PAPER NO. 7 Technology of Milk and Milk Products

MODULE NO. 21

Technology of Ice Cream and Frozen Desserts – II : Freezing

The quality, palatability and yield of the finished ice cream depend on the freezing of the mix.

The freezing process is divided into two main parts:

(i) The mix, with the proper amount of colour and flavouring material is generally added at the freezer. There it is quickly frozen while being agitated to incorporate air in such a way so as to produce and control formation of small ice crystals that is necessary to produce smoothness in body and texture, palatability and satisfactory overrun in the finished ice cream.

(ii) When ice cream is partially frozen to the proper consistency, it is drawn from the freezer into packages and quickly transferred to cold storage rooms, where the freezing and hardening process is completed without agitation.

Factors that favor small ice crystal formation in ice cream

In order to obtain smooth quality that is prized by the consumers, it is imperative to aim for freezing process and thereafter maintaining conditions that will enable prevalence of small ice crystals in ice cream. Such factors that favour small ice crystal formation are:

(i) Rapid crystallization
(ii) Agitation while freezing
(iii) Inoculation with many small crystal centers
(iv) High viscosity of the medium

Objectives of freezing

The objectives of freezing the ice cream mix in order to obtain ice cream are as follows:

(i) To achieve partial freezing of the product
(ii) Incorporation of air to give a fine, uniform and stable foam
(iii) A partial churning of the fat emulsion (in presence of emulsifier)

Freezing in a Batch ice cream freezer

Nowadays, use of batch freezer is confined to plants of moderate production and to supplement continuous freezers in making frozen desserts that are normally not made in large volume such as ices, sherbets and special flavored ice creams.

Out of horizontal and vertical batch freezers, the former one is most commonly used since the mix whips up faster.

The refrigeration is applied by means of a jacket around the cylindrical freezing chamber forming the jacket. Refrigeration is supplied or shut off by regulating the suction pressure maintained above the liquid ammonia in the chamber. The jacket is covered with an insulating material, which in turn is covered with a sheet metal.

There is provision of a 'dasher-scraper assembly' that consists of dashers, scrapers and expelling device. The dasher can be of several type viz., (i) Blade type, (ii) Squirrel cage type, and (iii) Compound action type. The outermost unit consists of scraper blades and the expelling device, while the innermost unit comprises of dasher or beater. The two units revolve in opposite direction at equal speed (about 140-250 rpm). The speed may vary based on the design and size of the freezer. The speed of the freezer should be such that maximum rates of freezing and whipping are obtained. The scraper blades are hinged so that the centrifugal force and the resistance of the mix will firmly force them against the outside of the freezing chamber. The function of such assembly is to (a) whip the mix, (b) keep the mix scraped free from the freezing surface, (c) circulate the mix in the freezer, from and to end, so that the overrun may be uniform and flavoring materials may be uniformly incorporated, and (d) to hasten the unloading of the freezer.

Direct motor driven freezer is preferred over belt-driven freezer; slippage of belt may occur at later stages of freezing in later case.

The temperature of refrigerant should be from -10 to -20^{o}F, in order to get a rapid formation of ice crystals. Ammonia is the most common refrigerant and has now nearly replaced other types for both batch and continuous ice cream freezers since (i) it is cheaper due to savings in power and equipment, and (ii) it increases the refrigeration capacity.

The batch freezer may be of capacity in terms of volume of finished ice cream that can be made per batch, ranging from 20 to 160 quart size (i.e. 22 – 176 lit.).

Freezing operation in a Batch ice cream freezer

Preparation of the freezer: Clean and dry parts of freezer are assembled using sanitized hands. The freezer chamber should then be sanitized either by use of hot water (180^{o}F) for about 10-15 min., followed by using cold pasteurized water or use a cold sanitizing (i.e. chlorine or iodophore) solution and draining the said solution.

Addition of ice cream mix: Ice cream mix at temperatures < 40^{o}F should be fed to the freezer chamber, after addition of colour and flavor to the mix. The total volume of the mix, flavor and colour should be about half of the total capacity of the freezing chamber. After the mix is filled inside the freezer barrel, the dasher assembly is started immediately followed by turning on of the refrigerant. After about 7 minutes of freezing, the consistency of ice cream can be visually seen through the feed inlet pipe (ice accumulates on the freezer door too). Now the refrigerant is to be shut off and air compressor started and air pressure adjusted to have desired overrun in ice cream, which may be accomplished in about 2-3 minutes. Some ice cream is then drawn out from the freezer outlet, checked for overrun and then directly filled in previously cooled cups or desired pack size. The ice cream should attain stiff consistency when ready to be filled in packages. The temperature of ice cream when drawn from the batch freezer is usually about 24-26^{o}F. The ice cream filled in the packages is then transferred immediately to a hardening room for hardening of ice cream.

Incorporation of particulate inclusions: Special precautions apply when adding acid fruits, nuts, etc. These should be added only after some extent of freezing of ice cream mix has taken place, prior to commencement of whipping.

Cleaning and sanitizing the freezer

After the ice cream is emptied from the freezer, the freezer barrel is filled with successive portions of cold and lukewarm (145^{o}F) water. Add suitable amount of washing powder to the water after rinsing is over. Just a touch of motor switch to give scraper one or two revolutions in the freezer is desirable. Remove the dasher assembly for thorough washing.

Freezing control devices in batch freezer

Willman controller: This device is used to indicate ‘refrigeration off’ point and the ‘correct overrun point’. It gives warning when the refrigeration-off point has been reached, on the basis of temperature of ice cream. The ‘refrigeration-off’ point is determined by judgment for the first few batches and the electric contact point adjusted accordingly. The controller makes use of a timing device which starts when ‘refrigeration-off’ point is reached and lights a second warning light when a set time has elapsed (indicating point at which overrun will be nearly correct).

Draw-Rite controller: An ammeter is connected in series with the motor and motor load is marked when the ‘refrigeration-off point’ is reached (increased ammeter reading). A second point is marked at motor load at the time the desired overrun has been reached (decreased ammeter reading). The refrigerant is shut off when the first marked point is reached and mix drawn from the freezer, when the second marked point is reached.

Freezing in a Continuous ice cream freezer

Principle of continuous freezing of mix

In this system, the mix and air are fed into the ice cream freezer by arranging two feed pumps in series, with an air inlet valve between them. The first pump regulates the rate of mix flow while the second one operates at a higher speed than the first. This together with regulation of inlet valve, controls the quantity of air drawn into the mix and provides the pressure for forcing the mixture through the freezer barrel.

Continuous ice cream freezing operation

A typical scraped surface freezer (SSF) consists of a cylindrical barrel with a refrigerant, such as vaporizing ammonia or Freon, surrounding it. Inside the barrel is a rotating shaft, or dasher, with scraper blades attached to it. Typically, the barrel and dasher assembly are made of stainless steel. Ice cream may be frozen either in a batch or continuous process. A batch process may take about 10 to 20 min to freeze. A continuous freezer, common to large operations, has a residence time on the order of 1 to 2 min. The refrigerant temperature is about −30°C.

Description of continuous ice cream freezer

There is provision of a freezer barrel. Such barrel is surrounded by a concentric outer cylinder carrying refrigerant of sufficient capacity to freeze the mix flowing through the barrel to a plastic mass. The mix is frozen by the time the mix passes through the length of the barrel.

The mutator shaft rotates at several hundred revolutions per minute within the barrel. The shaft carries knife blades so arranged that they continuously scrape the ice cream from the barrel surface, as it freezes there. Since the space between the mutator and the freezer barrel is less, the product passes through the barrel in a few seconds (5-15 sec) giving rise to 'instant' freezing. A 'solid mutator' is used for production of harder, extruded ice cream, while for soft ice cream an 'open mutator' is available. Hollow mutator overcomes the problem of sporadic ice accumulation on mutator resulting in high back pressure on the pumps. Moreover, they provide greater flexibility in the freezing and whipping conditions. The clearance between the mutator and the wall of the freezer tube is only ~ 5/16". As a result, the mix is in the freezer for only 5-15 sec. resulting in 'Instant' freezing.

Dashers are made in a variety of displacements, the percentage of the freezer barrel volume occupied by the dasher. Solid dashers have high displacement, typically about 80%, whereas open dashers have low displacement and often include beaters.

Pressure is maintained inside the barrel by a back pressure valve at the outlet of the freezer. Earlier models used spring loaded valves, in later machines, it is controlled pneumatically. Maintenance of correct back pressure helps in proper incorporation of air in small uniform cells throughout the mass of product during freezing.

Working of a continuous ice cream freezer

The mix and air are pumped into the machine by means of a two-stage pump (two separate pumps). The first stage pumps just the mix, while the second stage pumping more rapidly (twice the capacity of first pump), creates suction between these two stages and permits introduction of mix in controlled amounts. The second stage also provides the pressure which propels the product through the freezing chamber and through the discharge pipes. The air supply is drawn in through the air valve, which can be adjusted (20-30 psi pressure) so as to obtain the desired amount of overrun. At the freezer outlet a spring loaded valve/pneumatic valve assures back pressure on the freezing chamber so that air may be properly incorporated in ice cream.

To produce ice cream in the typical commercial process, the ingredients are first mixed together, then pasteurized, homogenized, cooled, and aged for at least 4 h at a temperature of about 4°C. Flavoring is then added before the mix is pumped into the scraped-surface freezer (SSF), where about 50% of the water is frozen and air is incorporated into the product. Upon exiting the SSF, inclusions and variegates may be added, and the soft product, at about −5 to −6°C, is filled into its retail container. In case, nut or fruit variety is to be made, the fruit or nut inclusion particulates can be added into the exiting partly frozen ice cream through use of a 'Fruit feeder machine'. The fruit feeder is connected to the outlet of the freezer.

The ice cream is sent to harden until the core reaches a specified temperature, usually about −18 °C. As the temperature drops and more ice crystallizes, the remaining water contains more and more sugar, which depresses the freezing point so that in the final, hardened product, about 75-90% of the water is frozen. The finished product is stored between −18 and −30°C, depending on the plant, distributed, and sold. In the supermarket, temperatures in certain types of freezer cabinets (particularly open-faced cabinets) can reach −9°C, and in frost-free consumer freezers, temperatures can vary quite widely during the frost-free cycle.

Changes that occur in ice cream mix during freezing

Initial freezing is a dynamic process: the mix is frozen while being agitated, which whips in the air, destabilizes the fat, and scrapes ice into the bulk fluid. Cold ice cream mix enters the freezer, with the refrigerant absorbing the heat in the mix until the super-cooling at the wall is great enough to initiate ice nucleation. As ice crystals form at the wall, the dasher blades scrape the surface layer from the wall about every 0.075 s, assuming 4 blades with a dasher speed of 200 rpm, and propel the ice layer, at a temperature of −20 to −25°C, into the bulk of the freezing ice cream mix. When the ice cream exits the freezer, it is usually around −5 to −6°C, and close to 50% of the water is frozen. The average ice crystal size exiting an ice cream freezer is 20 to 30 μm.

Ice crystal size could increase with dasher speed because of the extra mechanical energy and frictional heat being put into the system via the rotation of the dasher, which accelerates recrystallization. Conversely, increasing dasher speed could help reduce ice crystal size by scraping off a thinner ice layer. Hence it is reported that an optimum balance between rotation rate and heat generation is required, which would depend on the individual freezer and ice cream mix composition to produce the smallest ice crystals.

The operator’s principal work is to:

- Regulate the amount of air being introduced into the mix to give the desired overrun.
- Regulate the temperature of refrigerant in the freezing chamber.

Recirculation continuous ice cream freezer

One potential modification to the typical ice cream freezing process is to recirculate a portion of the product stream back to the freezer inlet stream. The benefit of this practice is mainly for start-up, where recirculation minimizes production of unused unfrozen product. The recirculation stream brings existing ice crystals into the mix where they can serve as seed crystals and can continue to grow in size. This results in a wider residence time distribution with a higher average residence time and, thus, a larger, wider crystal size distribution. Recirculation has a beneficial effect on the air cell size, however, because of the extra whipping (through increased residence time), breaks the air cells into smaller bubbles.

Low-temperature continuous freezers

In some models, there is a second freezer barrel so that ice cream in fact receives a second freezing – device that increases the capacity of machine. By rotating mutator at high speed in first barrel when ice cream is in early stages of freezing and therefore of lower viscosity. The mutator is at a lower speed in the second barrel, when freezing process is near completion and the product viscosity is high. In low temperature continuous freezer, ice cream can be drawn at -15^{o}C. This type of freezer is useful for stiff extrusions or for filing bulk cans (e.g. 2 gallon cans).

A new technology for reducing draw temperature and eliminating the need for hardening is cold extrusion. The process reportedly improves both the sensory and shelf-life properties of the ice cream. The low temperature extruder is placed after the normal SSF and can bring the draw temperature down to −15 to −18°C. The extruder may be in either a single-screw configuration, which churns the ice cream around the screw, or a twin-screw configuration, which kneads and churns the ice cream between two parallel screws. Both operate at a rotational rate of about 15 rpm. In the extruder, high homogeneous local shear breaks up the fat globules, ice crystals, and air cells into smaller units which improve the flowability of ice cream. Compared to conventional ice cream freezing and hardening, including a twin-screw cold extruder reduces ice crystal and air cell size by a factor of 2-3. The smaller fat globule aggregates resulting from the high shear in the cold extruder impart a creamy texture to the ice cream, without a buttery defect, making the technology useful for low-fat formulations. Such ice cream is more resistant to adverse handling conditions than regular frozen ice cream.

CIP of continuous freezer

- Rinse with water (≤ 100^{o}F) until the rinse water runs clear.

- Flush for 20-30 min with 150-160^{o}F water containing 0.5-0.7% alkali strength detergent.
- Rinse until the equipment is cooled.
- When using acid cleaner, circulate cleaning solution containing sufficient acid (phosphoric and hydroxyacetic acid) to give 0.5-0.6% acidity, at 150-160^{o}F and 5-7.5 ft./sec velocity for 20-30 min.
- Drain and rinse with water at 145^{o}F for 5-7 min.
- The freezer is made to run 10 sec for every 10 min. of cleaning operation.

Structure of frozen ice cream

The dispersion and emulsion consist primarily of a freeze-concentrated aqueous serum phase containing sugar and the dry matter contents surrounding dispersed ice crystals and fat globules. Ice crystals range in size from ~ 1 to > 150 μm in diameter, with an average size of 35 μm. Fat globules are ≤ 2 μm in diameter. The foam is formed by pockets of air (~ 20 to 50 μm diameter) dispersed throughout the emulsion and is supported by partially coalesced fat globules.

In 'Low-temperature freezing', the ice crystal size may be reduced as much as 40% e.g. from 45-55 um to 18-22 μm. The air cell size seems to remain about the same or become a little larger, but the number of air cells increases slightly in number. The air cell wall thickness is just 50-100 μm as against 100-150 μm in ice cream frozen in normal continuous freezer.

Ice crystal size is also important to ice cream shelf life. As the ice cream sits in storage, the ice crystals continually grow by recrystallization. The temperature fluctuations seen in a frost-free home freezer serve to accelerate this process.

Packaging of ice cream

When ice cream is drawn from the freezer, it is put into containers that give it the desired form and size for commercial handling during the hardening, shipping and marketing purposes. Packaging ice cream involves forming, filling, closing, weighing and bagging the containers.

The bulk containers may comprise of three types of packaging materials

(a) Fiberboard containers
(b) Metal containers
(c) Plastic containers made of polyethylene

Cups, tubs, cones, wrappers etc. are also used. Packaging in small single-service package can be made up of waxed paper or preferably polystyrene plastic cups.