Loss of ice through container openings during liquid-ice cooling of horticultural crops

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Vigneault, C. and Goyette, B. 2001. Loss of ice through container openings during liquid-ice cooling of horticultural crops. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 43:3.45-3.48. A family of standard, reusable, and recyclable plastic containers for handling, storing, and transporting horticultural crops, from field to market, has been developed. These can be used in precooling fruit and vegetables. The multi purpose use of these containers places a constraint on the design of the wall openings. The focus of this study is to establish an expression to determine the mass of ice lost from the containers during liquid-ice cooling of horticultural crops. Four different size ice particles were tested on four opening widths (3.18, 6.35, 9.53, and 12.7 mm). A correlation was derived for the mass of ice lost through container openings as a function of plate openings and size of ice particles. This expression can be used to compute the size of the container openings to minimize losses during liquid-ice cooling.

Keywords: packaging, precooling, liquid icing.

Une famille de contenants standard, recyclable et réutilisable a été développée pour la manutention, l’entreposage et le transport des produits horticoles à partir du champ jusqu’au marché d’alimentation. Ces contenants peuvent ainsi être utilisés lors du prérefroidissement des produits horticoles. La grande variété de l’usage de ces contenants apporte des contraintes dans la conception des ouvertures situées sur leurs parois. L’objectif de cette étude est de déterminer la masse de glace qui serait perdue à travers ces ouvertures lors de l’utilisation de glace liquide pour le prérefroidissement de produits horticoles. Quatre différentes grosseurs de particules de glace et quatre largeurs d’ouvertures (3.18, 6.35, 9.53 et 12.7 mm) ont été utilisées lors des essais. Une équation empirique a été établie pour décrire la relation qui existe entre la masse de glace perdue à travers d’ouvertures en fonction de la largeur de ces ouvertures et de la grosseur des particules. Cette équation peut être utilisée pour déterminer la largeur des ouvertures à utiliser lors de la conception de contenants pour minimiser la perte de glace lors de l’utilisation de glace liquide.

INTRODUCTION

Precooling of horticultural produce to near ideal holding temperature immediately after harvest is critical to providing longer shelf life. Precooling methods include: hydrocooling, liquid icing, vacuum cooling, forced-air cooling, and room cooling. Although some commodities can be cooled by several methods, most respond best to one cooling method. Each method has advantages and disadvantages. Liquid icing, also known as slush icing, is often used for cooling broccoli, sweet corn, carrots, brussels sprouts, and cantaloupes (Kasmire 1974). Liquid-ice cooling is used to achieve better contact with the commodities within packages. This method of cooling consists of mechanically or manually injecting a mixture of water-ice slurry into produce packages through handles or box apertures without removing the packages from pallets and opening their tops (Goyette et al. 2000). The water in the slurry acts as a carrier, which delivers ice throughout air voids between individual vegetables (Sargent et al. 1991). Generally, a pumping system allows the injection of the slurry into the containers and the water flowing out is recycled for exterior use. When the ice-water mix is depleted, the reservoir is refilled (Goyette 1994). The uniformity of the ice distribution in the boxes of produce is a very important factor in achieving rapid and uniform cooling (Prussia and Shewfelt 1984). For efficient cooling, the injected ice should remain within the container.

Containers for storing and transporting horticultural crops have been used in the fruit and vegetable industry for many years. In early years, wooden boxes were used for the storage and shipment of produce. Wooden boxes have many disadvantages and their use has been replaced, particularly for liquid icing, by the use of corrugated cartons coated to resist moisture damage. Recently, containers made of plastic materials have become more commonplace in the agri-food industry. These have the advantage of retaining their strength after wetting and can include wall openings that enable the use of other types of chilling fluid circulation, such as air and water.

To provide an efficient and uniform cooling throughout the entire container and throughout the entire stack of containers by minimizing energy losses, the design of these containers should take into consideration the various processes involved in the different precooling methods. For instance, wall openings should allow a surface area large enough to enhance cooling during forced-air cooling while minimizing the loss of ice through wall openings during liquid-ice cooling. Through experimentation, Vigneault and Émond (1997) determined that the opening surface for forced air-cooling should be approximately 20 to 30% to reduce pressure loss. In a study on continuous flow of liquid-ice systems, Vigneault et al. (1995) analysed the effects of different sizes of ice particle on the surface temperature of broccoli, the mass of ice remaining in the boxes of broccoli, and the icing efficiencies. It was
recommended to use ice particle with size ranging from 4.1 to 5.1 mm. Other parameters, such as fruit and vegetable weight and physical support, should also be considered for the final choice of width of opening; however, this is beyond the scope of this study.

The objective of this study was to derive an expression to determine the mass of ice lost from the container openings during liquid-ice cooling of horticultural crops. The results of this study are protected by Canadian and American patents (Vigneault and Émond 1997, 1998).

MATERIAL and METHODS

Experimental set-up
For the experiment, four different acrylic plates, 254 mm in diameter and 3.18 mm in thickness, were machined to represent four different opening widths (Fig. 1). The different widths were: 3.18, 6.35, 9.53, and 12.7 mm. In all four cases, the opening surface area represented 25% of the total surface area of the plates. A galvanized tube assembly, 305 mm in diameter and 230 mm in length, supporting the plate, served to collect the ice passing through the openings (Fig. 2). A plywood ring, 19 mm thick and 19 mm wide, was used to maintain the acrylic plate in place. This setup enabled the collection of all ice and water material flowing through the plate openings.

The mixture of water and ice (liquid ice) was circulated through the openings of the plates and a metallic sieve was used to collect the ice particles. The sieve was made of 1.5 mm x 1.5 mm openings, square in cross section.

A commercial machine (Ro-Tap™, Laval Lab, Laval, Québec) was used to obtain ice particles with an average size of approximately 7 mm. The particles were crushed and measured using the granulometric analysis method described in Vigneault et al. (1995). Four different particle sizes were formed using different techniques for ice crushing. The average size of the particles in each category was: 2.1, 3.2, 4.5, and 6.4 mm. For each particle size, a 1:1 ratio of 0°C water and ice was prepared as the cooling solution.

Preliminary tests were performed to determine the amount of ice and water (liquid-ice) required to complete all the experiments. Three mixtures of liquid-ice made with 1, 1.5, and 2 kg of ice were tested with each of the four plates using 6.4 mm ice particles. Four replicates were carried out for each test, following a solution ratio of 1:1 ice to water. These amounts of ice were sufficient to cover the entire plate surface area, forming ice bridges over the openings.

Experimental procedure
The tests were performed in the Postharvest Technology Laboratory of Agriculture and Agri-Food Canada in Saint-Jean-sur-Richelieu, Québec. All liquid icing experiments were performed under 0°C temperature conditions to prevent ice melting. The water used for the liquid-ice was initially cooled to 0°C. The four different size ice particles (2.1, 3.2, 4.5, and 6.4 mm) were applied on the four opening widths (3.18, 6.35, 9.53 and 12.7 mm) in the course of four replicates, for a total of 64 tests. The mixture was prepared using a 1:1 ratio of ice to water, mixed for a few seconds to obtain a homogeneous solution, and then rapidly poured over the plate. A 2-minute delay was necessary to drain the excess water. The amount of ice passing through the openings of the plate was collected by the sieve and weighed after 2 minutes. These measurements were taken using an electronic scale, ±1 g precision.

RESULTS

Preliminary trials to determine the minimum amount of ice necessary for complete coverage of the plate surface area are presented in Fig. 3. These tests demonstrated that the amount of ice poured on the plates (1, 1.5, or 2 kg) does not affect significantly the amount of ice flowing through the plate.
openings \((p > 0.1)\). This can be explained by the fact that ice particles pass through the openings until a bridge is formed, giving rise to a barrier and stopping further flow of ice through the openings. The minimum amount of ice necessary to completely cover the surface of the plate was observed to be 1.0 kg; however, based on technical considerations, 1.5 kg of ice was used during the experimentation.

Figure 4 presents the results obtained on the different sizes of ice particles passing through the plate opening. They are presented as mass of ice collected for the different widths of openings and sizes of ice particles. Regression analysis performed on the results yielded:

\[
M = 92.8S^{-1.58}W^{1.6}, \quad R^2 = 0.96
\]

where:
- \(M\) = mass of ice loss through the openings (g),
- \(S\) = granulometric size of ice particles (mm), and
- \(W\) = opening width (mm).

It was observed that when ice particles of 2.1 mm were applied to 12.7 mm openings, no bridging occurred over the openings and the ice passed through openings as it was poured over the plate. Therefore, this combination of ice particle size and plate opening size was abandoned. Furthermore, it was concluded that the efficient use of liquid-ice cooling with ice particles of 2.08 mm, in a container having openings of 12.7 mm would not be possible. This agrees with the recommendation of Vigneault et al. (1995) to use ice particles larger than 4.1 mm during liquid-ice cooling.

\[
M = 92.8S^{-1.58}W^{1.6}, \quad R^2 = 0.96
\]

Equation 1 provides an expression to determine the mass loss as a function of ice particle size and plate openings.

**CONCLUSION**

A family of standard, reusable, and recyclable plastic containers for handling, storing, and transporting horticultural crops from field to market has been developed. The multi purpose use of these containers places a constraint on the design of the wall openings. That is, during liquid-ice cooling, the wall openings should be narrow to retain the ice particles in the containers. During forced-air cooling, however, the container wall openings should be large and numerous to promote air circulation through the produce. Due to these constraints, a certain compromise must be made and a certain acceptable amount of ice will be lost during liquid-ice cooling. An expression was established to compute the mass of ice lost from the containers during liquid-ice cooling of horticultural crops. This correlation takes into consideration the width of container openings and size of ice particle used in the liquid-ice mixture. Container size openings to minimize losses during liquid-ice cooling can be computed using this expression.

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**REFERENCES**


