FREEZING PROCEDURE

The ice cream freezer has to freeze the mix to the desired consistency, and whip in the desired amount of air in a finely divided condition. The usual aim is to conduct the freezing and later hardening in such a manner as to obtain the smoothest possible texture. The factors involved will be discussed.

Freezing of an ice cream mix is freezing of a mixed solution. The solutes which determine the freezing point of this solution are the lactose and the soluble salts contained in the serum solids, and the sugars added as sweetening agents. The other constituents of the mix affect the freezing point only indirectly, by displacing water and affecting the in-water concentration of the solutes mentioned. Leighton has developed a reliable method for computing the freezing points of ice cream mixes from their known composition. He adds the lactose and sucrose content of the mix, expresses their concentration in terms of parts of sugar per 100 parts of water, and determines the freezing point depression due to the sugars by reference to published data for sucrose. This is justified since lactose and sucrose have the same molecular weight.

$$\% \text{ lactose in mix} = \% \text{ serum solids} \times 0.545$$

$$\frac{(\% \text{ lactose} + \% \text{ sucrose}) \times 100}{\% \text{ water in mix}} = \frac{\text{parts lactose} + \text{sucrose}}{\text{per 100 parts water}}$$

To the freezing point depression caused by these sugars he adds the depression which will be caused by the soluble milk salts. The depression caused by the salts is computed as follows:

Freezing point depression caused by serum

$$\text{solids in C} = \frac{\% \text{ serum solids} \times 2.37}{\% \text{ water in the mix}}$$

Table 1 presents the freezing points of various ice creams and a typical sherbet and an ice, as computed by Leighton's method.

The freezing point, of course, merely represents the temperature at which freezing commences. As in the case of all solutions, the unfrozen portion becomes more concentrated as the freezing progresses, and the freezing temperature therefore decreases as the freezing progresses. In a simple solution, containing only one solute, this trend would progress until the unfrozen portion represents a saturated solution of of the solute, and thereafter the tempertaure would remain constant until the freezing had been completed. This temperature is known as the *cryohyeric point* of the solute in question. In a mixed solution such as ice cream, containing several sugars and a number of salts, no such point can be recognized. On the contrary, the indications are quite definite that the sugars remain in solution in a supersaturated state in the unfrozen portion of the product. This is apparently due to the fact that by the time the saturation point has been reached, the temperature is so low and the viscosity so high that essentially a glass state exists. It is interesting to note, however, that in a mixed solution the temperature required for complete freezing must be somewhat below the cryohydric point of that solute which has the lowest cryohydric point. In the case of ice cream, that solute is calcium chloride, contained as a natural component of serum solids. The cryohydric point of calcium chloride is −59.8 F. Therefore, we may say that the ice cream ranges from 0 to 100 percent frozen between the approximate temperature range of from 27.5 to −67 F.

Table 1 .... Freezing Points of Typical Ice Creams, Sherbet and an Ice

	Composition of the Mix, Percent					Freezing Point F
	Fat	Serum Solids	Sugar	Stabilizer	Water	
Ice Cream	8.5	11.5	15	0.4	64.6	27.59
	10.5	11.0	15	0.35	63.15	27.57
	12.5	10.5	15	0.30	61.7	27.55
	14.0	9.5	15	0.28	61.22	27.68
	16.0	8.5	15	0.25	60.25	27.79
	10.5	8.4	S 12, D 4	0.40	64.7	27.39
Sherbet	1.2	1.0	S 22, D 8	0.50	67.3	25.97
Ice	0	0	S 23, D 9	0.50	67.5	25.68

S = sucrose D = Dextrose

Table 2 .... Freezing Behavior of a Typical Ice Cream

Water Frozen to Ice Percent	Freezing Point of Unfrozen Portion, F	Water Frozen to Ice Percent	Freezing Point of Unfrozen Portion, F
0	27.55	40	24.40
5	27.35	45	23.63
10	27.05	50	22.62
15	26.78	55	21.42
20	26.40	60	19.79
25	26.04	70	14.99
30	25.70	80	5.14
35	25.03	90	−22.29

Composition: fat, 12.5; serum solids, 10.5; sugar, 15; stabiliser, 0.30; water, 61.7.

In accordance with the above, the temperature to which the ice cream has been frozen becomes a measure of the degree to which it has been frozen. This is illustrated by Table 2, in which the freezing points of the unfrozen portions have been computed when from 0–90 percent of the original water has been frozen out as ice. For this purpose the third ice cream of Table 1 has been selected as being most typical of normal operations.

Refrigeration Requirements

Exact calculation of refrigeration requirements is complicated by the number of factors involved. The specific heat of the mix varies with its composition. According to Zhadan the specific heat of food products may be computed by assuming the following specific heats for the chief components: carbohydrates, 0.34; proteins, 0.37; fats, 0.40; water, 1.00. This does not include salts. Where they are present in significant amounts as in ice cream (9.5 percent of the serum solids), a specific heat of 0.20 will be quite accurate. The value given by Zhadan for fats is apparently for solid fats. For butterfat in a liquid condition Hammer and Johnson found the specific heat to be 0.52. In addition their data clearly show that the latent heat of fusion of fats becomes involved. From their data the latent heat of fusion of milk fat or butterfat appears to be about 35 Btu per lb. The change from liquid to solid fat occurs over a wide temperature range, approximately 80 to 40 F; whereas in changing from solid to liquid fat the range is approximately 50 to 105 F. This wide discrepancy between solidifying and melting behavior is apparently due to the fact that butterfat, more so than any other fat, is a mixture of glycerides, and mutual solubility of the glycerides is involved. In any case the latent heat of fusion of the fat is involved in cooling the mix from pasteurizing and homogenizing temperature, down to the usual aging temperature of 38 to 40 F. Instead of undertaking detailed calculations, based on such considerations as just presented, it is common practice to assume a specific heat of 0.80 for ice cream mix. This value is generous for mixes ranging from 36 to 40 percent total solids.

In calculating the refrigeration required in freezing and hardening, one is hardly justified in speaking of a specific heat for frozen ice cream. As has been shown in connection with Table 2, any change in temperature in freezing and hardening involves some latent heat of fusion of the water, as well as the sensible heat of the unfrozen mix and the ice. The heat units that become involved as latent heat of fusion per deg temp change differ according to whether the temp change is near the initial freezing point or farther along the freezing process. Near the initial freezing point much more latent heat of fusion is involved per degree temperature change than is true in well hardened ice cream, *e.g.*, at −10 to −11 F. For this reason it is preferable, instead of attempting to use an overall value in terms of specific heat, to compute as follows:

(1) Having in mind the temperature to which the freezing is to be carried, determine, by calculations such as those employed in connection with Table 2, how much water will be converted to ice. The heat to be removed is the product of the heat of fusion of ice and the pounds of water frozen.

(2) To compute the sensible heat that must be removed in the desired temperature change, the problem is treated as though the product were mix, *i.e.*, use the specific heat for ice cream mix. F temperature change×lb of product ×0.80 = sensible heat to be removed.

It is true that in such a calculation the water that is present is treated as though it all remained in a liquid form until the desired temperature has been reached, when as a matter of fact ice was forming progressively. Insofar as ice has a specific heat of 0.492 instead of 1.0 as for water, this treatment will err in the direction of generous refrigeration. To offset this there is the fact that in the freezer vigorous agitation is employed, which develops heat of friction. It has been estimated that approximately 80 percent of the energy input in the motor of the freezer is converted to heat in the product. Where the product is frozen to a stiff consistency and power requirements have thereby been increased, an additional allowance should be made for this factor, even though the discrepancy of the above calculation is involved.

Since capacities in the case of ice cream are customarily figured in terms of gallons, it becomes necessary to convert gallons to pounds of product. The weight of a gallon of ice cream mix ranges from 9.0 lb for mixes with a high fat content to 9.2 lb for mixes with a low fat content, and a high content of serum solids and sugar. The weight of a gallon of ice cream varies with the mix weight and overrun in accordance with the following relationship:

$$\text{Percentage overrun} = 100 \times \frac{\text{Wt per gal of mix—Wt per gal of ice cream}}{\text{Wt per gal of ice cream}}$$

For the purpose of calculating overrun any unit of volume can be used provided that same unit is used throughout.

Freezing Ice Cream

Two types of ice cream freezers are in general use: the *batch type*, which freezes a measured quantity of mix at one time, and the *continuous type*, which takes a continuous flow of ice cream mix and discharges a continuous flow of partly frozen ice cream. Both are arranged with a freezer cylinder having either an annular space or coils around the cylinder where cooling is accomplished by direct expansion; either in a flooded arrangement with an accumulator or controlled by a thermostatic expansion valve. The freezer cylinder is arranged with a dasher, having blades attached, which revolve within the cylinder. The sharpened metal blades scrape the inner surface of the cylinder to remove the frozen film of ice cream as it forms. Some freezers have beaters built into the dasher to aid the blades in the mixing and whipping action for the introduction of air into the mix as it is frozen, to produce the overrun desired.

Batch freezers range in sizes from 2 to 40 quarts of ice cream per batch, the smaller sizes being used for retail or soft ice cream operations, and the 40 quart size used in small commercial ice cream plants or in large plants for running small quantities for special orders. Batch freezers larger than the 40 quart size are not used extensively since the development of the continuous freezer, partly because of the limited hourly capacity and because of the labor required for operation. In operation, a measured quantity of mix is placed in the freezer cylinder and the required flavor, fruit, or nuts are added as freezing of the mix progresses. Freezing is continued until the desired consistency is obtained depending on the judgment of the operator or the indication of a meter showing an increase in the amperage drawn by the motor, as the partly frozen mix becomes stiffer. At the desired point of freezing the refrigeration is cut off from the freezer cylinder, usually by closing the refrigerant suction valve. The dasher continues operating until enough air has been taken into the mix by the whipping action to produce the overrun desired. The overrun is checked by taking a sample from the freezer and weighing it, or by the reading of the ammeter. When the desired overrun is obtained, the entire batch is discharged from the freezer cylinder into cans or cartons and the machine is then ready for a new batch of mix.

The output of a batch type freezer will vary with the sharpness of the blades, refrigeration supplied, and overrun desired. The average maximum output for commercial type batch freezers is eight batches per hour. This schedule would allow three to four minutes to freeze, two to three minutes to whip, and about one minute to empty the ice cream and refill with mix. For this time schedule, it is assumed the ice cream would be drawn from the freezer at not over 100 percent overrun, at a temperature of about 24 F, and a refrigerant temperature around the freezer cylinder of about −15 F.

Continuous ice cream freezers are a more recent development and range in sizes from 40–1050 gal per hr. This type machine is used almost exclusively in commercial ice cream plants. Where large capacities are required, multiple units are installed with the ice cream discharge from several machines connected together to supply the requirements of automatic or semi-automatic packaging or filling machines. In operation, the ice cream mix is continuously pumped to the freezer cylinder by a positive displacement type rotary pump. An air pressure is maintained within the cylinder ranging from 20 to 50 psig, supplied by either a separate air compressor or drawn in with the mix through the mix pump. The mix entering the rear of the freezer cylinder becomes partly frozen and takes on the overrun due to air pressure and to the agitation of the dasher and freezer blades as it moves to the front of the cylinder and is discharged. The output capacity of most continuous freezers can be varied from 50 to 100 percent rated capacity by regulating the variable speed control supplied for the mix pump. Continuous freezers can be used for nearly every flavor of ice cream, for iced milk, for sherbets, or for ices. Where flavors requiring nuts, whole fruit or candy pellets are run, the flavored mix is run through the continuous freezer and then passed through a fruit feeder, which automatically feeds and mixes the flavor particles into the ice cream. Fig. 1 shows the arrangement