# Continuous flow liquid-ice system tested on broccoli

C. VIGNEAULT, B. GOYETTE and G.S.V. RAGHAVAN

[1]*Horticultural Research and Development Center, Agriculture and Agro-Food Canada, Saint-Jean-sur-Richelieu, QC, Canada J3B 3E6; and* [2] *Agricultural and Biosystems Engineering Department, Macdonald Campus of McGill University, Sainte-Anne-de Bellevue, QC, Canada H9X 3V9.* [1]*Contribution No. 335/95.09.02R. Presented as ASAE Paper No. 93-6506. Received 23 August 1994; accepted 8 February 1995.*

Vigneault, C., Goyette, B. and Raghavan, G.S.V. 1995. **Continuous flow liquid-ice system tested on broccoli.** Can. Agric. Eng. 37:225-230. A continuous flow liquid-ice system was designed and tested for broccoli precooling. Ice particles were injected into a water stream, then the mixture was pumped into the box of produce. A granulometric method was adapted to measure ice particles. The effects of different ice particle sizes and ice-water ratios on the surface temperature of broccoli, the mass of ice remaining in the boxes of broccoli, and the icing efficiencies were analyzed. The results led to the establishment of recommended conditions for the operating parameters of the proposed system.

Keywords:vegetables, postharvest, precooling, ice particles, granulometric method.

Un système d'injection en continue de glace liquide a été développé et évalué pour le prérefroidissement du brocoli. Le procédé consiste à injecter les particules de glace dans un courant d'eau pour ensuite le pomper dans les boîtes de produits. Une méthode d'analyse granulométrique a été adaptée afin de mesurer les particules de glace. L'effet de la grosseur des particules de glace et du ratio glace-eau sur la température de surface du brocoli, la quantité de glace restant dans les boîtes de brocolis et l'efficacité du glaçage ont été analysés. Les résultats ont permis de faire des recommandations sur les paramètres opérationnels du système.

## INTRODUCTION

Respiration must be slowed down by rapid cooling (Fraser 1991) or precooling (ASHRAE 1986) immediately after harvest to delay the physiological deterioration of produce (fruits or vegetables) (Ryall and Lipton 1972). For example, broccoli respiration rate at 20°C is 15 times greater than at 0°C (ASHRAE 1981).

Liquid-icing is extensively used for precooling broccoli (Kader 1992). It is also recommended for root vegetables, artichokes, brussels sprouts, green onions, leeks, peas, some melons, and sweet corn (Kasmire and Thompson 1992).

Up to now, liquid-icing has been achieved by mixing crushed-ice with water in a large insulated reservoir (Fig. 1). The liquid-ice slush is pumped and introduced into the boxes by handle holes at the top sides of the containers. The advantages of liquid-icing include the maintenance of a cool and moist environment for the produce between the packing house and the market place and the elimination of additional handling of the stacked boxes (Mitchell 1992).

However, liquid-icing has many drawbacks. The produce and the packaging must be tolerant to water contact and prolonged exposure to 0°C. Also, even if liquid-icing is cost effective for large production units, small and medium production units cannot justify its use because of high initial and operating costs. Due to the buoyancy force on ice particles, the liquid-ice slush must be stirred continuously to obtain a uniform mixture. Furthermore, the system is generally operated by batches to maintain a constant ice-water ratio. Batch operation requires rapid ice and water feeding systems to reduce the off time during the filling of the liquid-ice reservoir. The stirring process and the batch operation procedure result in a high power requirement (22 kW) to precool 180 to 200 boxes of produce per hour. Finally, uniform ice distribution in the boxes can be difficult to achieve. This is important to obtain rapid and uniform cooling (Prussia and Shewfelt 1984). Ice particle size and ice-water ratios should affect ice distribution in the boxes, but information on this is absent from the literature.

The mean cooling rate of a produce is generally used to evaluate the cooling efficiency of a given cooling system. The cooling rate varies as a function of the specific mass, the heat capacity, the heat conductivity, the shape, size, and orientation of the produce in the container, and the temperature differential between the produce and the cooling fluid surrounding the produce. However, it is possible to eliminate the effect of each of these parameters. The efficiency of a cooling system may be evaluated based on its capacity to maintain the surface temperature of the produce at the lowest temperature it can tolerate for a long period of time. It has been demonstrated that the temperature at the surface of a produce can be calculated from the change of its inside temperature during the cooling process (Goyette 1994). The mean temperature at the surface of the produce could then be used as a convenient method to evaluate the operating parameters of the liquid-ice system.

The objectives of this project were to : i) develop a continuous flow liquid-ice system which has a lower power requirement than current systems, ii) evaluate the ASAE granulometric method for measuring ice particle size distributions, and iii) determine the recommended operating parameters of the new system for broccoli precooling.

## DESCRIPTION OF THE SYSTEM

The proposed liquid-ice system consists of a continuous ice feeding system that does not require a reservoir for ice-water mixing. The ice-water slush is used immediately after ice and

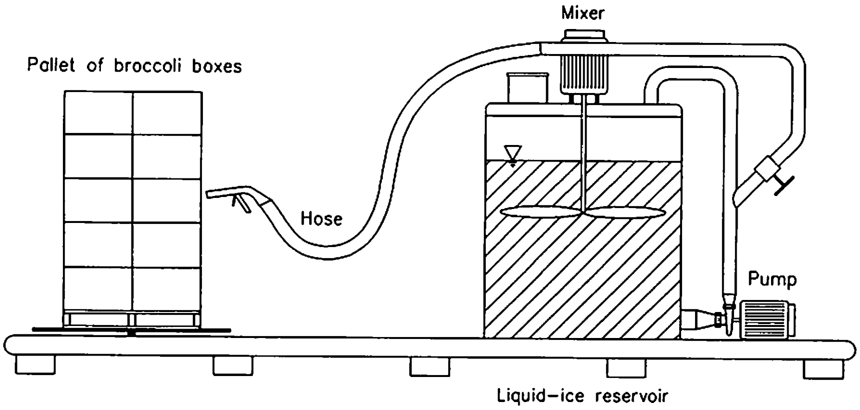


**Fig. 1. Schematic of conventional liquid-ice system precooling 180 boxes of broccoli per hour.**

water are mixed. The different components of the new system are presented in Fig. 2. Starting from the flaker, the ice goes through the storage room, the auger, the crusher, the crushed ice reservoir, the ice-water mixing chamber, the diaphragm pump, the injection and control handle, and the box of produce. Inside the boxes, the water separates from the ice and flows to the recycling reservoir where it is pumped again to the mixing chamber.

Each component of the system was chosen and specified to ice 150 to 200 boxes per hour. Preliminary tests were performed to determine the maximum diaphragm pump flow rate, to balance the control system as a function of the ice and water flow rate, and to establish the maximum ice-water ratio for plug free operation.

### Ice flaker and storage room

The ice is produced using a conventional ice flaker that sprays water onto the inside surface of an insulated freezing drum. The ice is removed using a helicoidal compression reamer rotating at a constant speed along the surface of the freezing drum. The flakes obtained are about 2.5 mm thick by 10 to 50 mm in length and width. The ice is produced continuously and stacked in an insulated storage room. An ice sensor stops the ice production when the storage room is filled.

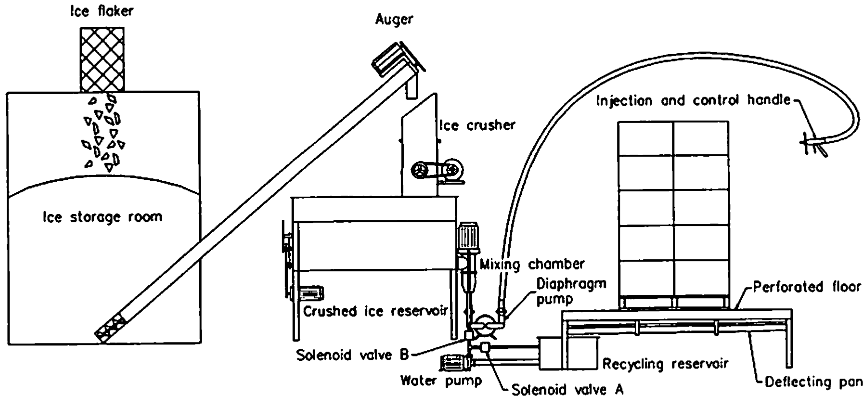


**Fig. 2. Schematic of the liquid-ice system developed during the project.**

### Ice feeder auger

A 100 mm diameter x 3.66 m long auger is used to feed the ice crusher. A funnel-shaped stand is required to permit full capacity operation of the auger when using manual feeding. A 0.35 kW electric motor drives the auger.

### Ice crusher

An ice crusher (Fig. 3) was built to reduce and standardize the ice particle size. It consists of a square casing containing a drum driven by a 0.75 kW electric motor. The ice crushing drum built from a 300 mm diameter, 300 mm long aluminum cylinder is driven at 540 rpm. Forty, 6 mm diameter 45 mm long pins are uniformly inserted at a 45° angle pointing towards the rotational direction of the drum and protruding 6 mm above the drum surface. The tips of these pins are sharpened at 45° angle to form the crushing teeth. A grid is mounted below the drum to sieve the ice particles and further reduce their size. Two grids (A and B) were constructed by welding 9 mm x 25 mm x 275 mm flat iron bars on two end plates 12.5 mm thick shaped to follow the contour of the cylinder with a clearance of 2.0 mm. The bars of grid A were spaced at 22 mm, covering half of the total surface underneath the crushing drum. The bars of grid B were spaced at 18 mm and covered the total surface underneath of the crushing drum. Three safety rods were added above the cylinder to avoid accident.

The rate at which the crusher processes the ice was 180 kg•min$^{-1}$ while no grid was used and 130 kg•min$^{-1}$ with the half grid (grid A) installed at the bottom of the crusher. When using the full grid (grid B), ice particles stuck together between the steel bars occasionally plugging the ice crusher outlet.

### Crushed ice reservoir

The crushed ice reservoir supplies a uniform ice flow rate to the mixing chamber (Fig. 4). This 1.8 x 0.9 m rectangular, open top reservoir is 0.3 m in height and has a V-shaped bottom section with two walls at 45° angle. Its volume is approximately 0.75 m$^3$. A bridge breaker, described later, and a 90 mm diameter x 1.8 m long auger supply the ice to the mixing chamber. A 0.75 kW variable speed DC electric motor operates the auger and the bridge breaker. The speed of the motor can be adjusted from 0 to 1750 rpm to supply the ice at the desired flow rate. A transmission reduces the speed of the DC motor. At full speed, the auger rotates at 150 rpm and the bridge breaker rotates at 6 rpm.

The ice flow rate of this auger, which feeds the mixing chamber, was selected as a function of the rotational speed of the DC motor. The ice flow rate entering

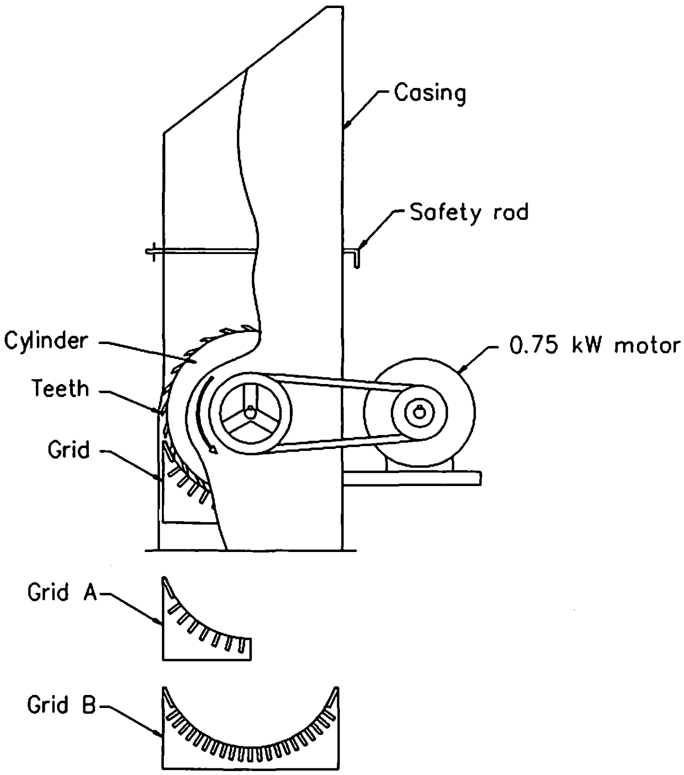


**Fig. 3. Ice crusher and grids A and B.**

the mixing chamber was sampled and weighed for each 10% gradation, between 30% to 100%, of the control panel of the DC motor. The tests were replicated twice. The mass flow ranged from 0.13 kg•s$^{-1}$ to 1.48 kg•s$^{-1}$. The results were not stable while operating the DC motor at slow speeds (under 50%), since a 17% variation between replicates was measured. This variation decreased very quickly with increased speed reaching 3% of the measured flow rate at full speed.

The bridge breaker is made of a central axle on which 17 blades are uniformly distributed. The blades are mounted at a 20° angle to push the ice backwards. This orientation of the blades is necessary to prevent packing of the ice in front of the crushed ice reservoir at the inlet of the mixing chamber.

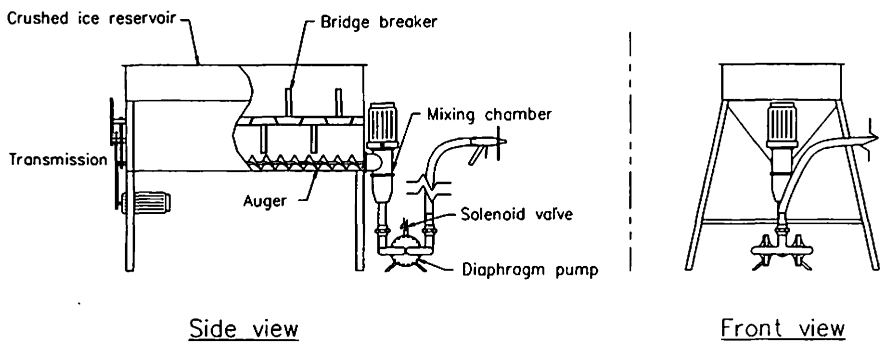


**Fig. 4. Schematic of the crushed ice reservoir and mixing chamber.**

### Mixing chamber

The mixing chamber (Fig. 4) consists of a cylindrical chamber placed at the exit of the crushed ice reservoir. The water and ice are introduced into the mixing chamber by two separate inlets (Fig. 5). A 90 mm diameter x 150 mm long vertical auger is placed inside of the mixing chamber to prevent blocking. A direct drive 0.25 kW electric motor drives this vertical auger. The ice-water slush exits the mixing chamber and flows through a 90 to 50 mm diameter funnel to the diaphragm pump.

### Diaphragm pump

A double action pneumatically-activated diaphragm pump circulates the ice-water slush into the boxes. The compressed air is produced by a 3.5 kW compressor which has a 360 L air reservoir. A manual gate valve and a normally-closed solenoid valve are installed on the air supply line. The manual valve regulates the air flow rate that controls the operating speed of the diaphragm pump. When the solenoid valve is activated, the compressed air is free to circulate and activates the diaphragm pump. This pump, with 50 mm diameter inlet and outlet channels, allows for the pumping of water containing non uniform solids like ice.

The maximum continuous flow rate was determined for the diaphragm pump. The air compressor operates the diaphragm pump at a decreasing flow rate until the pressure inside of the compressed air reservoir reached equilibrium. The flow rate of the diaphragm pump and the compressed air pressure were recorded after pressure inside the compressed air reservoir was constant for 10 minutes. A water flow rate of 3.3 L•s$^{-1}$ was obtained while operating at 150 kPa.

The maximum ice-water mass ratio for plug free operation was determined as follows. The diaphragm pump was operated at its maximum continuous flow rate. The ice was fed at 1.48 kg•s$^{-1}$. The water flow rate was adjusted to supply 1.8 kg•s$^{-1}$, which resulted in a 45% ice-water ratio. The water flow was then decreased by steps of 5% of ice-water ratios until the liquid-ice system plugged up. This test was repeated several times and showed that plugging occurred when the system was operated using an ice-water ratio of 70%. These tests were performed with the ice obtained using the crusher with no grid, but it was considered that the smaller ice particles would perform better. The ice particles produced without processing them using the ice crusher, were also tested. These particles contained some large ice chunks which plugged up the system regardless of the ice-water ratio. The maximum operating ice-water ratio was then fixed at 60% to avoid any plugging problem during the icing operation.

### Injection and control handle

An injection handle is used to inject the liquid-ice into the boxes of produce. The handle tip is designed to fit the handle holes of the boxes. An electric switch is mounted on the injection

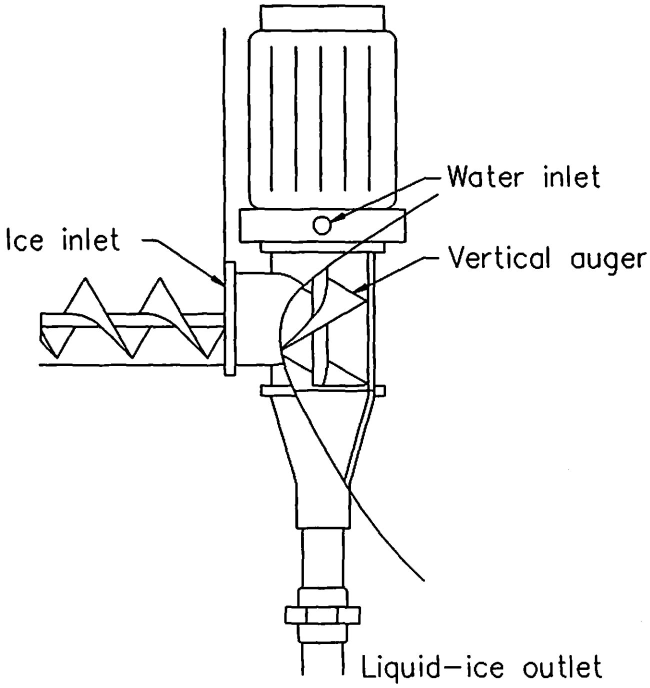


**Fig. 5. Schematic of the mixing chamber used with the liquid-ice system.**

handle to activate the solenoid valves of the system and the electric motor operating the crushed ice auger. For safety, the voltage used on the handle switch is 24 V.

### Water flow components

During liquid-icing, a pallet of produce is placed on an elevated perforated floor (Fig. 2). A 300 L water reservoir and three pans located under the perforated floor collect the water that flows out of the boxes. The water is recirculated from this reservoir by a 0.7 kW direct drive water pump to the ice-water mixing chamber. A manual valve placed on the exhaust line of the water pump allows adjustment of the water flow rate. Two solenoid valves, one normally opened (A) and one normally closed (B) are also placed in the exhaust line (Fig. 2) to direct the water flow. When activated, these valves direct the water towards the mixing chamber; otherwise, the water is directed towards the recycling reservoir. The flow rate of the water pump was measured at each one eighth of a turn from half a turn to fully open. The measurements were repeated twice. The flow rate ranged from 0.315 kg•s$^{-1}$ to 2.2 kg•s$^{-1}$ and showed a maximum variation between replicates of 5% of the measured flow rate.

## MATERIALS AND METHODS

### Mean ice particle size distributions

In a "liquid-ice" system, the ice particle size should affect the uniformity of ice distribution in the boxes of produce. Different ice particle sizes were obtained by crushing polyshaped ice flakes of about 50 mm maximal length and 2.5 mm in thickness. The ice crusher (Fig.3) was used to obtain ice particles of four different sizes when processing the ice using grid B, grid A, no grid, and finally using unprocessed ice flakes.

A granulometric analysis was used to determine the mean size of the four samples of ice particles by adapting the sieving method for feed ingredients (ASAE 1992). In the case of ice particles, the tests were performed in a freezer where the ice was kept at -5 to -7 °C to avoid ice particles sticking together and forming large ice chunks. The required equipment consists of a set of woven-wire cloth sieves having a diameter of 203 mm. The openings of the sieves were of the following sizes: 1.25, 5, 10, 14, 20, and 28 mm. A Ro-tap™ sieve shaker and a balance (0.1 g) were used.

Preliminary tests were performed to determine the shaking time and the mass and number of samples required to obtain significant results. Large samples usually require longer shaking time to separate the ice particles but smaller samples require extra care to recover all material from the sieves (ASAE 1992). Samples of 200, 400, and 600 g were tested.

The shaking time was determined by placing an ice sample on the top sieve of the set of sieves and shaking until the mass of material on the smallest sieve changes by less than 0.2% of the total mass. Each sieve was weighed after 30, 60, 90, and 120 s shaking time.

The different ice particle size distributions were tested with the sieving method. The number of samples required to differentiate each particle size was calculated following the statistical method described by Steel and Torrie (1980).

Based on the results obtained, five samples of about 400 g were required for each ice particle size with a shaking time of 60 s. The mean sizes of the ice particles were calculated and reported in terms of geometric mean size ($d_{gw}$) and geometric standard deviation ($S_{gw}$) by mass as recommended by ASAE (1992).

### Operating parameters

The following series of tests were performed to evaluate the effects of the ice-water ratio and the ice particle size distributions on the icing efficiency and the uniformity of the distribution of ice in the box of produce. The icing efficiency is defined as the ratio of the ice remaining in the box of produce compared to the ice that was circulated through the box. The ice remaining inside the box was determined by calculating the difference between the mass of the box containing the broccoli before being iced and five minutes after the end of the treatment. The ice circulated into the box is calculated by multiplying the time required to process a box by the ice flow rate. During the experiment, three ice-water ratios (40%, 50%, and 60%) and four mean ice particle sizes (3.2, 4.4, 5.1, and 6.9 mm) were tested. The liquid-ice mixture flow rate was kept constant at 2.5 kg•s$^{-1}$ during the experiment.

The cooling efficiency was evaluated by monitoring the temperature using thermocouples inserted at the centre of the broccoli stalks placed at three specific locations inside of the treated boxes (Fig. 6).These positions were: 1) near the ice-water inlet, 2) the upper part of the box at the opposite side of the ice-water inlet and, 3) the bottom part of the box at the opposite side of the ice-water inlet. For each treatment, three boxes of 14 bunched broccolis were treated with liquid-ice and stored in a refrigerated room 10 minutes after the end of the treatment. The temperature of the storage room was maintained at 5°C.

The surface temperature of the 108 tested broccolis (3 positions, 3 replicates, 3 ice-water ratios, 4 ice particle sizes) was calculated following the method described by Goyette (1994).

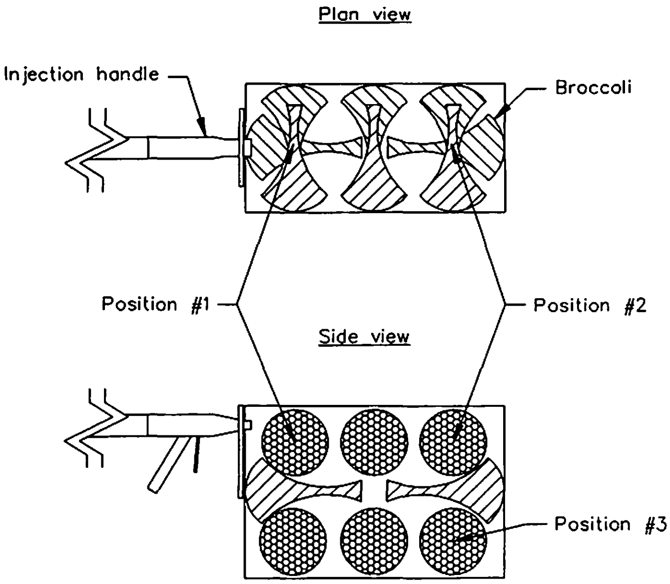


**Fig. 6. Typical box of 14 bunched broccolis and the three positions of the thermocouples.**

Considering that a larger surface of contact between the ice and the broccoli generates a lower surface temperature, the uniformity of the ice distribution inside of the box was evaluated by comparing the surface temperature of the broccoli.

## RESULTS AND DISCUSSION

### Mean ice particle size

The following results allowed determination of the procedure of the ice particle granulometric analysis. The mass difference of the smallest sieve containing material did not exceed 0.3 g between the time 60 s and 90 s while using 400 g. Equilibrium was then considered after a 60 s shaking period. The 600 g samples did not equilibrate within the 120 s shaking period. It appeared that this sample size was too large and the sieve was too full. The 200 g sample size also required 60 s to reach equilibrium but much longer time was required to clean the sieve to maintain acceptable precision of mass measurement. The method was then standardized to a 400 g sample and a shaking time of 60 s.

Preliminary tests were performed to calculate the number of replicates required for the granulometric method. Five replicates were required while using 0.6 mm as the half-width of the confidence interval $t_{4,\,0.025} = 2.78$.

The sieving of the five samples of each of the ice particle size distributions (Table I) allowed differentiation between their $d_{gw}$. $S_{gw}$ does not vary with $d_{gw}$ ($F_{1,20} = 0.494$, P=0.49) meaning that the proportion of the particle sizes is uniform among the samples.

### Operating parameters

Table II shows the mean temperature at the surface of broccoli for the different positions as a function of the ice-water ratios. Table III shows the mean surface temperature of broccoli for the different positions as a function of the ice particle size distributions. The interaction between the ice-water ratio and the ice particle sizes was not statistically significant. Only one ice particle size (4.4 mm) and one ice-water ratio (50%) showed a significant difference in the mean surface temperature as a function of its position inside the box.

**Table I: Geometric mean size ($d_{gw}$) and geometric standard deviation ($S_{gw}$) of the ice particles obtained from the different ice preparation methods**

| | Ice preparation method | | | |
|---|---|---|---|---|
| | Not crushed | Crushed no grid | Crushed 1/2 grid | Crushed full grid |
| $d_{gw}$ (mm) | 6.91 | 5.10 | 4.41 | 3.22 |
| $S_{gw}$ | 1.73 | 1.70 | 1.79 | 1.66 |

**Table II: Mean temperature (°C) at the surface of the broccoli as a function of position inside the box and the ice-water ratio**

| | Ice-water ratio (%) | | |
|---|---|---|---|
| Position | 40 | 50 | 60 |
| 1 | $2.2^{A}$ | $2.6^{A}$ | $1.8^{A}$ |
| 2 | $2.5^{A}$ | $3.5^{AB}$ | $1.9^{A}$ |
| 3 | $2.7^{A}$ | $4.3^{B}$ | $3.1^{A}$ |

Means with the same letter are not significantly different a $\alpha = 0.05$.

Table IV shows the mean surface temperature, the mass of ice in the boxes and the icing efficiency. The 4.4 mm ice particle size generated a significantly lower mean temperature at the surface showing a better ice distribution in the boxes. More ice was added inside the box while using the 4.4 and 5.1 mm ice particle sizes. The icing efficiency was significantly lower while using the 3.2 mm ice particle size, since a large portion of the ice flowed out of the boxes with the water during the liquid-icing process. A significantly higher surface temperature resulted from using the 3.2 mm and 6.9 mm ice particle sizes. These results are likely related to the fact that less ice remained inside the boxes when using these two particle sizes.

The effect of the ice-water ratio is presented at Table V. The ice-water ratio had no significant effect on the icing efficiency and the mass of ice remaining in the boxes. However, the 50% ice-water ratio produced a significantly higher temperature at the surface, this result has not been explained.

## CONCLUSION

A liquid-ice system was developed requiring only 6.3 kW to operate compared to the 22 kW normally used for the same icing productivity. The productivity of this system was about 180 boxes per hour under continuous operating conditions.

A granulometric method from ASAE standards was adapted to measure ice particle sizes. It allowed determina-

**Table III: Mean temperature (°C) at the surface of the broccolis as a function of position inside the box and the particle size**

| Position | Ice particle size distribution (mm) | | | |
|---|---|---|---|---|
| | 3.2 | 4.4 | 5.1 | 6.9 |
| 1 | $2.8^{A}$ | $0.9^{A}$ | $2.0^{A}$ | $3.2^{A}$ |
| 2 | $3.4^{A}$ | $1.5^{AB}$ | $2.3^{A}$ | $3.3^{A}$ |
| 3 | $3.4^{A}$ | $2.3^{B}$ | $3.2^{A}$ | $4.6^{A}$ |

Means with the same letter are not significantly different a $\alpha = 0.05$.

**Table IV: Mean temperature (°C) at the surface of the broccoli, mass of ice in the boxes and icing efficiency as a function of the ice particle size**

| Ice partcle size (mm) | Surface temperature (°C) | Mass of ice in the boxes (kg) | Icing efficiency (%) |
|---|---|---|---|
| 3.2 | $3.2^{CB}$ | $11.8^{BC}$ | $33^{B}$ |
| 4.4 | $1.5^{A}$ | $12.9^{AB}$ | $61^{A}$ |
| 5.1 | $2.5^{B}$ | $13.5^{A}$ | $62^{A}$ |
| 6.9 | $2.7^{C}$ | $11.1^{C}$ | $66^{A}$ |

Means with the same letter are not significantly different a $\alpha = 0.05$.

**Table V: Mean temperature (°C) at the surface of the broccoli, mass of ice in the boxes and icing efficiency as a function of the ice-water ratio**

| Ice-water ratio (%) | Surface temperature (°C) | Mass of ice in the boxes (kg) | Icing efficiency (%) |
|---|---|---|---|
| 40 | $2.4^{B}$ | $12.4^{A}$ | $55^{A}$ |
| 50 | $3.5^{A}$ | $11.9^{A}$ | $54^{A}$ |
| 60 | $2.3^{B}$ | $12.6^{A}$ | $57^{A}$ |

Means with the same letter are not significantly different a $\alpha = 0.05$.

tion of the geometric mean size of ice particles produced using four different crushing methods.

It was demonstrated that the ice particle sizes and the ice-water ratios affected the surface temperature of broccoli and hence the performance of a liquid-ice system. The recommended operational parameters of the new system were determined. The lowest mean temperature at the surface of broccoli was obtained using the 4.4 mm ice particle size. More uniform ice distribution, better icing efficiency, and more ice addition were obtained when using the 5.1 mm ice particle size. There was no significant difference for the mass of ice remaining in the boxes of produce and the icing efficiency for the different ice-water ratios. The 40% and 60% ice-water ratio generated a lower surface temperature than using 50%. However, for the same liquid-ice flow rate, 33% less time is required with the ice-water ratio of 60% to process one box of produce than using an ice-water ratio of 40%, thus increasing the productivity. It is recommended to use ice particle sizes ranging from 4.4 to 5.1 mm and the 60% ice-water ratio.

## REFERENCES


ASAE. 1992. ASAE S319.28. Method of determining and expressing fineness of feed materials by sieving. In *ASAE Standards 1992*, 402. St-Joseph, MI: ASAE.

ASHRAE. 1981. Thermal properties of foods. In *Fundamentals Handbook*, chapter 31. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1986. Methods of precooling fruits, vegetables, and ornamentals. In *Refrigeration Systems and Applications Handbook*, chapter 11. Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Fraser, H.W. 1991. Forced-air rapid cooling of fresh Ontario fruits and vegetables. AGDEX 202-736. Ontario Ministry of Agriculture and Food, Toronto, ON.

Goyette, B. 1994. Development and evaluation of a liquid ice system. Unpublished M. Sc. thesis. Macdonald Campus, McGill University, Montreal, QC.

Kader, A.A. 1992. *Postharvest technology of horticultural crops*, 2nd ed. Publication No. 3311. Cooperative Extension Division of Agriculture and Natural Resources, University of California, Davis, CA.

Kasmire, R.F. and J.E. Thompson. 1992. Selecting a cooling method. In Kader, A.A. 1992. *Postharvest technology of horticultural crops*, 2nd ed. Publication No. 3311. Cooperative Extension Division of Agriculture and Natural Resources, University of California, Davis, CA.

Mitchell, F.G. 1992. Cooling methods. In: Kader, A.A. (ed). 1992. Postharvest technology of horticultural crops. 2nd ed. Cooperative Extension University of California. Division of Agriculture and Natura Resources. University of California. Davis, CA. Publication no. 3311.

Prussia, S.E. and R.L. Shewfelt. 1984. Ice distribution for improved quality of leafy greens. ASAE Paper No 84-6014. St-Joseph, MI: ASAE.

Ryall, A.L. and W.J. Lipton. 1972. *Handling, transportation, and storage of fruits and vegetables. Volume 1: Vegetables and Melons.* The AVI Publishing Company, Inc. Wextport, CT.

Steel, R.G.D. and J.H. Torrie. 1980. *Principles and Procedures of Statistics: A Biometrical Approach.* New York, NY: McGraw-Hill Book Company.