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Refrigeration for Ice Cream Manufacturing

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Ice Cream is a frozen product obtained from milk of cow or buffalo or from cream, and/or other milk products.

An automatic candy plant in Delhi
Photo courtesy of Mother Dairy, Delhi

A modern ice cream factory at Nasik
Photo courtesy of HLL Walls

Ice Cream contains 12% milk fat, 10% milk solid not fat, 14% sugar, 0.35% stabilizers, 63% water and 70 to 100 % over run approximately. It may contain permitted stabilizers and emulsifiers not exceeding 0.5 5 by weight. The product shall contain not less than 10.0 % milk fat, 3.5 % protein and 36 % total solids.

To be advertised and sold as ice cream, the product must meet the minimum standards set up. Under existing law the fat content of ice cream must be butterfat derived from milk. Frozen desserts use vegetable fat in place of butter fat, and though they meet all the requirements of fat and solids cannot be sold as ice cream.

The raw materials, composition, body and texture, flavor, colour, processing and storage determine the quality of ice cream. Ice crystals that are formed during freezing should be smaller than 40 micron and uniform in size to make ice cream feel smooth. Large crystals give ice cream a gritty texture.

The best quality of non-fat milk solids for use in ice cream come from fresh whole milk; fresh skin, fresh sweet cream, or spray dried powder made from fresh whole milk or skin. Non fat solids add strength to the lamellae to permit greater control of over run. Some components of this group of solids bind quantities of water with careful processing. This assists in control of ice crystal size during freezing and hardening. The ice crystal size is an important property of the texture of the product.

The principal source of sweetening of ice cream is refined cane sugar. It can be added directly while formulation of the mix. The ice cream mix normally contains added sugars between 10% to 16%, usually around 14%. Adding sugar reduces the freezing point of the mix. Up to a certain limit this may improve body and texture, but excess sugar will prevent the product from freezing or hardening adequately at the temperatures normally used. This could result in a soft, soggy product with low over run.

Air is whipped more or less extensively into ice cream during freezing. The air must be clean. If compressed air is used it must be free from oil and must be filtered. To produce best body and texture, air bubbles in ice cream should be smaller than 100 microns. An over run of 100% doubles the volume.

Stabilizers are used to improve body and texture of ice cream. A stabilizer increases the water of hydration in the ice cream mix. It inhibits or retards ice crystal formation during freezing and hardening. The emulsifier acts to reduce the surface tension between the water fat phase to produce drier appearing product from the freezer. Emulsifiers are used in the manufacturing of ice cream to produce a richer product with a smoother texture and stiffer body and also to reduce whipping time.

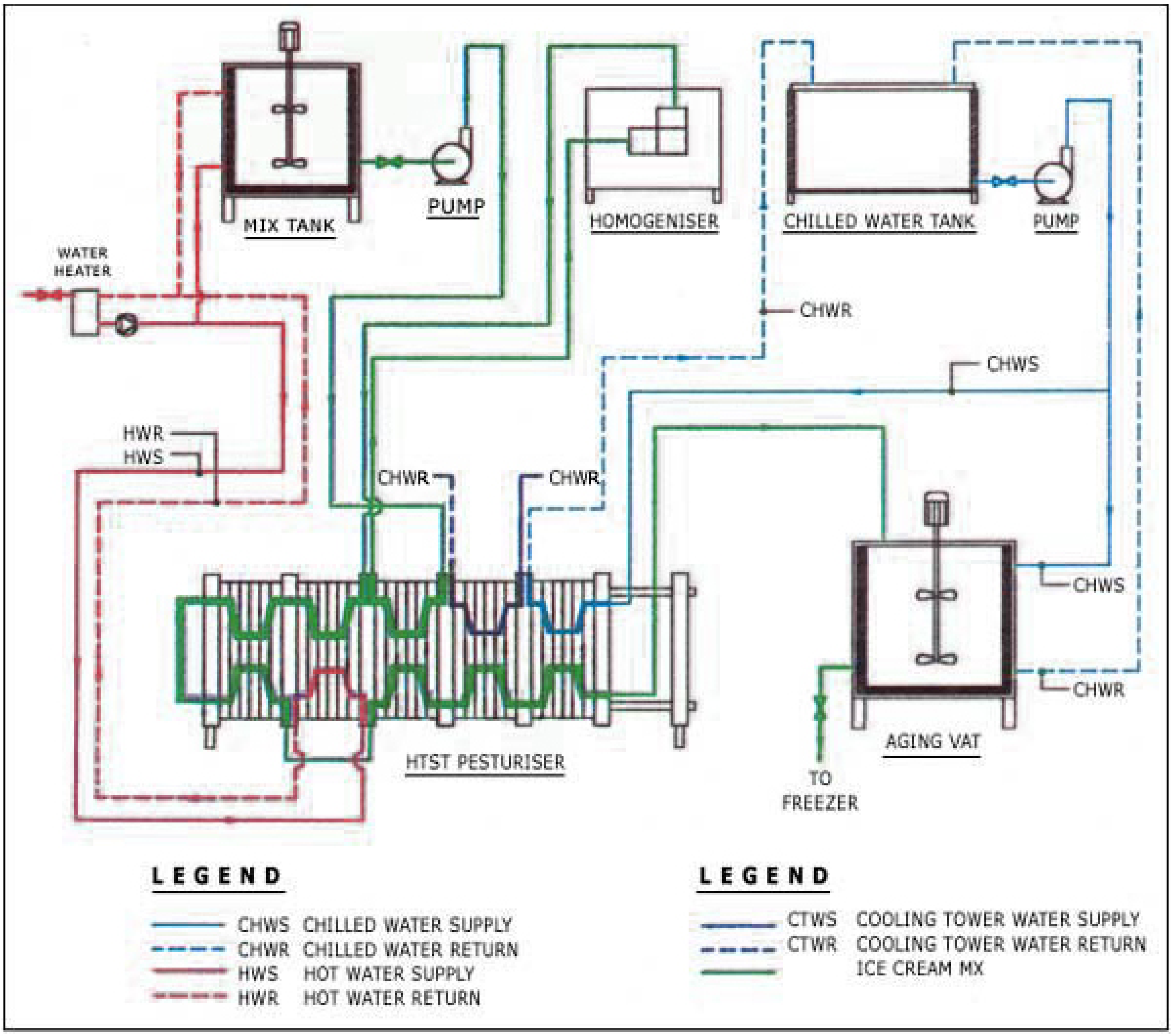

Fig. 1 : Process flow diagram for mix

Ice cream mix processing involves:

- **Mixing**

The formulation of an ice cream mix involves firstly a decision as to the composition of the final product. Dry raw materials, except flavor and colours are mixed together separately. These include milk powder, sugar, stabilizers and possibly other items. Liquid raw materials including milk, skim milk, condensed milk and cream are mixed together and warmed to 35 to 40 deg. C. The mixture of dry raw material is then carefully sprinkled into the mixture of liquid raw materials during agitation of the liquid. The temperature recommended above for the liquid mix assures relatively rapid dissolving and mixing of the two groups of components provided agitation is adequate. The mix is required to be heated up to 55 to 60 deg. C to dissolve most of the stabilizer and emulsifier.

- **Pasteurizing**

The mix is pasteurized to destroy any pathogenic organisms that might be present and to lower the bacterial count so as to enhance the keeping quality of the mix, possibly to comply with bacterial count standards, and to provide a temperature suitable for efficient homogenization. A pasteurizing temperature of 63 deg. C maintained for 30 minutes if fully adequate. General practice is to use temperatures of 63 to 60 deg. C and seldom as high as 80 deg. C. The mix should be homogenized at the pasteurizing temperature. Many large ice cream plants now use continuous pasteurizing methods commonly known as HTST pasteurization, which involve the use of plate type heat exchanger for heating and cooling the mix.

- **Homogenizing**

Ice cream mix must be homogenized. This is normally done during or immediately after pasteurization before the mix is cooled. Homogenization of mix is best done in two stages at a total pressure that may range from 140 to 250 bar.

For plain ice cream, homogenization at 140 bar and 65 deg. C is reported to give higher whipping ability than at other pressures but at the same temperature. The first stage homogenization is carried out at about 2/3 and 3/4 of the total pressure used. The second stage homogenization is carried out in the remaining range.

The purpose of homogenization is to disperse the far in a very finely divided condition so that it will not churn out during freezing. In milk and cream most of the far is in the form of globules as large as 10 or 12 microns in diameter or larger, especially if there has been some churning incidental during handling. In a properly homogenized mix there should be very few globules over two microns in diameter. Fig 2 shows two stage homogenization process of high fat mix.

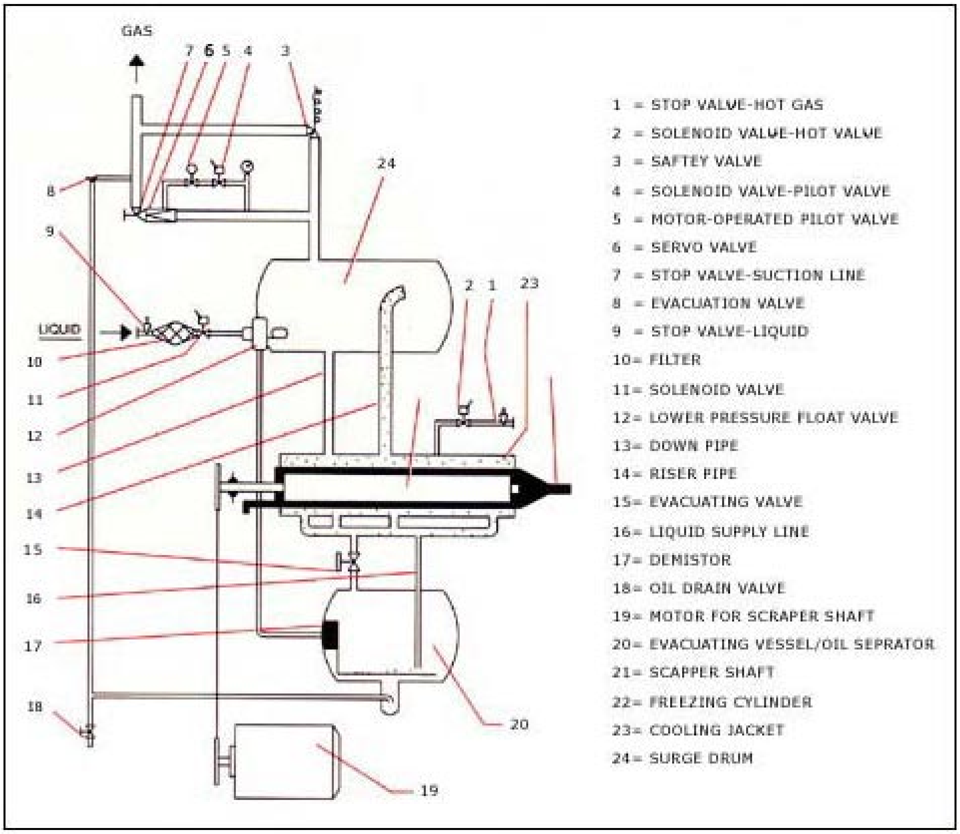

Fig. 2- Flooded arrangement for ice cream freezer
Courtesy of Gram Equipments, Denmark

- **Precooling and chilling**

Method of final cooling of ice cream mix after pasteurization depends on equipment being used and final mix temperature desired. It is desirable to have as cold as possible for greater capacity and less refrigeration load on the ice cream freezer. Plants generally use a vat-holding system of

Pasteurization and plate type heat exchanger for pre-cooling and final cooling. The pre-cooling section will cool ice cream mix to about 8 deg. C warmer than the entering water temperature. While final cooling section will cool ice cream mix to about 4 deg. C warmer than entering chilled water temperature. The final temperature be using chilled water will be about 5 deg. C. The regeneration heating and cooling effect can be obtained in a large size plate type heat exchanger. A final mix temperature of (-) 1 to 1 deg. C can be obtained using brine. For large ice cream plants, where low mix temperature is desired, and where plate type pasteurizing equipment is being used, it may be desirable to use separate equipment for deep cooling. Where plants have ample ice cream mix holding capacity so the mix may he held overnight, part of the final mix cooling may be done in the tanks by means of refrigerated surfaces built into the tanks. Using refrigerated mix holding tanks, the average rate of cooling may be estimated at 1 deg. C/h.

- **Aging**

Aging is a process of keeping mix in a jacketed vessel for 4 to 24 hrs at the same temperature at the temperature of 4 deg. C The purpose of the stage is to allow hydrocalloids to swell the casein to become hydrated, to increase viscosity, the texture to become finer, to improve the melting, to improve the whippability, fats to crystallize out and aroma to develop uniformly throughout. When the fat content is high and the homogenizing pressures low, longer holding times are used.

Ice cream manufacturing

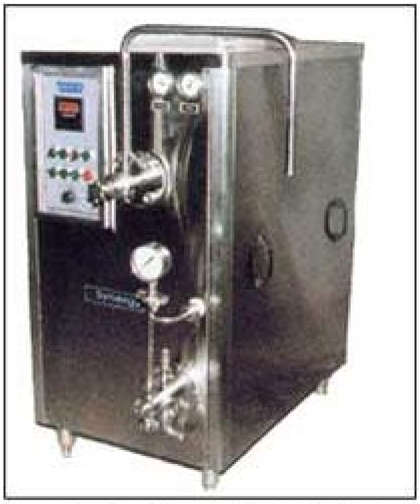

Photo 1 - Continuous ice cream freezer

Photo 2 - Batch ice cream freezer

Two types of ice cream freezers are in general use, the batch type, which freezes a measured quantity of mix at one time, and a continuous flow of ice cream mix and discharges out 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 either a flooded arrangement with an accumulator or direct expansion controlled by a thermostatic expansion valve. The freezer cylinder is arranged with a dasher having blades attached. The dasher revolves within the cylinder. The sharpened blades scrape the frozen film of ice cream as if forms on the inner surface of the cylinder. Some freezers have beaters built into the dasher to aid the blades in mixing and a whipping to produce the desired overrun. **Fig 2** and **Fig 3** show general arrangements for flooded and DX system ice cream freezers.

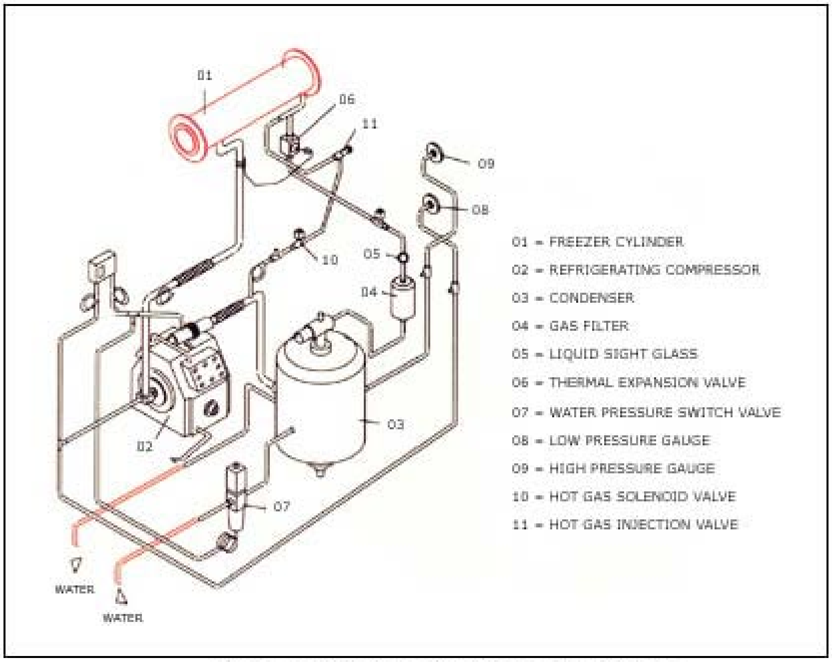

Fig. 3- DX system for ice cream freezer
Courtesy of technogel, Italy

Batch freezers range in sites from 2 to 40 liters of ice cream per batch and the batch may take 15-20 minutes to freeze. Batch freezers larger than the 40 liters size are now used extensively, partly because of the limited hourly capacity and because of the labour required in the operation.

Continuous ice cream freezers are a more recent development and range is sizes from 150-3000 litres per hour ice cream output. The type of machine shown in photo is used almost exclusively in commercial ice cream plants, where large capacities are required. In operation, the ice cream mix is continuously pumped to the freezer cylinder by a positive displacement pump. Air is supplied by either a separate air compressor or drawn in with the mix through the mix pump. The mixture of ice cream and air enters the rear of the ice cream freezer. The partially frozen ice cream is scraped out from the inner surface of the freezing the cylinder moves to the front of the cylinder and is discharged. **Fig 4** shows the flow diagram of ice cream mix in a freezer. Due to presence of air in the mix and agitation action by the dasher, air is entrapped within frozen ice cream and gives the overrun. The variation of ice cram discharge temperature can be obtained by regulating the evaporator temperature around the freezer cylinder by means of a suction pressure regulating valve. The average discharge temperature of ice cream from a continuous freezer is about (-) 5 deg. C when operating at about (-) 30 deg. C evaporating temperature of the refrigerant, at this temperature, only 40% of the total water available in ice cream mix is frozen. The flavored mix is run through a continuous freezer and then passed through a fruit feeder, which automatically mixes nuts or fruits into the ice cram.

Hardening of 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 ice cream is about (-) 13 deg. C and it is considered hard at (-)18 deg. C.

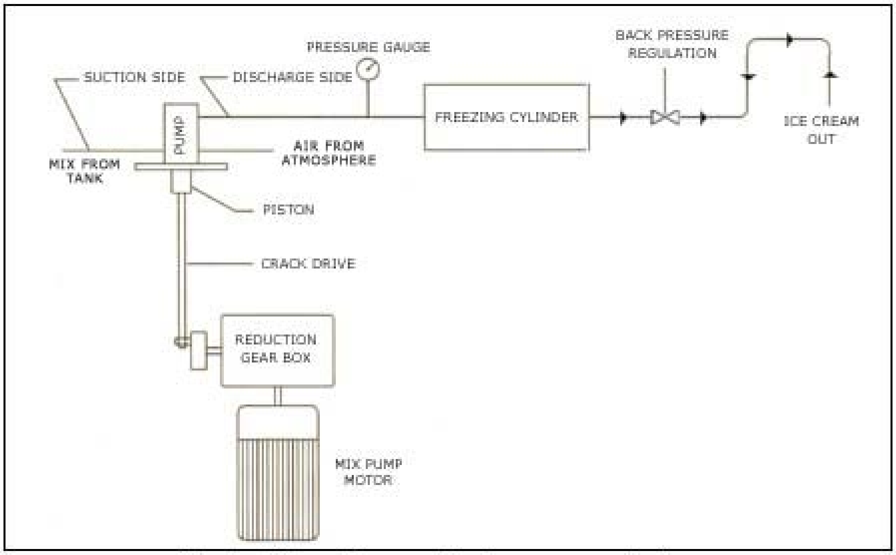

Fig. 4 - Flow diagram for ice cream mix freezer

It is necessary to freeze the remaining water content rapidly, so that the ice crystals formed will be small. For this reason most hardening chambers are maintained at a temperature of (-)35deg. C and in some cases as low as (-) 40deg. C. Hardening chambers are equipped with forced air circulation using unit coolers. The ice cream containers are arranged so air will circulate around them. It is desirable to maintain an air velocity in the range of 500-700 m/min.

The hardening systems include cabinets, hardening room, hardening tunnels land contact plate freezers. The tunnel design may be straight through with trolley, as shown in **fig 5** or spiral belt freezer, as shown in **fig 6**. The spiral type hardening tunnel typically receives the soft product at the bottom and discharges hardened product at the top. Operating speeds can be varied to match manufacturing speeds and time required for hardening the product.

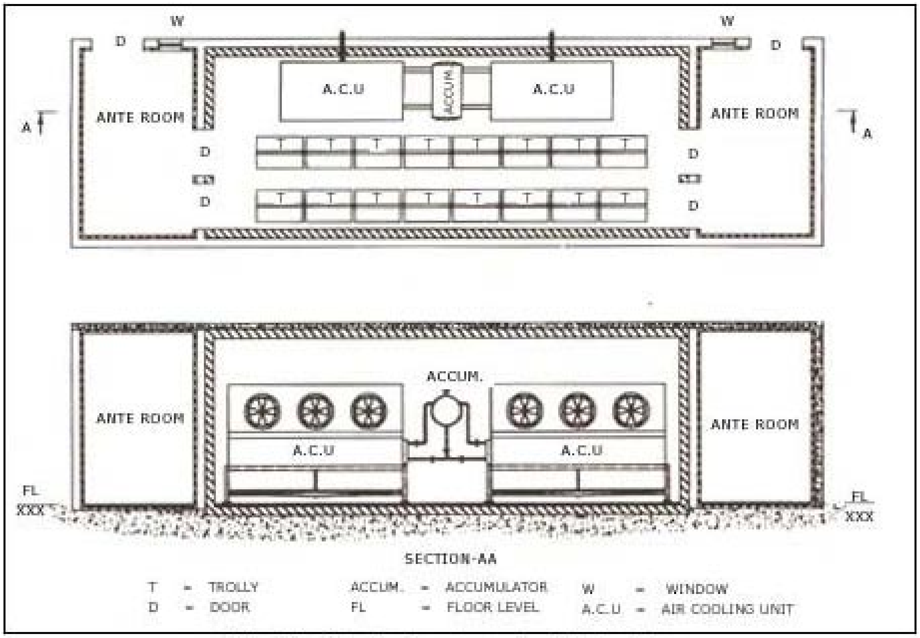

Fig. 5 - Hardening tunnel with trolley

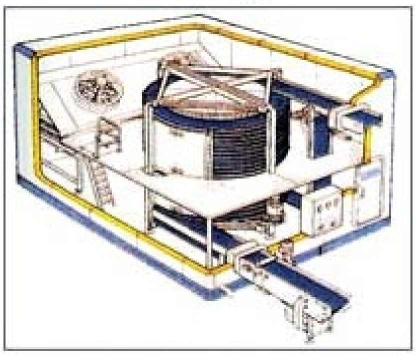

Figure 6 - Spiral Belt freezer

Storage and distribution

Under proper conditions, ice cream can be stored for several weeks. It is recommended to store ice cream at (-) 25 deg. C in a cold store. However prolonged storage is costly and the chemical, physical and microbiological quantities of the product do not improve during storage. Ice cream must be protected from surface evaporation, from shrinkage or loss of overrun, and from sugar crystallization. Proper packaging will provide considerable protection against surface deterioration.

Ice cream must be protected from melting during distribution. The required protection can be provided in several ways. For short periods of an hour or two, wrapped in closed packages, hardened ice cream can be placed inside the insulated container which prevents rapid changes of temperature. Extensive use of eutectic pads is done these days during distribution of ice cream. A solution of sodium chloride or mixture of salts is stored in eutectic pads at (-) 18deg. C. These pads provide refrigeration to the vans used for distribution of ice cream. For long periods, mechanical refrigeration must be supplied to preserve the frozen characteristics of the product. The temperature of the frozen products in the distribution system should never rise above the desired temperature in the retail counter i.e. (-) 20deg. C. Therefore, truck bodies should be well insulated, cooled prior to loading and kept cold by mechanical refrigeration. Exposure of frozen product to warm temperatures during unloading into store freezers must be limited to a few minutes to avoid heat shock and development of large ice crystals.

The refrigeration system

Nearly all commercial ice cream plants and particularly the larger plants, use ammonia as a refrigerant. However, refrigerant R-22 is used in smaller plants. Freezing equipment such as batch freezer, small size continuous ice cream freezer, refrigeration aging vat, surface cooler for cooling ice cream mix, ice cream storage cabinets etc. Use R-22, R-12 and R-134a refrigerants. A dedicated system is more desirable than a centralized installation.

For economy and safe operation it is recommended to use a multistage ammonia compression system. It is acceptable practice to select a evaporator temperature of (-) 40deg. C, (-) 30deg. C and (-) 10deg.C for hardening room, continuous freezer and cold store and ice bank systems respectively. Hence one or more booster compressor is used for different suction pressures and discharge into a second stage. **Fig 7** shows such a refrigeration system.

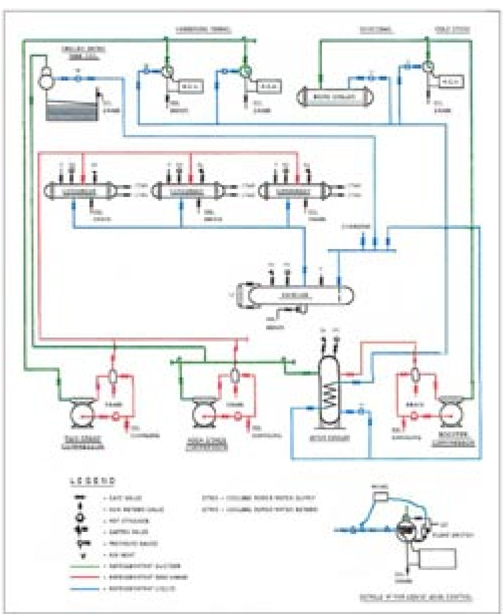

Figure 7 - Multi-stage evaporation system

Click to see clear picture

Many plants use an in - built two-stage compressor and select the number of cylinders for low stage and high stage on the basis of application. A separate compressor is used for high temperature refrigeration (for cooling of mix and ingredients cold store). **Fig 8** shows the schematic of an in-built two stage compression system.

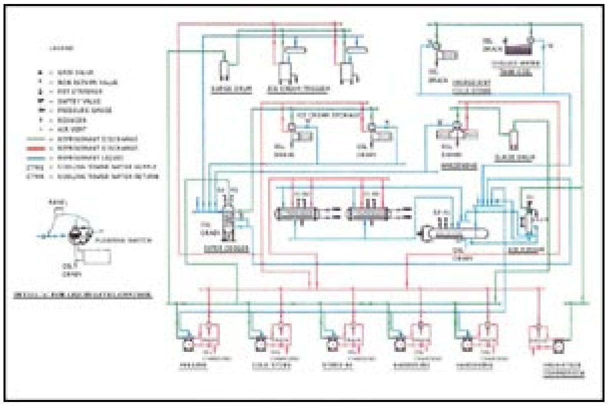

Fig. 8: Double stage compression system

Click to see clear picture

Refrigeration capacity

Exact calculation of refrigeration requirement involves a number of factors. The specific heat of mix varies with its composition and ingredients. Instead of undertaking detailed calculations it is common practice to assume a specific heat of 3.22 kJ/kgK for ice cream mix. This value is generous for mixes ranging from 36 to 40% total solids.

Similarly, in calculating the refrigeration required in freezing and hardening, it is difficult to estimate the correct specific heat as the freezing process is not completed at a constant temperature.

However, (-) 2.4deg. C may be considered as the freezing point for ice cream mix containing 15% sugar. The freezing point, of course, merely represents the temperature at which freezing starts. 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. **Table 1** presents freezing behavior of a typical ice cream having 12.5% fat, 15% sugar and a total of 38% solids.

Table 1 Freezing behavior of a typical ice cream

Water frozen to ice per cent	Freezing point of unfrozen position, deg C.
0	-2.47
10	-2.75
20	-3.11
30	-3.50
40	-4.22
50	-5.21

70	-9.45
90	-30.16

From **Table 1** the percentage of water frozen to ice can be determined by knowing the outlet temperature of ice cream from a continuous lice cream freezer. The total heat removal consists of:

- Sensible heat of mix up to freezing point.
- Heat of fusion for unfrozen portion of water.
- Sensible heat of ice cream up to storage temperature after freezing.

To compute the refrigeration capacity, following values are used:

- Specific heat of mix before freezing: 3.22 kJ/kg.K
- Heat of fusion: 245 kJ/kg of mix.
- Specific heat of ice cream below freezing: 1.87 kJ/kg.K.

A typical calculation for production of 1000 kg of ice cream is given below:

Mix cooling

Batch Pasteurization	**Alt I**
• Mix pasteurization temperature	69° C
• Cooling tower water temperature	32° C
• Pre-cooling of mix by cooling water	40° C
• Mix out let temperature	6° C
• Specific heat of mix	3.22 kJ/kg.K *
• Heat removed from mix by cooling tower water	**Q** = m x Cp x ΔT = 1000 x 3.22 x (69-40) = 92800 k.J * *
• Heat removed from mix by chilled water	**Q** = 1000 x 3.22 x (40-6) = 109480 kJ.

HTST pasteurization (with regeneration)	**Alt II**
• Mix inlet temperature	55° C
• Mix pasteurization temperature	80° C
• Regeneration efficiency	70%
• Temperature of mix at the end of regeneration	80 - 0.7 (80-55)= 62.5°C
• Mix cooling by cooling tower water	1000 x 3.22 x (62.5-40) = 72450 kJ
• Mix cooling by chilled water	100 x 3.22 x (40-6) = 109480 kJ

* To convert from kJ/kg.K to Btu/lb °F multiply by 0.24
** To convert from kJ to Btu multiply by 0.95

Aging vat

• Tank dimension (outside)	1000 mm dia x 1500 mm high
• Total insulation	100 mm EPS
• Over all heat transfer coefficient	0.308 W/m²K
• Agitator motor	1 kW
• Heat input factor	0.8
• Mix product cooling	1°C / h
• Inside temperature	4°C
• Room temperature	35°C

$$Q = U \times A \times \Delta T + \text{load of motor} + \text{product load}$$

$$= 0.308 \times (3.14 \times 1.0 \times 1.5 + 2 \times 3.14 \times 1 \times 1) \times (35-4) / 1000 + 0.8 \times 1 + (1000 \times 3.22 \times 1) /3600$$

$$= 1.75 \text{ kJ/s}$$

Continuous ice cream freezer

It is common practice to refer to the manufacturer's catalogue to find out the refrigeration requirement for a freezer.

It can be estimated as 2.5 kJ/s. For producing 100 1 / h (50kg /h) partially frozen ice cream at -5deg.C outlet temperature from 4 deg. C ice cream mix. Generally small size freezers are self contained type and a separate refrigeration system is not required. However, it is essential to check the catalogue for water supply temperature required for the condenser. It is general practice to specify +15 deg. C water temperature for condensers by Italian manufactures. In such cases, a provision has to be made to supply chilled water at the required temperature to achieve maximum output of the machine.

For a large size continuous freezer, sub-cooled liquid refrigerant is to be supplied from a central system and it is to be hooked up with the central refrigeration plant. In such a case, evaporating temperature of the freezer is required to be matched with the refrigeration system installed. It is a general practice to design the freezing cylinder, considering (-) 30 to (-) 34deg. C evaporating temperature.

Hardening of ice cream

For a sample calculation, it is assumed that:

• Water content in mix	61%
• Over run	100%
• Entering temperature of ice cream	(-) 5°C
• Water frozen percent at entering point	45%
• Ice cream outlet temperature	(-)18°C
• Hardening tunnel temperature	35°C
• Latent heat of hardening	1000 x 245 x 0.55 = 134750 kJ
• Sensible cooling before freezing	1000 x 3.22 x (-5 + 18) = 41860 kJ
• Total	= 176610 kJ
• Load due to heat of container assume @ 10%	= 17661 kJ
• Total product load per 1000 kg.	194271 kJ

In addition to the above, following loads should added to work out the final figure for the refrigeration load. These may be calculated as per standard procedure used for calculating cold storage refrigeration loads.

- Heat transmission through walls, ceiling and floor.
- Heat from fan motor.
- Heat from lights.
- Air infiltration
- Persons working inside
- Miscellaneous load

If trolleys and trays are used to transfer ice cream containers within the tunnel, the sensible cooling load for trolleys and trays should be added for estimation of total requirement.

Cold storage

It is general practice to maintain the temperature of a cold storage at (-) 25 to (-) 28 deg C. The refrigeration requirement for the cold storage is similar to any other cold storage. The product load may be considered as 1000 kg of ice cream input in a day with overnight holding, the load may be estimated as

$$= \frac{1000 \times 1.87 \times (-25 + 18)}{12 \times 3600}$$
$$= 0.303 \text{ kJ/s}$$

Other loads such as heat transmission and due to fan, lighting, infiltration, people, etc are to be added in working out the total refrigeration requirement for the cold storage.

Novelty and distribution

Many ice cream manufactures produce novelties of frozen product on a wood stick, these products are frozen in metal mould/trays which are submerged in a special brine tank having a built-in cooling coil or shell and tube chiller. The brine tank temperature is maintained at (-) 28 deg. C for manual operation and at (-) 35 deg. C for automatic operation.

Similarly, many plants use pre-frozen eutectic plates for transportation of ice cream. These plates are submerged for 8-12 hours in a brine tank having a built-in evaporator coil or shell and tube chiller to maintain the temperature of brine at (-) 28 deg. C The freezing point of eutectic solution is in the range of (-) 18 to (-) 23 deg. C The quantity of eutectic plates depends upon the distribution logistics and the volume of products to be transported.

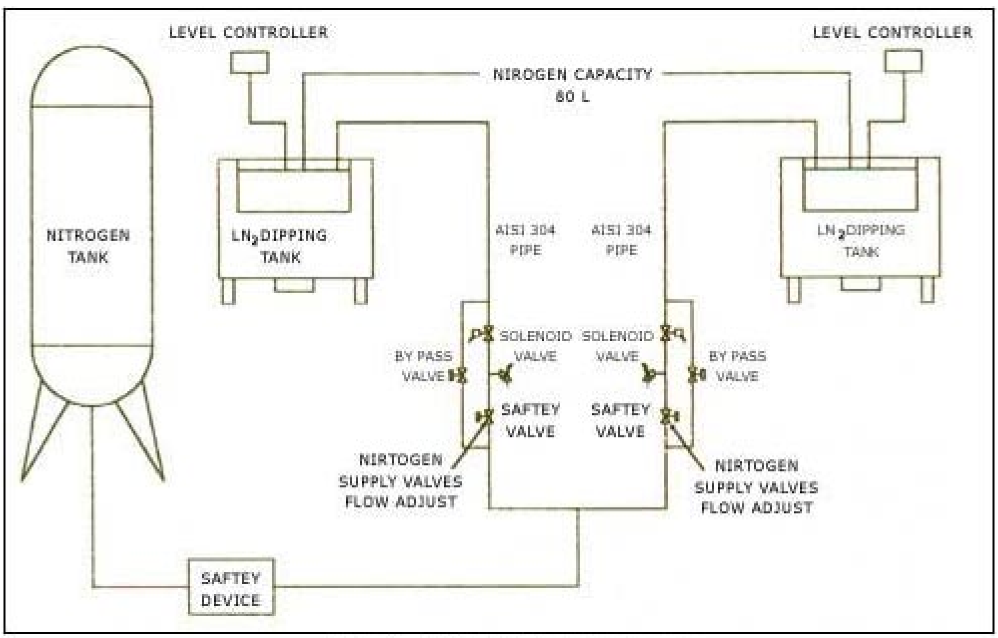

Fig. 9- LN^2 installation scheme

Modern Developments

There is a potential to realize higher profit by making and marketing usual ice cream and frozen desert products to the consumers with imagination and innovation. As a result, extrusion products are available in the market. In the extrusion production, ice cream is drawn at a low temperature of about (-) 6 deg. C from the freezer, pumped through an extruder nozzle and sliced into portions by a cutting assembly. The portions are placed on carrier plates and pass through a freezing chamber at (-) 40 deg. C with rapid air circulation for flash freezing. Each portion is removed from the carrier plates as it emerges from the freezing chamber. A portion is then submerged in a tropical fruit juice or chocolate. Before submerging in fruit juice it is required to be submerged in a liquid nitrogen bath for two to three times as per thickness of the coating requirement. This product is known as 'Solaro'. Thus, it requires a refrigeration system at cryogenic temperatures with installation of liquid nitrogen storage and transfer facilities. **Photo 3** shows 'Solaro' product and **Fig. 9** gives the details of LN2 installation required for such products.

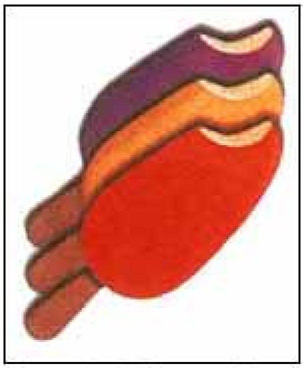

Photo 3- Solar product