Thermal protection of ice cream during storage and transportation

Denis Leducq, F.T. Ndoye, C. Charriau, G. Alvarez

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THERMAL PROTECTION OF ICE CREAM DURING STORAGE AND TRANSPORTATION

Denis LEDUCQ(*), Fatou Toutie NDOYE (*), Clara CHARRIAU(*), Graciela ALVAREZ(*)
(*)Irstea, UR GPAN, Antony, France
denis.leducq@irstea.fr

ABSTRACT

Ice cream is a very temperature sensitive product and temperature fluctuations during the storage and distribution steps of the food cold chain may result in changes in ice crystal size due to recrystallization phenomenon. An excessive increase of the mean ice crystal size results in a reduction of ice cream quality and a shortening of its shelf life. It is possible to improve the ice cream storage and transportation conditions by using an additional packaging with a low thermal diffusivity. Insulation material is usually chosen to reduce temperature fluctuations, but this paper proposes to evaluate the thermal protection of a phase change material (PCM) packaging and to compare its performance to a polystyrene configuration. The impact on temperature fluctuations and ice crystal size was characterized experimentally for a 5 months storage period and 3 different packaging materials: cartonboard, polystyrene and PCM. Measurements during a temperature abuse for 40 minutes at 20°C were also performed to evaluate the thermal protection provided by the different types of packaging. The results demonstrate that the use of an additional PCM packaging can have a significant impact on the final quality of the product during long term storage or for a product exposed to heat shock.

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 [1], [2].

During storage, ice cream is submitted to temperature fluctuations due to the on/off control of the refrigeration systems, typically 2 or 3°C [3], 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 possible solution to limit recrystallization is the use of thermal protective panels or covers, such as 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 [4]. 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.

In this work, experiments were conducted to evaluate the impact of the use of thermal energy storage devices (TESD) on the evolution of the quality of products stored during a long period, and consequently on recrystallization phenomena. A comparison with insulation panels is also presented.

2. MATERIAL AND METHODS

2.1 Experimental set-up

The experimental set-up consisted of an horizontal chest freezer equipped with on/off temperature control, and 3 rectangular cardboard boxes containing eight ice-cream 1L rectangular containers with the same dimensions: length of 180 mm, width of 100 mm, thickness of 70 mm. Commercial vanilla ice creams, majority formulated with skimmed milk, fat sugar and glucose syrup were purchased from supermarket. Ice cream boxes were stacked on two levels with four boxes per level. In order to limit the temperature fluctuations during storage, two options were investigated: limiting the heat flux around the ice-cream by adding an insulated package or buffering the heat transfer by using PCM panels.

Three types of boxes were used:

Box 1 Cartonboard box, containing 8 containers of 1 litre ice cream.

Box 2 : Same as box 1, except all the walls were insulated using an expanded polystyrene place (25mm thickness)

Box 3 : Same as box 1, except all the walls were covered with PCM rectangular bricks (220 x 150), similar thickness than the polystyrene insulation for box 2 (25 mm).

The selected PCM is a salt hydrate solution (water + sodium chloride + additives) and has a phase change temperature of -21°C and a subcooling temperature of -24.8°C.

Two T-type thermocouples were located at the core and the top surface of the ice cream inside one container and two were placed at the center and at the surface of the insulation and PCM panels. Ice crystal size was measured periodically using an in-situ method of counting and sizing particles: Focused Beam Reflectance Measurement (FBRM). A detailed description of the FBRM instrument used to perform ice crystal size analysis can be found in [5], [6].

2.2 Test procedure

Two procedures were used to characterize the thermal protection provided by insulated and PCM covers :

1. The boxes were kept under the same constant storage conditions for 140 days at a mean temperature of -22°C in a horizontal freezer operating with an on/off control operating between -20°C and -24°C. Samples of ice cream were analysed periodically every 30 days to measure the evolution of ice cream crystal size.
2. The ice cream boxes were first kept in a freezer at -23°C for 3 days and then exposed to 20°C ambient air during 40 min. Similarly to the long term storage experiment, the temperatures were measured inside the packaging, at the surface and the core of the ice cream. To avoid any rise of ice-cream temperature due to the contact of a PCM brick solidifying at its melting temperature of -21°C, bricks were solidified before the experiment.

3. RESULTS AND DISCUSSION

3.1 Long term storage

3.11 Ice crystal size

The mean Sauter chord length evolution after 140 days of constant temperature condition storage is presented in **Figure 1**, with a significant increase from 40 µm to 70 µm for the cartonboard box. The surface-volume mean length or Sauter length, more sensitive to changes in the volume of crystals than the mean length is defined as follows:

$$L_{32} = \frac{\int_0^{L_{max}} L^3 \psi(L) dL}{\int_0^{L_{max}} L^2 \psi(L) dL}$$

4.

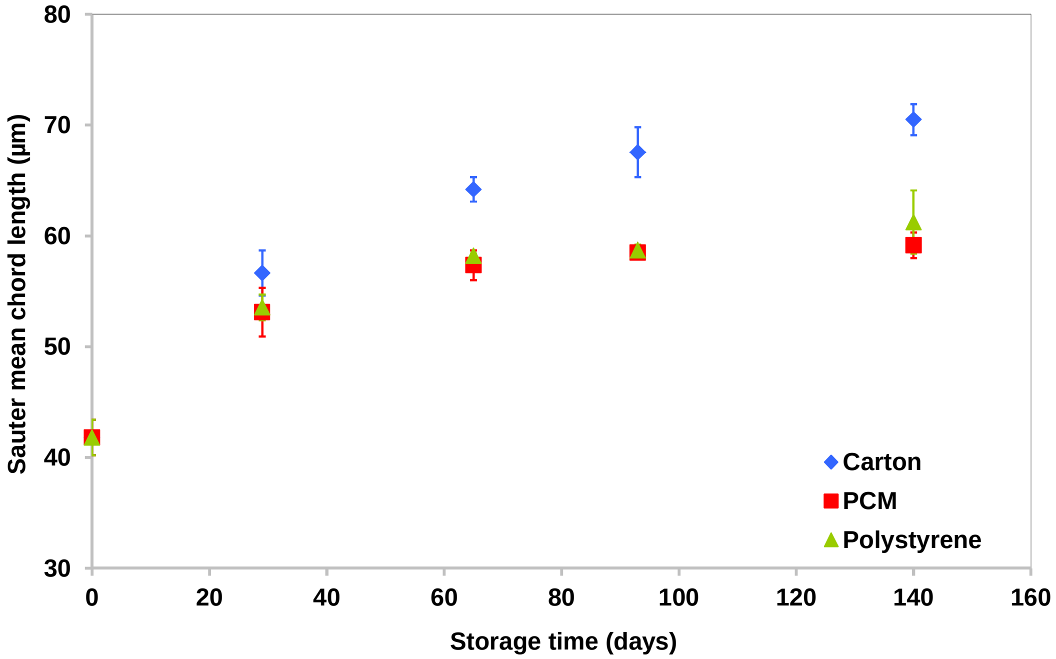

Figure 1 : change in average chord length during a 140 days storage

A 10 µm difference between the samples from the boxes without additional cover and the samples from the boxes was noted. No significant difference could be identified between the insulated packing box and the PCM covered box.

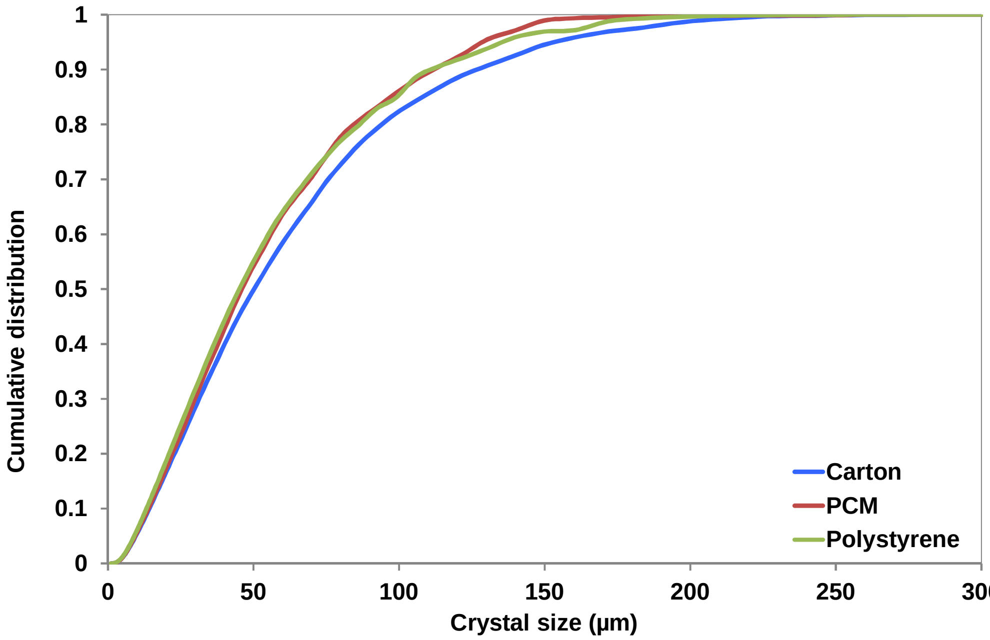

Figure 2 : Average crystal size distribution after 65 days without protection and with insulation or PCM

Figure 2 compares the crystal size distribution of samples from boxes without protection and from boxes with insulation and PCM covers, after 65 days of storage. For all of them, the evolution of ice crystal size distribution can be identified with 15% of the sizes greater than 100 µm for the ice cream stored without protection and 10% for ice cream with insulation or PCM covers. Again, no significant difference was identified between both protected packaging types.

3.1.2 Temperature fluctuations

Figure 3 illustrates the temperature changes inside the ice cream with oscillating temperature conditions due to the on/off control of the freezer depending on the protection packaging. As the temperature of the ambient air varies from -21.1°C to -22.6°C, fluctuations of temperature at the surface of the ice cream oscillates from -21.7 to -22.2°C with only cartonboard. For both insulated and PCM protection packaging, the amplitude is reduced from 0.5°C to 0.2°C, with no significant difference between the two packaging types.

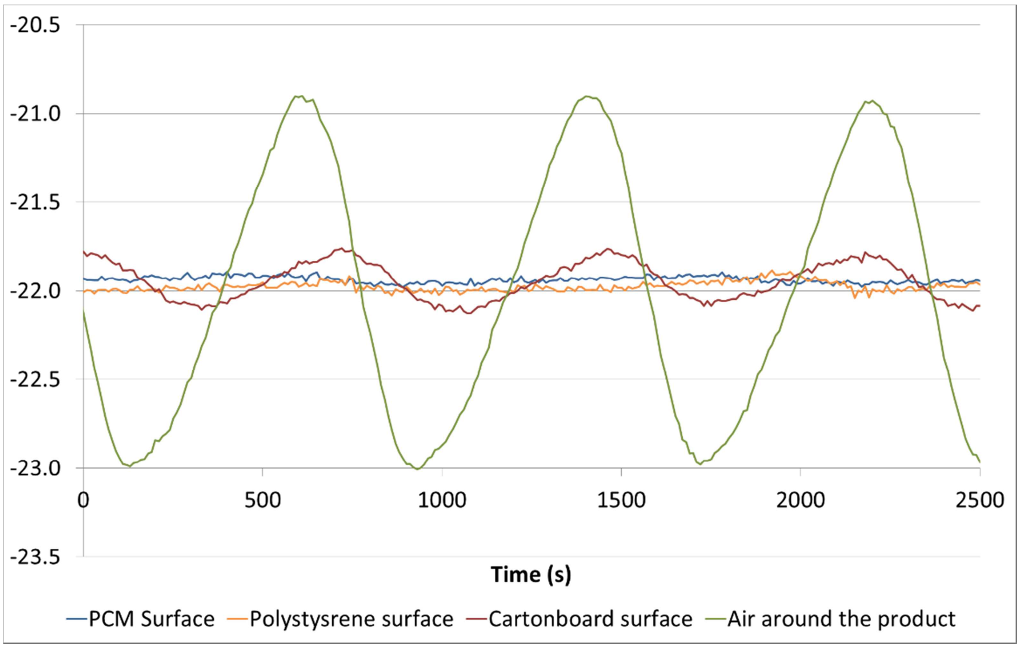

Figure 3 : Temperature fluctuations at the surface of ice cream with three different packagings

3.2 Temperature abuse

Figure 4 and **Figure 5** plot the temperature change during the temperature abuse that lasted 40 minutes, respectively at the surface (in contact of the upper lid of boxes) and at the core of the product. Large fluctuations in product temperature can be observed in the case of the reference cardboard box, with a maximum peak temperature of 18°C at the surface of the ice cream (**Figure 4**). Without any additional packaging, the product temperature rises quickly, especially at the surface, resulting in local melting of the ice cream.

The use of PCM or insulation packaging had a significant impact to limit the temperature increase of the ice cream during such a heat shock. With a 2.5 cm insulation, rise was limited to 9°C at the surface (**Figure 4**) and a rise of less than 1°C at the core (**Figure 5**) while with a PCM package, the temperature of the ice cream is restricted to a small range below 1°C in every region of the ice cream.

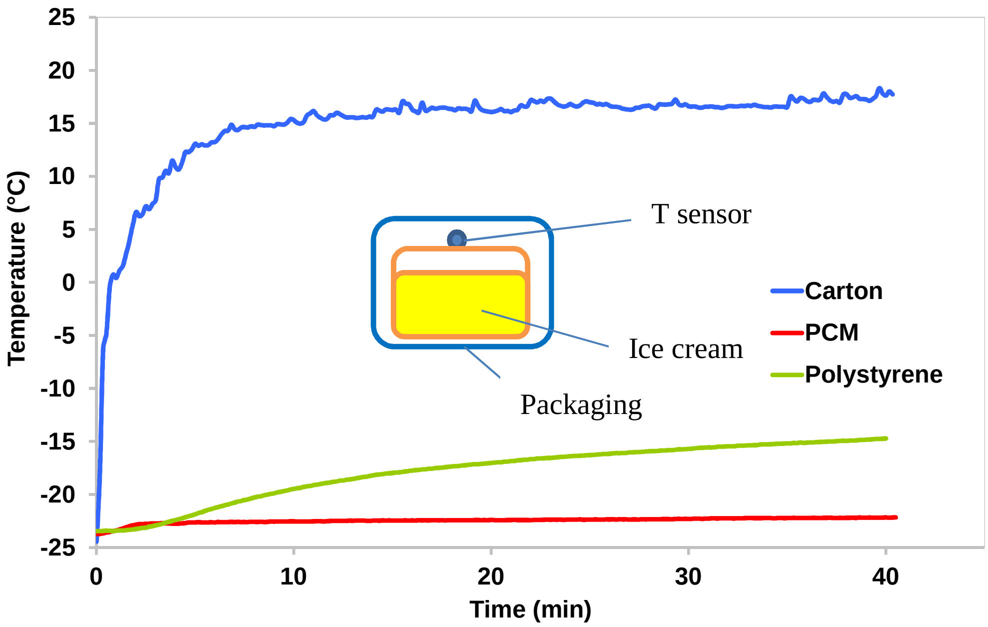

Figure 4 : Evolution of measured temperatures at the surface of ice cream subjected to temperature abuse of 20°C during 40min for the three configurations of boxes

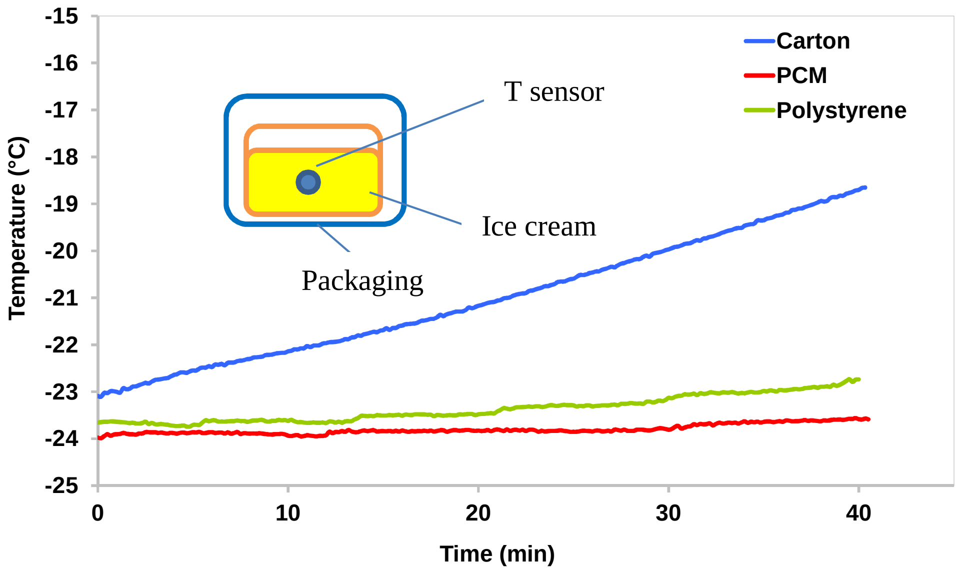

Figure 5 : Evolution of temperatures at the core of ice cream subjected to temperature abuse of 20°C during 40 min for the three configurations of boxes

5. CONCLUSION

To reduce the temperature variations of a sensitive product such as ice cream during long term storage, a low diffusivity material can be used as a protective panel around the containers. In this paper, insulation material (polystyrene) and a PCM (a salt hydrate) have been experimentally tested during 140 days storage. Crystal size was characterised for the two packagings and a significantly smaller mean crystal size was identified at the end of the experiment. The main advantage of using a PCM design is the small thickness necessary to get the same damping effect compared to the insulation material.

A second test exposed the boxes to ambient air during a limited time (40 min) and to monitor the temperature rising at the surface and at the core of the product. PCM thermal protection in this case provided the best results and could limit the temperature rising below 1°C. Only a 4mm thick slab is necessary to keep the product at the required temperature during a 40 min temperature abuse. Nevertheless it is important to select the PCM type in regard to the safety issues. It has to be noted that most of existing PCMS, based on hydrate solutions or organic products are food compatible. In the present study we choose a salt based low cost PCM.

6. ACKNOWLEDGEMENTS

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