the on/off control of the refrigeration systems, typically 2 or 3 °C (Ben-Yoseph and Hartel, 1998), and during transportation, the temperature of ice cream can increase by 3–8 °C depending on the type of distribution vehicle. Usually, the limited thermal insulation and low thermal buffering capacity of the standard carton board containers do not provide enough protection from unforeseen warming.

A solution for this problem could be the use of insulated thermal containers or phase change material (PCM) covers. A PCM is a material selected for its high latent heat storage potential. The phase change can occur in various forms: solid–liquid, solid–gas, liquid–gas, but solid–liquid PCMs are the most used since they have benefited from many developments during the past two decades (Li et al., 2013). Solid-liquid PCMs can store and release a large quantity of heat within a narrow temperature range, and have also proved to be economically attractive.

The two protections studied here have a large potential improvement in the storage conditions by maintaining the temperature within an adequate range. Both of them will limit the temperature fluctuations. But PCMs, because of their capacity to absorb and slowly release energy, increase the thermal inertia of the packaging, and may represent the most ideal solution for limiting the temperature peaks. They can be used in various forms: single removable bricks, flexible wraps, and probably in near future composite materials for packaging (by micro or nanoencapsulation in polymers for example). Packaging using improved insulation may be also expected to maintain the temperature within close limits, and insulation materials such as polystyrene are largely available and cheap. Most of the recent works about the use of PCM panels to improve storage condition of frozen food evaluated their efficiency as heat sinks during power loss or temperature abuse (Gin and Farid, 2010; Oró et al., 2013). The aim of this work is here to evaluate their efficiency on long term storage with temperature fluctuations, and to test their potential to improve the final quality of the product of a sensitive product such as ice cream. A comparison with insulation panels is also presented.