

Fig. 1 .... Equipment Diagram for Manufacture of Ice Cream

of a typical continuous ice cream freezer with a fruit feeder in an ice cream plant. Ice cream can be discharged from continuous freezers at temperatures of 25 F, as required for ice cream bar operations, to a very stiff consistency at 20 F, as required for automatic filling of small packages. When ample refrigerating effect is supplied, a variation of ice cream discharge temperature can be obtained by regulating the evaporator temperature around the freezer cylinder by means of a suction pressure regulating valve. For filling cans and cartons, the average discharge temperature from the continuous freezer is about 22 F, when operating with ammonia in a flooded system at about −25 F.

To calculate accurately the refrigeration requirement for freezing the ice cream mix in the freezer, the weight of the mix per gal and the amount of water should be known. This can be checked by weighing, knowing the percentage of water, or by calculating the weight from the mix formula, as per example below.

Mix	%
Butterfat	12.0
Serum solids	10.5
Sugar	16.0
Stabilizer	0.25
Egg solids	0.25
Total solids	39.00
Water	61.00

Specific gravity =

$$\frac{100}{\left(\frac{\%\text{ butter fat}}{0.93}+\frac{\%\text{ solids, not fat}}{1.58}+\frac{\%\text{ water}}{1.00}\right)}$$

The specific gravity of the ice cream mix listed above would be

$$\frac{100}{\left(\frac{12}{0.93}+\frac{27}{1.58}+\frac{61}{1.00}\right)}=1.099$$

Wt per gal of mix = wt of 1 gal of water × sp gr mix, or
8.355 × 1.099 = 9.16 lb

The overrun in ice cream will vary from 60 to 100 percent. Lower overrun is usually used where a quality product is desired. Higher overrun is used to produce a competitive product which will be within the state laws governing weight required for a definite quantity. The overrun developed in the ice cream produced will affect the refrigeration required for a definite quantity of ice cream produced per hour.

For a continuous freezer, the refrigerating effect required to freeze 100 gal of ice cream per hr would be calculated as shown below, assuming 100 percent overrun, with the typical mix shown above going to the freezer at a temperature of 40 F, and containing 61 percent water. The temperature at which freezing would start, in this particular mix, would be about 27 F, and at a temperature of 22 F, approximately 48 percent of the water content would be frozen.

The following formula would be used to calculate the weight of mix required to produce 100 gal of ice cream:

$$\frac{100}{100+\%\text{ overrun}}\times 100\text{ gal}\times\text{wt mix per gal}$$

For the ice cream being considered, the weight of mix required for 100 gal would be:

$$\frac{100}{100+100}\times 100\times 9.16=458\text{ lb}$$

Calculations of refrigerating effect to freeze 100 gal of ice cream per hr are as follows:

Sensible heat of mix	458 × (40 − 27) × 0.80 =	4,763 Btu
Latent heat	458 × 0.61 × 0.48 × 144 =	19,311 Btu
Sensible heat of slush	458 × (27 − 22) × 0.65 =	1,488 Btu
Heat from motors	5½ Hp × 2,545 =	13,998 Btu
	Total =	39,560 Btu
5% Losses from freezer and piping (estimated)	=	1978 Btu
	Total refrigeration =	41,538 Btu
	=	3.46 tons

Under the conditions as given it would be recommended that a factor of 3.5 tons refrigeration per 100 gal per hour of 100 percent overrun ice cream be used.

In continuous freezer operation, for ice cream having overrun other than 100 percent, the heat gain from motors and losses from the freezer and piping would remain about the same, but the refrigerating effect necessary would vary with the weight of mix required to produce 100 gal of ice cream, as shown below:

Overrun, %	Ammonia Refrigeration Tons/100/gal./hr @ 3 psi Suction Pressure
60	4.04
70	3.88
80	3.74
90	3.61
100	3.50
110	3.39
120	3.30

Hardening Ice Cream

After the ice cream leaves the freezer, it is in a semi-solid state and must be further refrigerated to become solid enough for storage and distribution. The ideal serving temperature of ice cream is about 8 F, and it is considered hard at 0 F. To retain a smooth texture in hardened ice cream, it is necessary to freeze the remaining water content rapidly, so that the ice crystals formed will be small. For this reason most hardening rooms are maintained at temperatures of −20 F and in some cases as low as −30 F. The most recently constructed hardening rooms are arranged with forced air circulation, either from a unit cooler or a remote bank of coils. With the ice cream containers arranged so air will circulate around them, the hardening time is about one half that of rooms having overhead coils or coil shelves and gravity circulation. With forced air circulation in the hardening room and with

average plant conditions of hardening ice cream in two and one-half or five gallon containers (or quart and pint bricks in wire basket containers), all spaced to allow air circulation, the time to harden will be about 10 hours. Hardening rooms are usually sized to allow space for a minimum of three times the daily peak production and for a stock of all flavors, with the sizing based on 10 gal per sq ft of floor area, which includes aisles.

Some larger plants use ice cream hardening tunnels which discharge into a low temperature storage room. Because of the various size packages to be hardened, most tunnels are the air blast type, operating at temperatures of −30 to −40 F and in some cases as low as −50 F. Quart or pint cartons are usually hardened in these blast tunnels in about one hour. Temperatures in the storage room are held at about −10 F. Space in storage rooms can be estimated at 25 gal per sq ft, stacked solid 6 ft high, including space for aisles.

Refrigeration required to harden one gal of ice cream will vary with the temperature from the freezer and amount overrun.

For a sample calculation, it is assumed that the temperature of the ice cream entering the hardening room is 25 F and the overrun is 100 percent. At this temperature approximately 30 percent of the water would be frozen in the ice cream freezer with the remainder to be frozen in the hardening room. The weight of one gal of ice cream at 100 percent overrun, from a mix weighing 9.16 lb per gal, would be 4.58 lb. The mix is assumed to contain 61 percent water and the hardening room is at a temperature of −20 F.

Latent heat of hardening	4.58 × 0.61 × 0.70 × 144 =	282 Btu
Sensible heat	4.58 × (25 + 20) × 0.50 =	103 Btu
	Total =	385 Btu
Loss due to heat of container and exposure to outside air, assumed 10%	=	40 Btu
	Total Btu per gal to harden =	425 Btu

Percent overrun, when calculated on the basis of the quantity of ice cream delivered by the freezer or of the quantity placed in the hardening room, would affect the refrigeration required to harden one gallon of ice cream.

Suggested refrigeration requirements are:

% overrun	Hardening Load, Btu per Gal Ice Cream
60	532
70	500
80	470
90	447
100	425
110	405
120	386

As an example of calculating the refrigerating load in an ice cream hardening room, it is assumed 1000 gal of ice cream at 100 percent overrun are to be hardened in 10 hr in a forced air circulation room at a temperature of − 20 F. The hardening room, for three times this daily output, should have 300 sq ft floor area, measuring approximately 15 × 20 × 9 ft high. The total insulated surface of 1230 sq ft requires 8 in. of corkboard, or equivalent. The heat conductance through the insulated surface is selected at 0.04 Btu per sq ft per hr F. Average ambient temperature is assumed to be 90 F:

Heat leakage	1,230 × 0.04 × (90 + 20) =	5,412 Btu
Heat from fan motor	2 hp × 2,545 / 0.85 =	5,969 Btu
Heat from lights	600 watts × 3.4 =	2,040 Btu
Air infiltration and persons in room (Approximately 20% leakage)	=	1,082 Btu
Hardening ice cream	1,000 gal × 425 Btu per gal / 10 hr hardening time =	42,500 Btu
	Total =	57,003 Btuh
	=	4.75 tons

Other products, such as sherbets, ices, ice milk, and novelties, usually represent a small percentage of the total output of the plant, but should be included in the total requirement of the hardening room.

Frozen Suckers and Ice Cream Bars

Many ice cream plants manufacture and distribute novelties frozen on a wood stick, or chocolate covered ice cream bars. These products are frozen in metal trays, each containing 24 molds, which are submerged in a special brine tank having a built-in evaporator surface and arranged with brine agitation. The frozen sucker mix is usually made up in a mixing tank where it is cooled to about 40 F and then a measured quantity of the mix is poured into the tray molds. The tray molds are then placed in the brine tank where they are completely frozen. The brine tank temperature should be maintained at about −30 F, which will result in a freezing rate of about 20 min per tray, and will produce a small ice crystal structure in the frozen sucker. The refrigeration calculations to freeze 100 doz suckers per hr, at 3 oz per sucker, based on a mix containing 85 percent water are:

Weight of mix estimated at 100×12×3/16×1.06 (sp gr) =239 lb

Cooling mix	239 × (40 − 27) × 0.87 =	2,700 Btu
Freezing	239 × 0.85 × 144 =	29,232 Btu
Subcooling	239 × (27 + 30) × 0.5 =	6,813 Btu
Cooling trays (50 per hr)	50 × 8 lb × (60 + 30) × 0.12 =	4,320 Btu
Heat from agitator	1 hp × 2,545 =	2,545 Btu
Leakage through tank	3 × 12 × 3 ft deep =	750 Btu
Loss, top of tank and piping (assumed) =		7,500 Btu
	Total =	53,860 Btu
	=	Approx. 4.5 tons

In freezing ice cream bars, the partly frozen ice cream is taken from the freezer at a temperature of about 25 F and placed in the tray molds to be hardened in the brine tank. Using calculations similar to the above it is estimated that 2.2 tons refrigeration would be required to freeze 100 doz 3-oz ice cream bars per hr having an overrun of 100 percent. If handled rapidly after being taken from the brine tank, very little refrigeration is required from the hardening room for storage of frozen suckers or ice cream bars.

REFRIGERATING EQUIPMENT

Soft ice cream or counter type freezers, either batch or continuous models, are designed for use with Refrigerant 12 or Refrigerant 22 and are usually arranged in a self-contained cabinet with the condensing unit mounted under the freezer. Nearly all commercial ice cream plants, and particularly the larger plants, use ammonia. Some smaller plants are able to operate continuous ice cream freezers and refrigerate ice cream hardening rooms, to acceptable temperatures, with single stage refrigerant compressors. In nearly all cases, these plants will operate their compressors at conditions above the maximum compression ratio recommended by the manufacturer, and will experience trouble with high discharge temperatures, oil failure, and compressor break-down.