Related Commercial Resources

CHAPTER 20

DAIRY PRODUCTS

Milk Production and Processing 20.1
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Frozen Dairy Desserts 20.13
Ultrahigh-Temperature (UHT) Sterilization and Aseptic Packaging (AP) 20.19
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RAW milk is either processed for beverage milks, creams, and related milk products for marketing, or is used for the manufacture of dairy products. Milk is defined in the U.S. *Code of Federal Regulations* and the *Grade A Pasteurized Milk Ordinance* (PMO). Milk products are defined in 21CFR131 to 135. Public Law 519 defines butter. Note that there are many nonstandard dairy-based products that may be processed and manufactured by the equipment described in this chapter. Dairy plant operations include receiving raw milk; purchase of equipment, supplies, and services; processing milk and milk products; manufacture of frozen dairy desserts, butter, cheeses, and cultured products; packaging; maintenance of equipment and other facilities; quality control; sales and distribution; engineering; and research.

Farm cooling tanks and most dairy processing equipment manufactured in the United States meet the requirements of the *3-A Sanitary Standards* (IAMFES). These standards set forth the minimum design criteria acceptable for composition and surface finishes of materials in contact with the product; construction features such as minimum inside radii; accessibility for inspection and manual cleaning; criteria for mechanical and chemical cleaning or sanitizing in place (CIP and SIP); insulation of nonrefrigerated holding and transport tanks; and other factors that may adversely affect product quality and safety or the ease of cleaning and sanitizing equipment. Also available is *3-A Accepted Practices*, which deals with construction, installation, operation, and testing of certain systems rather than individual items of equipment.

The *3-A Sanitary Standards* and *Accepted Practices* are developed by the 3-A Standards Committees, which are composed of conferees representing state and local sanitarians, the U.S. Public Health Service, dairy processors, and equipment manufacturers. Compliance with the *3-A Sanitary Standards* is voluntary, but manufacturers who comply and have authorization from the 3-A Symbol Council may affix to their equipment a plate bearing the 3-A Symbol, which indicates to regulatory inspectors and purchasers that the equipment meets the pertinent sanitary standards.

MILK PRODUCTION AND PROCESSING

Handling Milk at the Dairy

Most dairy farms have bulk tanks to receive, cool, and hold milk. Tank capacity ranges from 200 to 5000 gal, with a few larger tanks. As cows are mechanically milked, the milk flows through sanitary pipelines to an insulated stainless steel bulk tank. An electric-motor-driven mechanical agitator stirs the milk, and mechanical refrigeration begins to cool it even during milking.

The *Pasteurized Milk Ordinance* (PMO) requires a tank to have sufficient refrigerated surface at the first milking to cool to 50°F or less within 4 h of the start of the first milking and to 45°F or less within 2 h after completion of milking. During subsequent milkings, there must be enough refrigerating capacity to prevent the temperature of the blended milk from rising above 50°F. The nameplate must state the maximum rate at which milk may be added and still meet the cooling requirements of the *3-A Sanitary Standards*.

Automatic controls maintain the desired temperature within a preset range in conjunction with agitation. Some dairies continuously record temperatures in the tank, a practice required by the PMO for bulk milk tanks manufactured after January 1, 2000. Because milk is picked up from the farm tank daily or every other day, milk from the additional milkings generally flows into the reservoir cooled from the previous one. Some large dairy farms may use a plate or tubular heat exchanger for rapid cooling. Cooled milk may be stored in an insulated silo tank (a vertical cylinder 10 ft or more in height).

Milk in the farm tank is pumped into a stainless steel tank on a truck for delivery to the dairy plant or receiving station. The tanks are well insulated to alleviate the need for refrigeration during transportation. Temperature rise when testing the tank full of water should not be more than 2°F in 18 h, when the average temperature difference between the water and the atmosphere surrounding the tank is 30°F.

The most common grades of raw milk are Grade A and Manufacturing Grade. Grade A raw milk is used for market milk and related products such as cream. Surplus Grade A milk is used for ice cream or manufactured products. To produce Grade A milk, the dairy farmer must meet state and federal standards; a few municipal governments also have raw milk regulations.

For raw milk produced under the provisions of the Grade A PMO recommended by the U.S. Public Health Service, the dairy farmer must have healthy cows and adequate facilities (barn, milkhouse, and equipment), maintain satisfactory sanitation of these facilities, and have milk with a bacteria count of less than 100,000 per mL for individual producers. Commingled raw milk cannot have more than 300,000 counts per mL. The milk should not contain pesticides, antibiotics, sanitizers, and so forth. However, current methods detect even minute traces of these prohibited substances, and total purity is difficult. Current regulators require no positive results on drug residue. Milk should be free of objectionable flavors and odors.

Receiving and Storing Milk

A milk processing plant receives, standardizes, processes, packages, and merchandises milk products that are safe and nutritious for human consumption. Most dairy plants either receive raw milk in bulk from a producer or arrange for pickup directly from dairy farms. The milk level in a farm tank is measured with a dipstick or a direct-reading gage, and the volume is converted to weight. Fat test and weight are common measures used to base payment to the farmer. A few organizations and the state of California include the percent of nonfat solids and protein content.

Plants can determine the amount of milk received by (1) weighing the tanker, (2) metering milk while pumping from the tanker to

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The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

a storage tank, or (3) using load cells on the storage tank or other methods associated with the amount in the storage tank.

Milk is generally received more rapidly than it is processed, so ample storage capacity is needed. A holdover supply of raw milk at the plant may be needed for start-up before arrival of the first tankers in the morning. Storage may also be required for nonprocessing days and emergencies. Storage tanks vary in size from 1000 to 60,000 gal. The tanks have a stainless steel lining and are well insulated.

The *3-A Sanitary Standards* for silo-type storage tanks specify that the insulating material should be of a nature and an amount sufficient to prevent freezing during winter in colder climates, or an average 18 h temperature change of no more than 3°F in the tank filled with water when the average temperature differential between the water and the surrounding air is 30°F. Inside tanks should have a minimum insulation R-value of 8, whereas partially or wholly outside tanks have a minimum R-value of 12. R-value units are $ft^2 \cdot °F \cdot h/Btu$. For horizontal storage tanks, the allowable temperature change under the same conditions is 2°F.

Agitation is essential to maintain uniform milkfat distribution. Milk held in large tanks, such as the silo type, is continuously agitated with a slow-speed propeller driven by a gearhead electric motor or with filtered compressed air. The tank may or may not have refrigeration, depending on the temperature of the milk flowing into it and the maximum holding time.

If refrigeration is provided for milk in a storage tank, it may be by use of a refrigerated jacket around the interior lining of the silo or tank. This cooling surface may be an annular space from a plate welded to the outside of the lining for direct refrigerant cooling or circulation of chilled water or a water/propylene glycol solution. Another system provides a distributing pipe at the top for chilled liquid to flow down the lining and drain from the bottom. Some plants pass milk through a plate cooler (heat exchanger) to keep all milk directed into the storage tanks at 40°F or less. Direct refrigerant cooling must be carefully applied to prevent milk from freezing on the lining. This limits the evaporator temperature to approximately 25 to 28°F.

Separation and Clarification

Before pasteurizing, milk and cream are standardized and blended to control the milkfat content within legal and practical limits. Nonfat solids may also need to be adjusted for some products; some states require added nonfat solids, especially for lowfat milk such as 2% (fat) milk. Table 1 shows the approximate legal milkfat and nonfat solids requirements for milks and creams in the United States.

One means of obtaining the desired fat standard is by separating a portion of the milk. The required amount of cream or skim milk is returned to the milk to control the final desired fat content. Milk with excessive fat content may be processed through a standardizer-clarifier that removes fat to a predetermined percentage (0.1 to 2.0%) and clarifies it at the same time. To increase the nonfat solids, condensed skim milk or low-heat nonfat dry milk may be added.

Milk separators are enclosed and fed with a pump. Separators designed to separate cold milk, usually not below 40°F, have increased capacity and efficiency as milk temperature increases. Capacity of a separator is doubled as milk temperature rises from 40 to 90°F. The efficiency of fat removal with a cold milk separator decreases as temperature decreases below 40°F. The maximum efficiency for fat removal is attained at approximately 45 to 50°F or above. Milk is usually separated at 70 to 90°F, but not above 100°F in warm milk separators. If raw, warmed milk or cream is to be held for more than 20 min before pasteurizing, it should be immediately recooled to 40°F or below after separation.

The pump supplying milk to the separator should be adjusted to supply milk at the desired rate without causing a partial churning action.

An automated process uses a meter-based system that controls the separation, fat and/or nonfat solids content, and ingredient addition for a variety of common products. If the initial fat tests fed into the computer are correct, the accuracy of the fat content of the standardized product is ±0.01%.

At an early stage between receiving and before pasteurizing, the milk or resulting skim milk and cream should be filtered or clarified, optimally during the transfer from the pickup tanker into the plant equipment. A clarifier removes extraneous matter and leucocytes, thus improving the appearance of homogenized milks.

Table 1 U.S. Requirements for Milkfat and Nonfat Solids in Milks and Creams

	Legal Minimum					
	Milkfat, %			Nonfat Solids, %		
Product	Federal	Range	Most Often	Federal	Range	Most Often
Whole milk	3.25	3.0 to 3.8	3.25	8.25	8.0 to 8.7	8.25
Lowfat milk	0.5	0.5 to 2.0	2.0	8.25	8.25 to 10.0	8.25
Skim milk	0.5*	0.1 to 0.5	0.5*	8.25	8.25 to 9.0	8.25
Flavored milk	—	2.8 to 3.8	3.25	8.25	7.5 to 10.0	8.25
Half-and-half	10.5	10.0 to 18.0*	10.5	—	—	—
Light (coffee) cream	18.0	16.0 to 30.0*	18.0	—	—	—
Light whipping cream	30.0	30.0 to 36.0*	30.0	—	—	—
Heavy cream	36.0	36.0 to 40.0	36.0	—	—	—
Sour cream	18.0	14.4 to 20.0	18.0	—	—	—

*Maximum

Pasteurization and Homogenization

There are two systems of pasteurization: batch and continuous. The minimum feasible processing rate for continuous systems is about 2000 lb/h. Therefore, batch pasteurization is used for relatively small quantities of liquid milk products. The product is heated in a stainless steel-lined vat to not less than 145°F and held at that temperature or above for not less than 30 min. The Grade A PMO requires that batch or vat pasteurizers keep the vapor space above liquid product at a temperature at least 5°F higher than the minimum required temperature of pasteurization during the holding period. Pasteurizing vats are heated with hot water or steam vapor in contact with the outer surface of the lining. One heating method consists of spraying heated water around the top of the lining. It flows to the bottom, where it drains into a sump, is reheated by steam injection, and returns to the spray distributor. Steam-regulating valves control the hot-water temperature. The maximum temperature difference between the milk or milk product throughout the vat during its holding period must not exceed 1°F. Therefore, the vat must have adequate agitation throughout the holding period. Whole and lowfat milk, half-and-half, and coffee cream are cooled, usually in the vat, to 130°F and then homogenized. Cooling is continued in a heat exchanger (e.g., a plate or tubular unit) to 40°F or lower and then packaged.

Plate coolers may have two sections, one using plant water and the second using chilled water or propylene glycol. The temperature of the product leaving the cooler depends on the flow rates and temperature of the cooling medium.

Most pasteurizing vats are constructed and installed so that the plant's cold water is used for initial product cooling after pasteurization. For final vat cooling, refrigerated water or propylene glycol is recirculated through the jacket of the vat to attain a product temperature of 40°F or less. Cooling time to 40°F should be less than 1 h.

High-temperature short-time (HTST) pasteurization is a continuous process in which milk is heated to at least 161°F and held at this temperature for at least 15 s. The complete pasteurizing system usually consists of a series of heat exchanger plates contained in a press, a milk balance tank, one or more milk pumps, a holding tube, flow diversion valve, automatic controls, and sources of hot water or steam and chilled water or propylene glycol for heating and cooling the milk, respectively. Homogenizers are used in many HTST systems as timing pumps used to process Grade A products. The heat exchanger plates are arranged so that milk to be heated or cooled flows between two plates, and the heat exchange medium flows in the opposite direction between alternate pairs of plates.

Ports in the plates are arranged to direct the flow where desired, and gaskets are arranged so that any leakage will be from the product to the heating or cooling media, to minimize potential for product contamination. Terminal plates are inserted to divide the press into three sections (heating, regenerating, and cooling) and arranged with ports for inlet and outlet of milk, hot water, or steam for heating, and chilled water or propylene glycol for cooling. To provide a sufficient heat-exchange surface for the temperature change desired in a section, milk flow is arranged for several passes through each section. The capacity of the pasteurizer can be increased by arranging several streams for each pass made by the milk. The capacity range of a complete HTST pasteurizer is 100 to about 100,000 lb/h. A few shell-and-tube and triple-tube HTST units are in use, but the plate type is by far the most prevalent.

Figure 1 shows one example of a flow diagram for an HTST plate pasteurizing system. Raw product is first introduced into a constant-level (or balance) tank from a storage tank or receiving line by either gravity or a pump. A uniform level is maintained in this tank by a float-operated valve or similar device. A booster pump is often used to direct flow through the regeneration section. The product may be clarified and/or homogenized or directly pumped to the heating section by a timing pump. From the heating section, the product continues through a holding tube to the flow diversion valve. If the product is at or above the preset temperature, it passes back through the opposite sides of the plates in the regeneration section and then through the final cooling section. The flow diversion valve is set at 161°F or above; if the product is below this minimum temperature, it is diverted back into the balance tank for repasteurization. Heat exchange in the regeneration section causes cold raw milk to be heated by hot pasteurized milk going downstream from the heater section and flow diversion valve. According to the PMO, the pasteurized milk pressure must be maintained at least 1 psi above the raw. The flow rate and temperature change are about the same for both products.

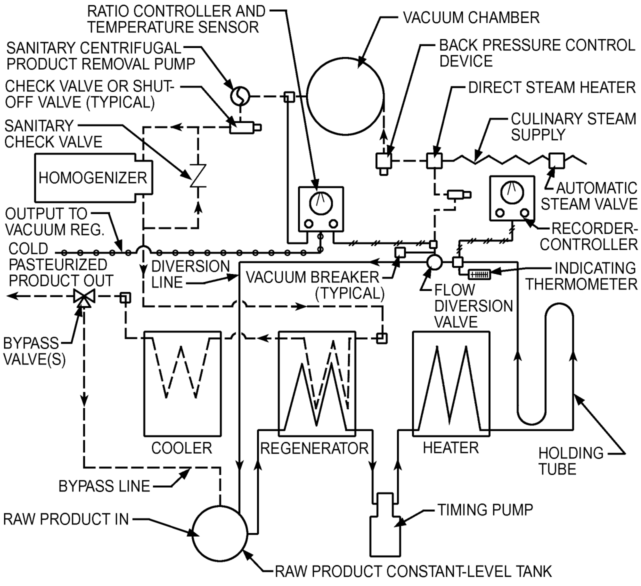

Fig. 1 Flow Diagram of Plate HTST Pasteurizer with Vacuum Chamber

Most HTST heat exchangers achieve 80 to 90% regeneration. The cost of additional equipment to obtain more than 90% regeneration should be compared with savings in the increased regeneration to determine feasibility. The percentage of regeneration may be calculated as follows for equal mass flow rates on either side of the regenerator:

$$\frac{138°\text{F (regeneration)} - 40°\text{F (raw product)}}{161°\text{F (pasteurization)} - 40°\text{F (raw product)}} = \frac{98}{121} = 81\%$$

The temperature of a product going into the cooling section can be calculated if the percent regeneration is known and the raw product and pasteurizing temperatures are determined. If they are 80%, 45°F, and 161°F, respectively,

$$(161 - 45) \times 0.80 = 92.8°\text{F}$$
$$161 - 92.8 = 68.2°\text{F}$$

The product should be cooled to at least 40°F, preferably lower, to compensate for the heat gain while in the sanitary pipelines and during the packaging process (including filling, sealing, casing, and transfer into cold storage). Average temperature increases of milk between discharge from the HTST unit's cooling section and arrival at the cold storage in various containers are as follows: glass bottles, 8°F; preformed paperboard cartons, 6°F; formed paperboard, 5°F; and semirigid plastic, 4°F.

Some plate pasteurizing systems are equipped with a cooling section using propylene glycol solution to cool the milk or milk product to temperatures lower than are practical by circulating only chilled water. This requires an additional section in the plate heat exchanger, a glycol chiller, a pump for circulating the glycol solution, and a product-temperature-actuated control to regulate the flow of glycol solution and prevent product freezing.

Some plants use propylene glycol exclusively for cooling, thus avoiding the use of chilled water and the requirement for two separate cooling sections. Milk is usually cooled with propylene glycol to approximately 34°F, then packaged. The lower temperature allows the milk to absorb heat from the containers and still maintain a low enough temperature for excellent shelf life. Milk should not be cooled to less than 33.5°F because of the tendency toward increased foaming in this range. Propylene glycol is usually chilled to approximately 28 to 30°F for circulation through the milk-cooling section.

Product flow rate through the pasteurizer may be more or less than the filling rate of the packaging equipment. Pasteurized product storage tanks are generally used to hold the product until it is packaged.

The number of plates in the pasteurizing unit is determined by the volume of product needed per unit of time, desired percentage of regeneration, and temperature differentials between the product and heating and cooling media. The heating section usually has ample surface so that the temperature of hot water entering the section is no more than 2 to 6°F higher than the pasteurizing, or outlet, temperature of the product. This temperature difference is often called the **approach** of the heat exchanger section.

On larger units, steam may be used for the heater section instead of hot water. The cooling section is usually sized so that the temperature of pasteurized product leaving the section is about 4 to 5°F higher than the entering temperature of chilled water or propylene glycol.

The holding tube size and length are selected so that not less than 15 s will elapse for the product to flow from one end of the tube to the other. An automatic, power-actuated, flow diversion valve, controlled by a temperature recorder-controller, is located at the outlet end of the holding tube and diverts flow back to the raw product constant-level tank as long as the product is below the minimum set pasteurizing temperature. The product timing pump is a variable-speed, positive-displacement, rotary type that can be sealed by the local government milk plant inspector at a maximum speed and volume. This ensures a product dwell time of not less than 15 s in the holding tube.

To reduce undesirable flavors and odors in milk (usually caused by specific types of dairy cattle feed), some plants use a vacuum process in addition to the usual pasteurization. Milk from the flow diversion valve passes through a direct steam injector or steam infusion chamber and is heated with culinary steam to 180 to 200°F. The milk is then immediately sprayed into a vacuum chamber, where it cools by evaporation to the pasteurizing temperature and is promptly pumped to the regeneration section of the pasteurizing unit. The vacuum in the evaporating chamber is automatically controlled so that the same amount of moisture is removed as was added by steam condensate. Noncondensable gases are removed by the vacuum pump, and vapor from the vacuum chamber is condensed in a heat exchanger cooled by the plant water.

The vacuum chamber can be installed with any type of HTST pasteurizer. In some plants, after preheating in the HTST system, the product is further heated by direct steam infusion or injection. It then is deaerated in the vacuum chamber. The product is pumped from the chamber by a timing pump through final heating, holding, flow diversion valve, and regenerative and cooling sections. Homogenization may occur either immediately after preheating for pasteurization or after the product passes through the flow diversion valve. Preferred practice is to homogenize after deaeration if the product is heated by direct steam injection and deaerated.

Where volatile weed and feed taints in the milk are mild, some processors use only a vacuum treatment to reduce off-flavor. The main objection to vacuum treatment alone is that, to be effective, the vacuum must be low enough to cause some evaporation, and the moisture so removed constitutes a loss of product. The vacuum chamber may be installed immediately after preheating, where it effectively deaerates the milk before heating, or immediately after the flow diversion valve, where it is more effective in removing volatile taints.

Nearly all milk processed in the United States is homogenized to improve stability of the milkfat emulsion, thus preventing creaming (concentration of the buoyant milkfat at the top of containerized milk) during normal shelf life. The homogenizer is a high-pressure reciprocating pump with three to seven pistons, fitted with a special homogenizing valve. Several types of homogenizing valves are used, all of which subject fat globules in the milk stream to enough shear to divide into several smaller globules. Homogenizing valves may either be single or two in series.

For effective homogenization of whole milk, fat globules should be 2 μm or less in diameter. The usual temperature range is from 130 to 180°F, and the higher the temperature within this range, the lower the pressure required for satisfactory homogenization. The homogenizing pressure for a single-stage homogenizing valve ranges from about 1200 to 2500 psi for milk; for a two-stage valve, from 1200 to 2000 psi on the first stage plus 300 to 700 psi on the second, depending on the design of the valve and the product temperature and composition. To conserve energy, use the lowest homogenizing pressure consistent with satisfactory homogenization: the higher the pressure, the greater the power requirements.

Packaging Milk Products

Cold product from the pasteurizer cooling section flows to the packaging machine and/or a surge tank 1000 to 10,000 gal or larger. These tanks are stainless steel, well insulated, and have agitation and usually refrigeration.

Milk and related products are packaged for distribution in paperboard, plastic, or glass containers in various sizes. Fillers vary in design. Gravity flow is used, but positive piston displacement is used on paper machines. Filling speeds range from roughly 16 to 250 units/min, but vary with container size. Some fillers handle only one size, whereas others may be adjusted to automatically fill and seal several size containers. Paperboard cartons are usually formed on the line ahead of filling, but may be preformed before delivery to the plant. Semirigid plastic containers may be blow-molded on the line ahead of the filler or preformed. Plastic pouches (called bags) arrive at the plant ready for filling and sealing. Filling dispenser cans and bags is a semimanual operation.

The paperboard milk carton consists of a 16 mil thick kraft paperboard from virgin paper with a 1 mil polyethylene film laminated onto the inside and a 0.75 mil film onto the outside. Gas or electric heaters supply heat for sealing while pressure is applied.

Blow-molded plastic milk containers are fabricated from high-density polyethylene resin. The resin temperature for blow-forming varies from 340 to 425°F. The molded gallon weighs approximately 60 to 70 g, and the one-half gallon, about 45 g. Contact the blow-molding equipment manufacturer for refrigeration requirements of a specific machine. The refrigeration demand to cool the mold head and clutch is large enough to require consideration in planning a plastic blow-molded operation. Blow-molding equipment may use stand-alone direct-expansion water chillers, or combine blow-molding refrigeration with the central refrigeration system to achieve better overall efficiency.

Packages containing the product may be placed into cases mechanically. Stackers place cases five or six high, and conveyors transfer stacks into the cold storage area.

Equipment Cleaning

Several automatic clean-in-place (CIP) systems are used in milk processing plants. These may involve holding and reusing the detergent solution or the preparation of a fresh solution (single-use) each day. Programming automatic control of each cleaning and sanitizing step also varies. Tanks, vats, and other large equipment can be cleaned by using spray balls and similar devices that ensure complete coverage of soiled surfaces. Tubing, HTST units, and equipment with relatively low volume may be cleaned by the full-flood system. Solutions should have a velocity of not less than 5 fps and must be in contact with all soiled surfaces. Surfaces used for heating milk products, such as in batch or HTST pasteurization, are more difficult to clean than other equipment surfaces. Other surfaces difficult to clean are those in contact with products that are high in fat, contain added solids and/or sweeteners, or are highly viscous. The usual cleaning steps for this equipment are a warm-water rinse, hot-acid-solution wash, rinse, hot-alkali-solution wash, and rinse. Time, temperature, concentration, and velocity may need to be adjusted for effective cleaning. Just before use, surfaces in contact with product should be sanitized with chemical solution, hot water, or steam. During CIP, the cooling section is isolated from the supply of chilled water or propylene glycol to minimize parasitic load on the refrigeration system.

Milk Storage and Distribution

Cases containing packaged products are conveyed into a cold-storage room or directly to delivery trucks for wholesale or retail distribution. The temperature of the storage area should be between 33 and 40°F, and for improved keeping quality, the product temperature in the container on arrival in storage should be 40°F or less.

The refrigeration load for cold-storage areas includes transmission through the building envelope, product and packaging materials temperature reduction, internally generated loads (e.g., lights, equipment motors, personnel), infiltration load from air exchange with other spaces and the environment, and refrigeration equipment-related load (e.g., fan motors, defrost). See Chapter 13 for a more detailed discussion of refrigeration load calculations.

Moisture load in these storage areas is generally high, which can lead to high humidity or wet conditions if evaporators are not selected properly. These applications usually require higher temperature differences between refrigerant and refrigerated-space set-point temperatures to achieve lower humidity. In addition, supply air temperatures should be controlled to prevent product freezing. Using reheat coils to provide humidity control is not recommended, because bacteriological growth on these surfaces could be rapid. Evaporators for these applications should have automatic coil defrost to remove the rapidly forming frost as required. Defrost cycles add to the refrigeration load and should be considered in the design.

A proprietary system used in some plants sprays coils continuously with an aqueous glycol solution to prevent frost from forming on the coil. These fan-coil units eliminate defrosting, can control humidity to an acceptable level with less danger of product freezing, and reduce bacteriological contamination. The glycol absorbs the water, which is continuously reconcentrated in a separate apparatus with the addition of heat to evaporate the water absorbed at the coil. A separate load calculation and analysis is required for these systems.

The floor space required for cold storage depends on product volume, height of stacked cases, packaging type (glass requires more space than paperboard), handling (mechanized or manual), and number of processing days per week. A 5 day processing week requires a capacity for holding product supply for 2 days. A very general estimate is that 100 lb of milk product in paperboard cartons can be stored per square foot of area. Approximately one-third more area should be allowed for aisles. Some automated, racked storages are used for milk products, and can be more economical than manually operated storages.

Milk product may be transferred by conveyor from storage room to dock for loading onto delivery trucks. In-floor drag-chain conveyors are commonly used, especially for retail trucks. Refrigeration losses are reduced if the load-out doorway has an air seal to contact the doorway frame of the truck as it is backed to the dock.

Distribution trucks need refrigeration to protect quality and extend storage life of milk products. Refrigeration capacity must be sufficient to maintain Grade A products at 45°F or less. Many plants use insulated truck trailer bodies with integral refrigerating systems powered by an engine or that can be plugged into a remote electric power source when it is parked. In some facilities, cold plates in the truck body are connected to a coolant source in the parking space. These refrigerated trucks can also be loaded when convenient and held over at the connecting station until the next morning.

Half-and-Half and Cream

Half-and-half is standardized at 10.5 to 12% milkfat and, in most areas of the United States, to about the same percent nonfat milk solids. Coffee cream should be standardized at 18 to 20% milkfat. Both are pasteurized, homogenized, cooled, and packaged similarly to milk. Milkfat content of whipping cream is adjusted to 30 to 35%. Take care during processing to preserve the whipping properties; this includes the omission of the homogenization step.

Buttermilk, Sour Cream, and Yogurt

Retail buttermilk is not from the butter churn but is instead a cultured product. To reduce microorganisms to a low level and improve the body of the resulting buttermilk, skim milk is pasteurized at 180°F or higher for 0.5 to 1 h and cooled to 70 to 72°F. One percent of a lactic acid culture (starter) specifically for buttermilk is added and the mixture incubated until firmly coagulated by the correct lactic acid production (pH 4.5). The product is cooled to 40°F or less with gentle agitation to inhibit serum separation after packaging and distribution. Salt and/or milkfat (0.5 to 1.0%) in the form of cream or small fat granules may be added. Packaging equipment and containers are the same as for milk. Pasteurizing, setting, incubating, and cooling are usually accomplished in the same vat. Rapid cooling is necessary, so chilled water is used. If a 500 gal vat is used, as much as 25 to 30 tons of refrigeration may be needed. Some plants have been able to cool buttermilk with a plate heat exchanger without causing a serum separation problem (wheying off).

Cultured half-and-half and cultured sour cream are also manufactured this way. Rennet may be added at a rate of 0.5 mL (diluted in water) per 10 gal cream. Take care to use an active lactic culture and to prevent postpasteurization contamination by bacteriophage, bacteria, yeast, or molds. An alternative method consists of packaging the inoculated cream, incubating, and then cooling by placing packages in a refrigerated room.

For yogurt, skim milk may be used, or milkfat standardized to 1 to 5%, and a 0.1 to 0.2% stabilizer may be added. Either vat pasteurization at 150 to 200°F for 0.5 to 1 h or HTST at 185 to 285°F for 15 to 30 s can be used. For optimum body, milk homogenization is at 130 to 150°F and 500 to 2000 psi. After cooling to between 100 and 110°F, the product is inoculated with a yogurt culture. Incubation for 1.5 to 2.0 h is necessary; the product is then cooled to about 90°F, packaged, incubated 2 to 3 h (acidity 0.80 to 0.85%), and chilled to 40°F or below in the package. Varying yogurt cultures and manufacturing procedures should be selected on the basis of consumer preferences. Numerous flavorings are used (fruit is quite common), and sugar is usually added. The flavoring material may be added at the same time as the culture, after incubation, or ahead of packaging. In some dairy plants, a fruit (or sauce) is placed into the package before filling with yogurt.

Refrigeration

The refrigerant of choice for production plants is usually ammonia (R-717). Some small plants may use halocarbon refrigerants; in large plants, halocarbons may be used with a centralized ammonia refrigeration system for special, small applications. The halocarbon refrigerant of choice is currently R-22; however, the Montreal Protocol outlines a phaseout schedule for the use of R-22 and other hydrochlorofluorocarbon (HCFC) refrigerants. Currently, no consensus alternative for R-22 has been identified. Two HFC blends, R-507 and R-404a, are currently favored for refrigeration applications.

Product plants use single-stage compression, and new applications are equipped with rotary screw compressors with microprocessors and automatic control. Older plants may be equipped with reciprocating compressors, but added capacity is generally with rotary screw compressors.

Most refrigerant condensing is accomplished with evaporative condensers. Freeze protection is required in cold climates, and materials of construction are an important consideration in subtropical climates. Water treatment is required.

Evaporators or cooling units for milk storage areas use either direct ammonia (direct-expansion, flooded or liquid overfeed), chilled water, or propylene glycol. In choosing new systems, evaluation should involve capital requirements, operating costs, ammonia charges, and plant safety.

Direct use of ammonia has the potential for the lowest operating cost because the refrigeration system does not have the increased losses associated with exchanging heat with a secondary cooling medium (chilled water or propylene glycol). However, direct use of ammonia requires larger system charges and more ammonia in production areas.

To limit ammonia charges in production areas, many plants use a secondary cooling system that circulates chilled water or propylene glycol where needed. If chilled water is used, it must be supplied at 33 to 34 °F to cool milk products below 40°F. Chilled water is often used in combination with falling-film water chillers and ice-building chillers to cool water so close to its freezing point. Ice-building and falling-film chillers should be compared for each application, considering both initial capital and operating costs. Sizing ice builders to build ice during periods when chilled water is not required allows installation of a refrigeration system with considerably less capacity than is required for the peak cooling load. When chilled water is required, melting ice adds cooling capacity to that supplied by the refrigeration system. Additional information on ice thermal storage is found in Chapter 34 of the 2003 *ASHRAE Handbook—HVAC Applications*. The advantage of this system is a lower ammonia charge compared to the direct use of ammonia.

Other plants use propylene glycol at 28 to 30°F for process cooling requirements. This system cools propylene glycol in a welded-plate or shell-and-tube heat exchanger. The ammonia feed system is either gravity-flooded or liquid-overfeed. Advantages to this system are a reduced ammonia charge compared to direct use of ammonia (especially with a plate heat exchanger) and a lower cooling fluid temperature to achieve lower milk product temperatures. This system may have a higher operating cost, because there is no stored refrigeration, and possibly higher pumping requirements compared to chilled water. Commercially available propylene glycol packages for closed cooling systems include biological growth and corrosion inhibitors. The concentration of propylene glycol necessary in the system should be determined by consulting the glycol manufacturer to ensure adequate freeze protection as well as protection against biological growth and corrosion.

In addition, there are combination systems in which chilled water is used for most of the process requirements and a separate, smaller propylene glycol system is used in final cooling sections to provide lower milk product temperatures.

Other plant refrigeration loads, such as air conditioning of process areas, may be met with the central ammonia refrigeration system. The choice between chilled water and propylene glycol may also depend on the plant winter climate conditions and location of piping serving the loads.

Most new or expanded plants rely on automated operation and computer controls for operating and monitoring the refrigeration systems. There also is a trend to use welded-plate heat exchangers for water and propylene glycol cooling in milk product plants and to reduce or eliminate direct ammonia refrigeration in plant process areas. This approach may add somewhat to the capital and operating costs, but it can substantially reduce the ammonia charge in the system and confines ammonia to the refrigeration machine room area.

BUTTER MANUFACTURE

Much of the butter production is in combination butter-powder plants. These plants get the excess milk production after current market needs are met for milk products, frozen dairy desserts, and, to some extent, cheeses. Consequently, seasonal variation in the volume of butter manufactured is large; spring is the period of highest volume, fall the lowest.

Separation and Pasteurization

After separation, cream with 30 to 40% fat content is either pumped to the pasteurizer or cooled to 45°F and held for later pasteurization. Cream from cold milk separation does not need to be recooled except for extended storage. Cream is received, weighed, sampled, and, in some plants, graded according to flavor and acidity. It is pumped to a refrigerated storage vat and cooled to 45°F if held for a short period or overnight. Cream with developed acidity is warmed to 80 to 90°F, and neutralized to 0.12 to 0.15% titratable acidity just before pasteurization. If acidity is above 0.40%, it is neutralized with a soda-type compound in aqueous solution to about 0.30% and then to the final acidity with aqueous lime solution. Sodium neutralizers include $NaHCO_3$, Na_2CO_3, and NaOH. Limes are $Ca(OH)_2$, MgO, and CaO.

Batch pasteurization is usually at 155 to 175°F for 0.5 h, depending on intended storage temperature and time. HTST continuous pasteurization is at 185 to 250°F for at least 15 s. HTST systems may be plate or tubular. After pasteurization, the cream is immediately cooled. The temperature range is 40 to 55°F, depending on the time that the cream will be held before churning, whether it is ripened, season (higher in winter because of fat composition), and churning method. Ripening consists of adding a flavor-producing lactic starter to tempered cream and holding until acidity has developed to 0.25 to 0.30%. The cream is cooled to prevent further acid development and warmed to the churning temperature just before churning. First, tap water is used to reduce the temperature to between 80 and 100°F. Refrigerated water or brine is then used to reduce the temperature to the desired level. The cream may be cooled by passing the cooling medium through a revolving coil in the vat or through the vat jacket, or by using a plate or tubular cooler. Ripening cream is not common in the United States, but is customary in some European countries such as Denmark.

If the temperature of 1000 lb of cream is to be reduced by refrigerated water from 104 to 39°F, and the specific heat is 0.85 Btu/lb·°F, the heat to be removed is

$$1000(104 - 39)0.85 = 55{,}250 \text{ Btu}$$

This heat can be removed by 55,250/144 = 384 lb of ice at 32°F plus 10% for mechanical loss.

The temperature of refrigerated water commonly used for cooling cream is 33 to 34°F. The ice-builder system is efficient for this purpose. Brine or glycol is not currently used. About 265 gal of cream can be cooled from 100 to 40°F in a vat using refrigerated water in an hour.

After a vat of cream has cooled to the desired temperature, the temperature increases during the following 3 h because heat is liberated when fat changes from liquid to a crystal form. It may increase several degrees, depending on the rapidity with which the cream was cooled, the temperature to which it was cooled, the richness of the cream, and the properties of the fat.

Rishoi (1951) presented data in Figure 2 that show the thermal behavior of cream heated to 167°F followed by rapid cooling to 86°F and to 50.7°F, as compared with cream heated to 122°F and cooled rapidly to 88.5°F and to 53.6°F. The curves indicate that when cream is cooled to a temperature at which the fat remains liquid, the cooling rate is normal, but when the cream is cooled to a temperature at which some fractions of the fat have crystallized, a spontaneous temperature rise takes place after cooling.

Rishoi also determined the amount of heat liberated by the part of the milkfat that crystallizes in the temperature range of 85 to 33°F. The results are shown in Figure 3 and Table 2.

Table 2 shows that, at a temperature below 50°F, about one-half of the liberated heat evolved in less than 15 s. The heat liberated during fat crystallization constitutes a considerable portion of the refrigeration load required to cool fat-rich cream. Rishoi states,

> If we assume an operation of cooling cream containing 40% fat from about 150 to 40°F, heat of crystallization evolved represents about 14% of the total heat to be removed. In plastic cream containing 80% fat it represents about 30% and in pure milkfat oil about 40%.

Churning

To maintain the yellow color of butter from cream that came from cows on green pasture in spring and early summer, yellow coloring can be added to the cream to match the color obtained naturally during other periods of the year. After cooling, pasteurized cream should be held a minimum of 2 h and preferably overnight. It is tempered to the desired batch churning temperature, which varies with the season and feed of the cows but ranges from 45°F in early summer to 56°F in winter, to maintain a churning time 0.5 to 0.75 h. Lower churning time results in soft butter that is more difficult (or impossible) to work into a uniform composition.

Most butter is churned by continuous churns, but some batch units remain in use, especially in smaller butter factories. Batch churns are usually made of stainless steel, although a few aluminum ones are still in use. They are cylinder, cube, cone, or double cone in shape. The inside surface of metal churns is sandblasted during fabrication to reduce or prevent butter from sticking to the surface.

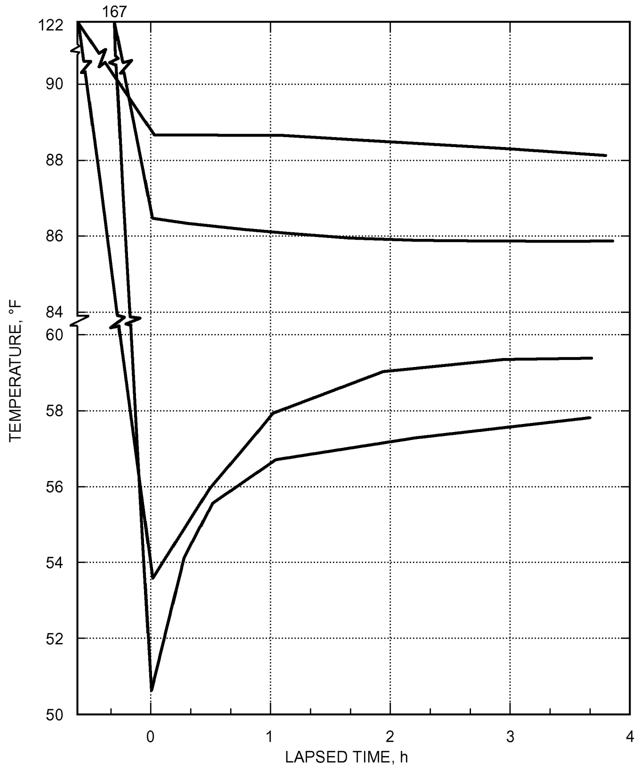

Fig. 2 Thermal Behavior of Cream Heated to 167°F Followed by Rapid Cooling to 86°F and to 50.7°F; Comparison with Cream Heated to 122°F, then Rapid Cooling to 88.5°F and to 53.6°F

Table 2 Heat Liberated from Fat in Cream Cooled Rapidly from about 86°F to Various Temperatures

Calculated temperature for zero time, °F:	33.4	39.6	53.1	58.0	63.4	80.4	85.6*
First observed temperature:	36.2	43.7	54.5	58.6	63.8	80.4	85.6
Final equilibrium temperature:	39.3	46.1	58.0	60.7	65.3	82.6	85.6
Lapsed time, min	**Btu Liberated per Pound**						
0.25	18.3	16.7	7.75	2.9	2.3	0	0
15	23.6	20.0	12.8	7.2	5.2	0.35	0
30	25.5	23.9	18.0	12.2	9.0	2.1	0
60	30.4	27.5	21.4	14.0	10.2	2.7	0
120	32.4	29.3	25.0	14.7	10.6	2.9	0
180	32.9	30.2	26.6	16.0	10.6	4.3	0
240	34.0	30.9	27.2	17.5	10.6	4.9	
300	33.6	31.8	27.9	18.4		5.0	
360	33.6	32.5	27.2	18.8		5.0	

Percent heat liberated at zero time compared with that at equilibrium: 54.5, 51.3, 27.7, 20.7, 21.7.

Percent total heat liberated compared with that liberated at about 32°F: 100.0, 95.7, 82.0, 55.0, 31.0, 12.5, 0.

Iodine values of three samples of butter produced while these tests were in progress were 28.00, 28.55, and 28.24.

*Cooled in an ice-water bath.

Metal churns may have accessories to draw a partial vacuum or introduce an inert gas (e.g., nitrogen) under pressure. Working under a partial vacuum reduces air in the butter. Churns have two or more speeds, with the faster rate for churning. The higher speed should provide maximum agitation of the cream, usually between 0.25 to 0.5 rev/s.

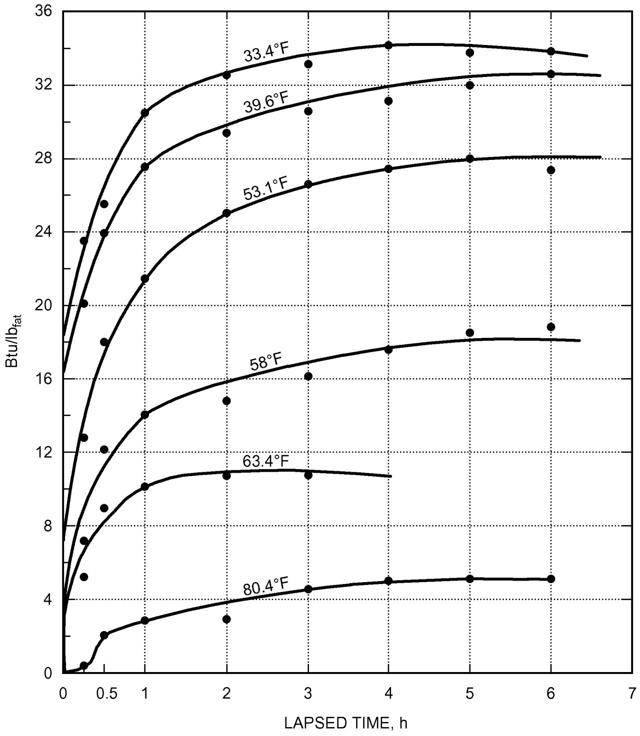

Fig. 3 Heat Liberated from Fat in Cream Cooled Rapidly from Approximately 86°F to Various Temperatures

(Rishoi 1951)

When churning, temperature is adjusted and the churn is filled to 40 to 48% of capacity. The churn is revolved until the granules break out and attain a diameter of 5 mm or slightly larger. The buttermilk, which should have no more than 1% milkfat, is drained. The butter may or may not be washed. The purpose of washing is to remove buttermilk and temper the butter granules if they are too soft for adequate working. Wash water temperature is adjusted to 0 to 10°F below churning temperature. The preferred procedure is to spray wash water over granules until it appears clear from the churn drain vent. The vent is then closed, and water is added to the churn until the volume of butter and water is approximately equal to the former amount of the cream. The churn revolves slowly 12 to 15 times and drained or held for an additional 5 to 15 min for tempering so granules will work into a mass of butter without becoming greasy.

The butter is worked at a slow speed until free moisture is no longer extruded. Free water is drained, and the butter is analyzed for moisture content. The amount of water needed to obtain the desired content (usually 16.0 to 18.0%) is calculated and added. Salt may be added to the butter. The salt content is standardized between 1.0 and 2.5% according to customer demand.

Dry salt may be added either to a trench formed in the butter or spread over the top of the butter. It also may be added in moistened form, using the water required for standardizing the composition to not less than 80.0% fat. Working continues until the granules are completely compacted and the salt and moisture droplets are uniformly incorporated. Moisture droplets should become invisible to normal vision with adequate working. Most churns have ribs or vanes, which tumble and fold the butter as the churn revolves. The butter passes between the narrow slit of shelves attached to the shell and the roll. A leaky butter is inadequately worked, possibly leading to economic losses because of weight reduction and shorter keeping quality. The average composition of U.S. butter on the market has these ranges:

Fat	80.0 to 81.2%	Moisture	16.0 to 18.0%
Salt	1.0 to 2.5%	Curd, etc.	0.5 to 1.5%

Cultured skim milk is added to unsalted butter as part of the moisture and thoroughly mixed in during working. On rare occasions, cultured skim milk may be used to increase acid flavor and the diacetyl content associated with butter flavor.

Butter may be removed manually from small churns, but it is usually emptied mechanically. One method is to dump butter from the churn directly into a stainless steel boat on casters or a tray that has been pushed under the churn with the door removed. Butter in boats may be augered to the hopper for printing (forming the butter into retail sizes) or pumping into cartons 60 to 68 lb in size. The bulk cartons are held cold before printing or shipment. Butter may be stored in the boats or trays and tempered until printing. A hydraulic lift may be used for hoisting the trays and dumping the butter into the hopper. Cone-shaped churns with a special pump can be emptied by pumping butter from churn to hopper.

Continuous Churning

The basic steps in two of the continuous buttermaking processes developed in the United States are as follows:

1. Fat emulsion in the cream is destabilized and the serum separated from the milkfat.
2. The butter mix is prepared by thoroughly blending the correct amount of milkfat, water, salt, and cultured skim milk (if necessary).
3. This mixture is worked and chilled at the same time.
4. Butter is extruded at 38 to 50°F with a smooth body and texture.

Some European continuous churns consist of a single machine that directly converts cream to butter granules, drains off the buttermilk, and washes and works the butter, incorporating the salt in continuous flow. Each brand of continuous churn may vary in equipment design and specific operation details for obtaining the optimum composition and quality control of the finished product. Figure 4 shows a flow diagram of a continuous churn.

In one such system, milk is heated to 110°F and separated to cream with 35 to 50% fat and skim milk. The cream is pasteurized at 203°F for 16 s, cooled to a churning temperature of 46 to 55°F, and held for 6 h. It then enters the balance tank and is pumped to the churning cylinder, where it is converted to granules and serum in less than 2 s by vigorous agitation. Buttermilk is drained off and the granules are sprayed with tempered wash water while being agitated.

Next, salt, in the form of 50% brine prepared from microcrystalline sodium chloride, is fed into the product cylinder by a proportioning pump. If needed, yellow coloring may be added to the brine. High-speed agitators work the salt and moisture into the butter in the texturizer section and then extrude it to the hopper for packaging into bulk cartons or retail packages. The cylinders on some designs have a cooling system to maintain the desired temperature of the butter from churning to extrusion. The butterfat content is adjusted by fat test of the cream, churning temperature of the cream, and flow rate of product.

Continuous churns are designed for CIP. The system may be automated or the cream tank may be used to prepare the detergent solution before circulation through the churn after the initial rinsing.

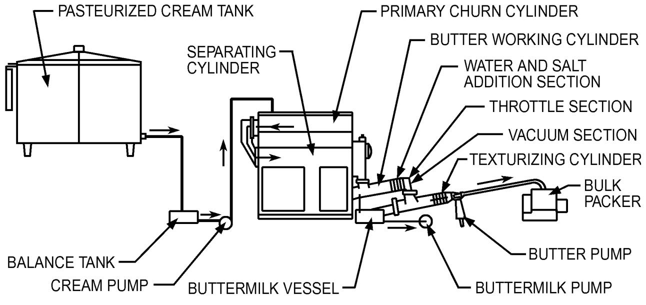

Fig. 4 Flow Diagram of Continuous Butter Manufacture

Packaging Butter

Printing is the process of forming (or cutting) butter into retail sizes. Each print is then wrapped with parchment or parchment-coated foil. The wrapped prints may be inserted in paperboard cartons or overwrapped in cellophane, glassine, and so forth, and heat-sealed. For institutional uses, butter may be extruded into slabs. These are cut into patties, embossed, and each slab of patties wrapped in parchment paper. Most common numbers of patties are 48 to 72 per lb.

Butter keeps better if stored in bulk. If the butter is intended to be stored for several months, the temperature should not be above 0°F, and preferably below –20°F. For short periods, 32 to 40°F is satisfactory for bulk or printed butter. Butter should be well protected to prevent absorption of off-odors during storage and weight loss from evaporation, and to minimize surface oxidation of fat.

The specific heat of butter and other dairy products at temperatures varying from 32 to 140°F is given in Table 3. The butter temperature when removed from the churn ranges from 56 to 62°F. Assuming a temperature of 60°F of packed butter, the heat that must be removed from 1000 lb to reduce the temperature to 32°F is

$$1000(60 - 32)0.52 = 14{,}560 \text{ Btu}$$

It is assumed that the average specific heat at the given range of temperatures is 0.52 Btu/lb·°F. Heat to be removed from butter containers and packaging material should be added.

Deterioration of Butter in Storage

Undesirable flavor in butter may develop during storage because of (1) growth of microorganisms (proteolytic organisms causing putrid and bitter off-flavors); (2) absorption of odors from the atmosphere; (3) fat oxidation; (4) catalytic action by metallic salts; (5) activity of enzymes, principally from microorganisms; and (6) low pH (high acid) of salted butter.

Normally, microorganisms do not grow below 32°F; if salt-tolerant bacteria are present, their growth will be slow below 32°F. Microorganisms do not grow at 0°F or below, but some may survive in butter held at this temperature. It is important to store butter in a room free of atmospheric odors. Butter readily absorbs odors from the atmosphere or from odoriferous materials with which it comes into contact.

Oxidation causes a stale, tallowy flavor. Chemical changes take place slowly in butter held in cold storage, but are hastened by the presence of metals or metallic oxides.

Table 3 Specific Heats of Milk and Milk Derivatives, Btu/lb·°F

	32°F	59°F	104°F	140°F
Whey	0.978	0.976	0.974	0.972
Skim milk	0.940	0.943	0.952	0.963
Whole milk	0.920	0.938	0.930	0.918
15% cream	0.750	0.923	0.899	0.900
20% cream	0.723	0.940	0.880	0.886
30% cream	0.673	0.983	0.852	0.860
45% cream	0.606	1.016	0.787	0.793
60% cream	0.560	1.053	0.721	0.737
Butter	(0.512)*	(0.527)*	0.556	0.580
Milkfat	(0.445)*	(0.467)*	0.500	0.530

*For butter and milkfat, values in parentheses were obtained by extrapolation, assuming that the specific heat is about the same in the solid and liquid states.

With almost 100% replacement of tinned copper equipment with stainless steel equipment, a tallowy flavor is not as common as in the past. Factors that favor oxidation are light, high acid, high pH, and metal.

Enzymes present in raw cream are inactivated by current pasteurization temperatures and holding times. The only enzymes that may cause butter deterioration are those produced by microorganisms that gain entrance to the pasteurized cream and butter or survive pasteurization. The chemical changes caused by enzymes present in butter are retarded by lowering the storage temperature.

A fishy flavor may develop in salted butter during cold storage. Development of the defect is favored by high acidity (low pH) of the cream at the time of churning and by metallic salts. With the use of stainless steel equipment and proper control of the butter's pH, this defect now occurs very rarely. For salted butter to be stored for several months, even at –10°F, it is advisable to use good-quality cream; avoid exposing the milk or cream to strong light, copper, or iron; and adjust any acidity developed in the cream so that the butter serum has a pH of 6.8 to 7.0.

Total Refrigeration Load

Some dairy plants that manufacture butter also process and manufacture other products such as ice cream, fluid milk, and cottage cheese. A single central refrigeration system is used to provide refrigeration to all of these loads. The method of determining the refrigeration load is illustrated by the following example.

Example 1. Determine the product refrigeration load for a plant manufacturing butter from 12,600 lb of 30% cream per day in three churnings.

Solution: Assume that refrigeration is accomplished with chilled water from an ice builder. See Figure 5 for a workflow diagram.

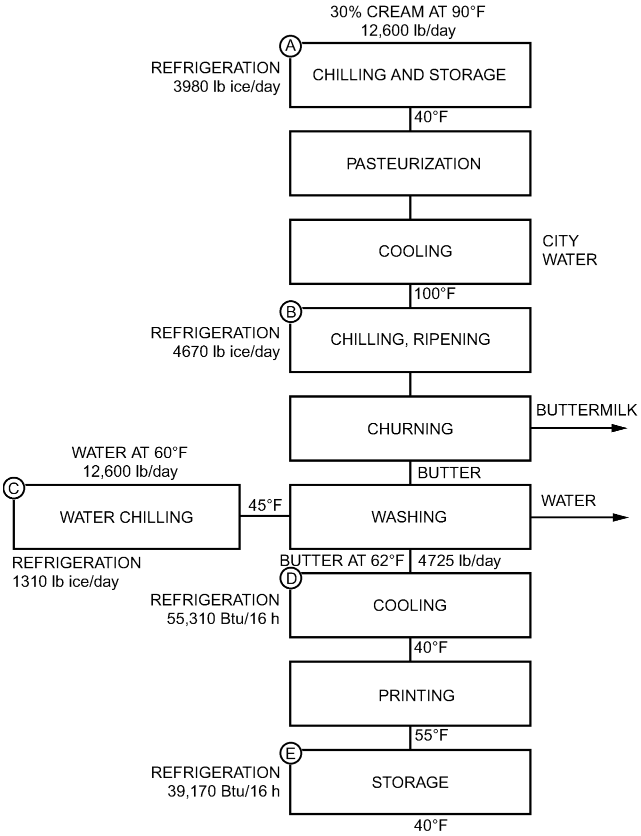

Fig. 5 Butter Flow Diagram

The cream is cooled in steps A and B. The butter is then cooled through steps C, D, and E. Refrigerated water is normally used as a cooling medium in steps A, B, and C. The ice builder system is used to produce 34°F water, and the load should be expressed in pounds of ice that must be melted to handle steps A, B, and C. This load is added to the refrigerated water load from the various other products such as milk, cottage cheese, and so forth, in sizing the ice builder.

A. If cream is separated in the plant rather than on the farm, it must be cooled from 90°F separating temperature to 40°F for holding until it is processed.

$$\frac{12{,}600(90-40)0.91}{144} = 3980\ \mathrm{lb_{ice}/day}$$

B. After pasteurization, the temperature of the cream is reduced to approximately 100°F with city water, then down to 40°F with refrigeration.

$$\frac{12{,}600(100-40)0.89}{144} = 4670\ \mathrm{lb_{ice}/day}$$

C. After churning, the 60°F butter wash water (city water) is usually cooled to 45°F, then used to wash the butter granules. A mass of water equal to the mass of cream churned may be used.

$$\frac{12{,}600(60-45)1.00}{144} = 1310\ \mathrm{lb_{ice}/day}$$

$$\begin{array}{rr} \text{Total ice load} & 9960\ \mathrm{lb_{ice}/day} \\ \text{Plus 10\% mechanical loss} & 1000\ \mathrm{lb_{ice}/day} \\ \hline \text{Total ice required} & 10{,}960\ \mathrm{lb_{ice}/day} \end{array}$$

D. Approximately 4725 lb of butter is obtained. (12,600 lb cream × 30% fat = 3780 lb of fat. If butter contains approximately 80% fat, 3780 lb divided by 80% equals approximately 4725 lb of butter.) The butter temperature going into the refrigerated storage room is usually about 62°F and must be cooled to 40°F in the following 16 h. (For long-term storage, butter is held at –10 to 0°F.) The average specific heat for butter over this range is 0.52 Btu/lb·°F.

$$\begin{array}{rcr} 4725(62-40)0.52 & = & 54{,}050\ \text{Btu} \\ \text{300 lb (metal container)} & & \\ \times(75-40)0.12 & = & 1{,}260\ \text{Btu} \\ \cline{3-3} \text{Total/24 h} & & 55{,}310\ \text{Btu} \end{array}$$

E. After 24 h or longer, the butter is removed from the cooler to be cut and wrapped in 1 lb or smaller units. During this process, the butter temperature rises to approximately 55°F, which constitutes another product load in the cooler when it goes back for storage.

$$\begin{array}{rcr} 4725(55-40)0.52 & = & 36{,}860\ \text{Btu} \\ \text{200 lb (paper container)} & & \\ \times(75-40)0.33 & = & 2{,}310\ \text{Btu} \\ \cline{3-3} \text{Total/24 h} & & 39{,}170\ \text{Btu} \end{array}$$

Total of Steps D and E, Product Load in Cooler:

$$\frac{39{,}170+55{,}310}{16\ \text{h}} = 5910\ \text{Btu/h}$$

Whipped Butter

To whip butter by the batch method, the butter is tempered to 62 to 70°F, depending on factors such as the season and type of whipper. The butter is cut into slabs for placing into the whipping bowl. The whipping mechanism is activated, and air is incorporated until the desired overrun (volume increase) is obtained, usually between 50 and 100%. Whipped butter is packaged mechanically or manually into semirigid plastic containers.

With one continuous system, butter directly from cooler storage is cut into pieces and augered until soft. However, it can be tempered and the augering step omitted. The butter is then pumped into a cylindrical continuous whipper that uses the same principles as those for incorporating air in ice cream. Air or nitrogen is incorporated until the desired overrun is obtained. Another continuous method (used less commercially) is to melt butter or standardize butter oil to the composition of butter with moisture and salt. The fluid product is pumped through a chiller/whipper. Metered air or nitrogen provides overrun control. Soft whipped butter is pumped to the hopper of the filler and packaged in rigid or semirigid containers, such as plastic. It is chilled and held in storage at 32 to 40°F.

CHEESE MANUFACTURE

Approximately 800 cheeses have been named, but there are only 18 distinctly different types. A few of the more popular types in the United States are cheddar, cottage, roquefort or blue, cream, ricotta, mozzarella, Swiss, edam, and provolone. Such details of manufacture as setting (starter organisms, enzyme, milk or milk product, temperature, and time), cutting, heating (cooking), stirring, draining, pressing, salting, and curing (including temperature and humidity control) are varied to produce a characteristic variety and its optimum quality.

Production of cheddar cheese in the United States currently exceeds the other cured varieties; however, mozzarella production is a close second and is gaining fast. For uncured cheese varieties, cottage cheese production is much greater than that of the others. Another trend in the cheese industry is large factories. These plants may have sufficient curing facilities for the total production. If not, the cheese is shipped to central curing plants.

The physical shape of cured cheese varies considerably. Barrel cheese is common; it is cured in a metal barrel or similar impervious container in units of approximately 500 lb. Cheese may also be cured in rectangular metal containers holding 2000 lb.

The microbiological flora of cured cheese are important in the development of flavor and body. Heating the milk for cheese is the general practice. The milk may be pasteurized at the minimum HTST conditions or be given a subpasteurization treatment that results in a positive phosphatase test, which checks for inactivated enzymes indicating the presence of raw milk. Subpasteurization is possible with good-quality milk (low level of spoilage microorganisms and pathogens). Such milk treatments give the cheese some characteristics of raw-milk cheese in curing, such as production of higher flavors, in a shorter time. Pasteurization to produce phosphatase-negative milk is used in making soft, unripened varieties of cheese and some of the more perishable of the ripened types such as camembert, limburger, and munster.

The standards and definitions of the Food and Drug Administration (FDA) and of most state regulatory agencies require that cheese that is not pasteurized must be cured for not less than 60 days at not less than 35°F. Raw-milk cheese contains not only lactic-acid-producing organisms such as *Lactococcus lactis*, which are added to the milk during cheesemaking, but also the heterogeneous mixture of microorganisms present in the raw milk, many of which may produce gas and off-flavors in the cheese. Pasteurization gives some control over the bacterial flora of the cheese.

Freshly manufactured cured cheese is rubbery in texture and has little flavor; perhaps the more characteristic flavor is slightly acid. The presence of definite flavor(s) in freshly made cheese indicates poor quality, probably resulting from off-flavored milk. On curing under proper conditions, however, the body of the cheese breaks down, and the nut-like, full-bodied flavor characteristic of aged cheese develops. These changes are accompanied by certain chemical and physical changes during curing. The calcium paracaseinate of cheese gradually changes into proteoses, amino acids, and ammonia. These changes are a part of ripening and may be controlled by time and temperature of storage. As cheese cures, varying degrees of lipolytic activity also occur. In the case of blue or roquefort cheese, this partial fat breakdown contributes substantially to the characteristic flavor.

During curing, microbiological development produces changes according to the species and strains present. It is possible to predict from the microorganism data some of the usual defects in cheddar. In some cheeses (e.g., Swiss), gas production accompanies the desirable flavor development.

Cheese quality is evaluated on the basis of a scorecard. Flavor and odor, body and texture, and color and finish are principal factors. They are influenced by milk quality, the skill of manufacturing (including starter preparation), and the control effectiveness of maintaining optimum curing conditions.

Cheddar Cheese

Manufacture. Raw or pasteurized whole milk is tempered to 86 to 88°F and pumped to a cheese vat, which typically holds approximately 40,000 lb of milk. It is set by adding 0.75 to 1.25% active cheese starter and possibly annatto yellow color, depending on market demand. After 15 to 30 min, when the milk has reached the proper acidity (0.05 to 0.1%), 99 mL of single-strength rennet per 1000 lb milk is diluted in water 1:40 and slowly added with agitation of milk in the vat. After a quiescent period of 25 to 30 min, the curd should have developed proper firmness. The curd is cut into 0.25 to 0.40 in. cubes. After 15 to 30 min of gentle agitation, cooking is begun by heating water in the vat jacket using steam or hot water for 30 to 40 min. The curd and whey should increase 2°F per 5 min, and a temperature of 100 to 102°F is maintained for approximately 45 min.

In batch systems, the whey is drained and curd is trenched along both sides of the vat, allowing a narrow area free of curd the length of the midsection of the vat. Slabs about 10 in. long are cut and inverted at 15 min periods during the cheddaring process (matting together of curd pieces). When acidity of the small whey drainage is at a pH of 5.3 to 5.2, the slabs are milled (cut into small pieces) and returned to the vat for salting and stirring, or the curd goes to a machine that automatically adds salt and uniformly incorporates it into the curd. Weighed curd goes into hoops, which are placed into a press, and 20 psi is applied. After 0.5 to 1 h, the hoops are taken out of the press, the bandage adjusted to remove wrinkles, and then the cheese is pressed overnight at 25 to 30 psi or higher. Cheese may be subjected to a vacuum treatment to improve body by reducing or eliminating air pockets. After the surface is dried, the cheese is coated by dipping into melted paraffin or wrapped with one of several plastic films, or oil with a plastic film, and sealed. Yield is about 10 lb per 100 lb of milk.

Faster and more mechanized methods of making cheddar cheese have evolved. The stirred curd method (which omits the cheddaring step) is being used by more cheesemakers. Deep circular or oblong cheese vats with special, reversible agitators and means for cutting the curd are becoming popular. Curd is pumped from these vats to draining and matting tables with sloped bottoms and low sides, then milled, salted, and hooped. In one method, curd (except for Odenburg cheddar) is carried and drained by a draining/matting conveyor with a porous plastic belt to a second belt for cheddaring and transport to the mill. The milled curd is then carried to a finishing table or conveyor, where it is salted, stirred, and moved out for hooping or to block formers.

Another system, imported from Australia, is used in a number of cheddar cheese factories. This system requires a short method of setting. After the curd is cut and cooked, it is transferred to a series of perforated stainless steel troughs traveling on a conveyor for draining and partial fusion. The slabs are then transferred into buckets of a forming conveyor, transferred again to transfer buckets, and finally to compression buckets where cheddaring takes place. Cheddared slabs are discharged to a slatted conveyor, which carries them to the mill and then to a final machine where the milled curd is salted, weighed, and hooped.

Curing. Curing temperature and time vary widely among cheddar plants. A temperature of 50°F cures the cheddar more rapidly than lower temperatures. The higher the temperature above 50°F to about 80°F, the more rapid the curing and the more likely that off-flavors will develop. At 50°F, 3 to 4 months are required for a mild to medium cheddar flavor. Six months or more are necessary for an aged (sharp) cheddar cheese. Relative humidity should be roughly 70%. Cheddar intended for processed cheese is cured in many plants at 70°F because of the economy of time. Some experts suggest that cheddar, after its coating or wrapping, should be held in cold storage at approximately 40°F for about 30 days, then transferred to the 50°F curing room. During cold storage, the curd particles knit together, forming a close-bodied cheese. The small amount of residual lactose is slowly converted to lactic acid, along with other changes in optimum curing.

The maximum legal moisture content of cheddar is 39% and the fat must be not less than 50% of total solids. The amount of moisture directly affects the curing rate to some extent within the normal range of 34 to 39%. Cheese with loose or crumbly body and a high acidity is less likely to cure properly. For best curing, the cheese should have a sodium chloride content of 1.5 to 2.0%. A lower percentage encourages off-flavors to develop, and higher amounts retard flavor development.

Moisture Losses. Weight loss of cheese during curing is largely attributed to moisture loss. Paraffined cheddar cheese going into cure averages approximately 37% moisture. After a 12-month cure at 40°F, paraffined cheese averages approximately 33% moisture. This is a real loss to the cheese manufacturer unless the cheese is sold on the basis of total solids. Control of humidity can have an important role in moisture loss. Figure 6 shows the loss from paraffined longhorns in boxes held at 38°F and 70% rh over 12 months. The conditions were well controlled, but the average loss was 7%. The high loss shown on the graph was influenced by the larger surface area in 12 lb longhorns, compared to 70 lb cheddars. Curing the cheese within a good-quality sealed wrapper having a low moisture transmission (but some oxygen and carbon dioxide) largely eliminates moisture loss.

Provolone and Mozzarella (Pasta Filata Types)

Provolone is an Italian plastic-curd cheese representative of a large group of pasta filata cheeses. These cheeses vary widely in size and composition, but they are all manufactured by a similar method. After the curd has been matted, like cheddar, it is cut into slabs, which are worked and stretched in hot water at 150 to 180°F. The curd is kneaded and stretched in the hot water until it reaches a temperature of about 135°F. The maker then takes the amount necessary for one cheese and folds, rolls, and kneads it by hand to give the cheese its characteristic shape and smooth, closed surface. Molding machines have been developed for large-scale operations to eliminate this hand labor. The warm curd of some varieties of pasta filata is placed in molds and submerged in or sprayed with 36°F cold water to harden into the desired shape. The hardened cheese is then salted in batch or continuous brine tanks for final cooling and salting, depending on the size and variety. Some pasta filata cheese, such as mozzarella for pizza, is packaged for shipment with wrappers to protect it for the period it is held before use. This cheese may be sealed under vacuum in plastic bags for prolonged holding.

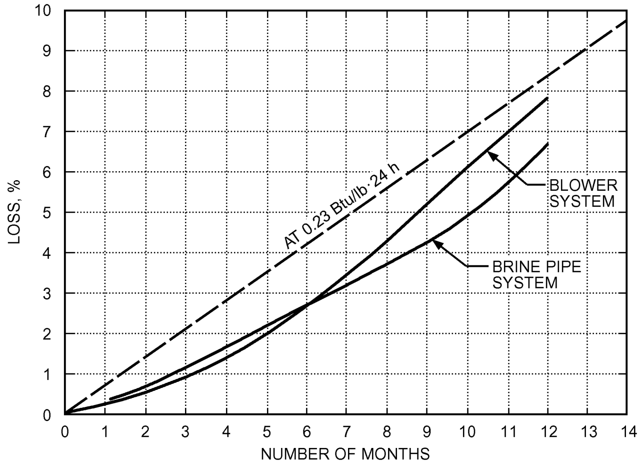

Fig. 6 Cheese Shrinkage in Storage

Provolone is salted by submersion in 24% sodium chloride solution at 45°F for 1 to 3 days, depending on the size, and then hung to dry. If a smoked flavor is desired, it is then transferred to the smokehouse and exposed to hickory or other hardwood smoke for 1 to 3 days. The cheese is hung in a curing room for 3 weeks at 55°F and then for 2 to 10 months at 40°F. Size and shape vary, but the most common in the United States is 14 lb and pear-shaped. Moisture content ranges from 37 to 45% and the salt from 2 to 4%. Milkfat usually comprises 46 to 47% of the total solids. The yield is roughly 9.5 lb per 100 lb of milk.

Swiss Cheese

One of the distinguishing characteristics of Swiss cheese is the eye formation during curing. These eyes result from the development of CO_2. Raw or heat-treated milk is tempered to 95°F and pumped to a large kettle or vat. One starter unit, consisting of 27 mL of *Propioni bacterium shermanii*, 165 mL of *Lactococcus thermophilus*, and 165 mL of *Lactobacillus bulgaricus*, is added per 1100 lb of milk. After mixing, 77 mL of rennet per 1100 lb is diluted 1:40 with water and slowly added with agitation of the milk. Curd is cut when firm (after 25 to 30 min) into very small granules. After 5 min, curd and whey are agitated for 40 min, and then the steam is released into the jacket without water. Curd is heated slowly to 122 to 130°F in 30 to 45 min. Without additional steam, the cooking is continued until curd is firm and has no tendency to stick when a group of particles is squeezed together (0.5 to 1 h and whey pH 6.3). Curd is dipped into hoops (160 lb) and pressed lightly for 6 h, redressing and turning the hoops every 2 h. Pressing is continued overnight. The next step is soaking the cheese in brine until it has about 1.5% salt. Table 4 shows temperature and time at which curing occurs. The minimum milkfat content is 43% by weight of solids and the maximum moisture content is 41% by weight (21CFR133).

Roquefort and Blue Cheese

Roquefort and blue cheese require a mold (*Penicillium roquefortii*) to develop the typical flavor. Roquefort is made from ewes' milk in France. Blue cheese in the United States is made from cow's milk. The equipment used for the manufacture and curing of blue cheese is the same as that used for cheddar, with a few exceptions. The hoops are 7.5 in. in diameter and 6 in. high. They have no top or bottom covers and are thoroughly perforated with small holes. A manually or pneumatically operated device with 50 needles, which are 6 in. long and 0.125 in. in diameter, is used to punch holes in the curd wheels. An apparatus is also needed to feed moisture into the curing room to maintain at least 95% rh without causing a drip onto the cheese.

Table 4 Swiss Cheese Manufacturing Conditions

Processing Step	Temperature, °F	Relative Humidity, %	Time
Setting	95	—	0.4 to 0.5 h
Cooking	122 to 130	—	1.0 to 1.5 h
Pressing	80 to 85	—	12 to 15 h
Salting (brine)	50 to 52	—	2 to 3 days
Cool room hold	50 to 60	90	10 to 14 days
Warm room hold	70 to 75	80 to 85	3 to 6 weeks
Cool room hold	40 to 45	80 to 85	4 to 10 mos

The milk may be raw or pasteurized and separated. The cream is bleached and may be homogenized at low pressure. Skim milk is added to the cream, and the milk is set with 2 to 3% active lactic starter. After 30 min, 3 to 4 oz of rennet per 1100 lb is diluted with water (1:35) and thoroughly mixed into the milk. When the curd is firm (after 30 min), it is cut into 5/8 in. cubes. Agitation begins 5 min later. After whey acidity is 0.14% (1 h), the temperature is raised to 92°F and held for 20 min. The whey is drained and trenched. Approximately 2 lb of coarse salt and 1 oz of *P. roquefortii* powder are mixed into each 100 lb of curd.

The curd is transferred to stainless steel perforated cylinders (hoops). These hoops are inverted each 15 min for 2 h on a drain cloth, and curd matting continues overnight. The hoops are removed and surfaces of the wheels covered with salt. The cheese is placed in a controlled room at 60°F and 85% rh and resalted daily for 4 more days (5 days total). Small holes are punched through the wheels of cheese from top to bottom of the flat surfaces to provide oxygen for mold growth. The cheese is placed in racks on its curved edge in the curing room and held at 50 to 55°F and not less than 95% humidity. At the end of the month, the cheese surfaces are cleaned; the cheese is wrapped in foil and placed in a 36 to 40°F cold room for 2 to 4 months (Table 5). The surfaces are again scraped clean, and the wheels are wrapped in new foil for distribution.

Originally, roquefort and blue cheese were cured in caves with high humidity and constant cool temperature. Refrigerating insulated blue cheese curing rooms to the optimum temperature is not difficult. However, maintaining a uniform relative humidity of not less than 95% without excessive expense seems to be an engineering challenge, at least in some plants.

Cottage Cheese

Cottage cheese is made from skim milk. It is a soft, unripened curd and generally has a cream dressing added to it. There are small and large curd types, and may have added fruits or vegetables. Plant equipment may consist of receiving apparatus, storage tanks, clarifier/separator, pasteurizer, cheese vats with mechanical agitation, curd pumps, drain drum, blender, filler, conveyors, and accessory items such as refrigerated trucks, laboratory testing facilities, and whey disposal equipment. The largest vats have a 45,000 lb capacity. The basic steps are separation, pasteurization, setting, cutting, cooking, draining and washing, creaming, packaging, and distribution.

Skim milk is pasteurized at the minimum temperature and time of 161°F for 15 s to avoid adversely affecting curd properties. If heat treatment is substantially higher, the manufacturing procedure must be altered to obtain good body and texture quality and reduce curd loss in the whey. Skim milk is cooled to the setting temperature, which is 86 to 90°F for the short set (5 to 6 h) and 70 to 72°F for the overnight set (12 to 15 h). A medium set is used in a few plants. For the short set, 5 to 8% of a good cultured skim milk (starter) and 1 to 1.5 mL of rennet diluted in water are added per 1000 lb of skim milk. For the long set, 0.25 to 1% starter and 0.5 to 1 mL of diluted rennet per 1000 lb are thoroughly mixed into the skim milk. The use of rennet is optional.The setting temperature is maintained until the curd is ready to cut. The whey acidity at cutting time depends on the total solids content of the skim milk (0.55% for 8.7% and 0.62% for 10.5%). The pH is typically 4.80, but it may be necessary to adjust for specific make procedures.

The curd is cut into 0.5 in. cubes for large curd and 0.25 in. for small curd cottage cheese. After the cut curd sets for 10 to 15 min, heat is applied to water in the vat jacket to maintain a temperature rise in the curd and whey of 2°F each 5 min. In very large vats, jacket heating is not practical, and superheated culinary steam in small jet streams is used directly in the vat; 20 to 30 min after cutting, very gentle agitation is applied. Heating rate may be increased to 3 or 4°F per 5 min as the curd firms enough to resist shattering. Cooking is completed when the cubes contain no whey pockets and have the desired firmness. The final temperature of curd and whey is usually 120 to 130°F, but some cheesemakers heat to 145°F when making the small curd.

After cooking, the hot water in both the jacket and the whey is drained. Wash water temperature is adjusted to about 70°F for the first washing and added gently to the vat to reduce curd temperature to 80 to 85°F. After gentle stirring and a brief hold, the water/whey mixture is drained. The temperature of the second wash is adjusted to reduce the curd temperature to 50 to 55°F, and to 40°F with a third wash. Water for the last wash may have 3 to 5 ppm of added chlorine. The curd is trenched for adequate drainage. The dressing is made from lowfat cream, salt, and usually 0.1 to 0.4% stabilizer based on cream weight. Salt averages 1%, and milkfat must be 4% or more in creamed cottage cheese or 2% in lowfat cottage cheese. The dressing is cooled to 40°F and blended into the curd.

A cheese vat can be reused sooner if the cheese pumps quickly convey curd and whey after cooking to a special tank for whey drainage, washing, and blending of dressing and curd. Creamed cottage cheese is transferred mechanically to an automatic packaging machine. One type of filler uses an oscillating cylinder that holds a specific volume. Another type has a piston in a cylinder that discharges a definite volume. Common retail containers are 32, 16, 12, and 8 oz sizes of semirigid plastic. Cottage cheese is perishable and must be stored at 40°F or lower to prolong the keeping quality to 2 or 3 weeks. A good yield is 15.5 lb of curd per 100 lb of skim milk with 9% total solids.

Other Cheeses

Table 6 presents data on a few additional common varieties of cheese in the United States. Except for soft ripened cheeses such as camembert and liederkranz, freezing cheese results in undesirable texture changes. This can be serious, as in the case of cream cheese, where a mealy, pebbly texture results. Other types, such as brick and limburger, undergo a slight roughening of texture, which is undesirable but which still might be acceptable to certain consumers. As a general rule, cheese should not be subjected to temperatures below 29°F.

When cured cheese is held above the melting point of milkfat, it becomes greasy because of oiling off. The oiling-off point of all types of cheese except processed cheese begins at 68 to 70°F. Consequently, storage should be substantially below the melting point (Table 7). Uncured cheese (i.e., cottage, cream) is highly perishable and thus should not be stored above 45°F and preferably at 35°F.

Table 5 Typical Blue Cheese Manufacturing Conditions

Processing Step	Temperature, °F	Relative Humidity, %	Time
Setting	85 to 86	—	1 h
Acid development	85 to 86	—	1 h
(after cutting)	92	—	120 s
Curd matting	70 to 75	80 to 90	18 to 24 h
Dry salting	60	85	5 days
Curing	50 to 55	>95	30 days
Additional curing	36 to 40	80	60 to 120 days

Table 6 Curing Temperature, Humidity, and Time of Some Cheese Varieties

Variety	Curing Temperature, °F	Relative Humidity, %	Curing Time
Brick	50 to 65	90	60 days
Romano	50 to 60	85	5 to 12 mos
Mozzarella	70	85	24 to 72 h
Edam	50 to 60	85	3 to 4 mos
Parmesan	55 to 60	85 to 90	14 mos
Limburger	50 to 60	90	2 to 3 mos

Table 7 Temperature Range of Storage for Common Types of Cheese

Cheese	Ideal Temperature, °F	Maximum Temperature, °F
Brick	30 to 34	50
Camembert	30 to 34	50
Cheddar	30 to 34	60
Cottage	30 to 34	45
Cream	32 to 34	45
Limburger	30 to 34	50
Neufchatel	32 to 34	45
Processed American	40 to 45	75
Processed brick	40 to 45	75
Processed limburger	40 to 45	75
Processed Swiss	40 to 45	75
Roquefort	30 to 34	50
Swiss	30 to 34	60
Cheese foods	40 to 45	55

Processing protects cheese from oiling off. By heating the bulk cheese to temperatures of 140 to 180°F, and incorporating emulsifying salts, a more stable emulsion is formed than in natural or non-processed cheese. Processed cheese will not oil off even at melting temperatures. Because of the temperatures used in processing, processed cheese is essentially a pasteurized product. Microorganisms causing changes in the body and flavor of the cheese during cure are largely destroyed; thus, there is practically no further flavor development. Consequently, the maximum permissible storage temperature for processed cheese is considerably higher than any of the other types. Table 7 shows the maximum temperatures of storage for cheese of various types.

Refrigerating Cheese Rooms

Cheeses that are to be dried before wrapping or waxing enter the cooler at approximately room temperature. Sufficient refrigerating capacity must be provided to reduce the cheeses to drying-room temperature. The product load may be taken as 1 ton for each 12,000 to 15,000 lb per day. Product load in a cheese-drying room is usually small compared to total room load. Extreme accuracy in calculating product load is not warranted.

When determining peak refrigerating load in a cheese-drying room, remember that peak cheese production may coincide with periods of high ambient temperature. In addition, these rooms normally open directly into the cheese-making room, where both temperature and humidity are quite high. Also, traffic in and out of the drying room may be heavy; therefore, ample allowance for door losses should be made. Two to three air changes per hour are quite possible during the flush season. See Chapter 13 for information on load calculations.

To maintain desired humidity, refrigerating units for the cheese-drying room should be sized to handle the peak summer load with not more than a 15°F difference between the return air temperature and evaporator temperature. Units operated from a central refrigerating system should be equipped with suction pressure regulators.

Temperature may be controlled through a room thermostat controlling a solenoid valve in the liquid supply to the unit or units, assuming a central refrigeration system is being used. Fans should be allowed to run continuously. A modulating suction-pressure regulator is not a satisfactory temperature control for a cheese-drying room because it causes undesirable variations in humidity.

Air circulation should only be enough to ensure uniform temperature and humidity throughout the room. Strong drafts or air currents should be avoided because they cause uneven drying and cracking of the cheeses. The most satisfactory refrigerating units are the ceiling-suspended between-the-rails type or the penthouse type. One unit for each 400 to 500 ft^2 of floor area usually ensures uniform conditions. One unit should be placed near the door to the room to cool warm, moist air before it can spread over the ceiling. Otherwise, condensation dripping from the ceiling and mold growth could result.

Humidity control during winter may present problems in cold climates. Because most of the peak-season refrigeration load is due to insulation losses and warm air entering through the door, refrigerating units may not operate enough during cold weather to remove moisture released by the cheese, resulting in excess humidity and improper drying. Within certain limits, the sensible load must be increased to meet the latent load. One way to do this is to run evaporators in a modified hot-gas defrost mode with fans energized to increase the sensible load on the space. If there are several units in the room, the refrigeration may be turned off on some while the evaporating pressure is lowered. Fans should be left running to ensure uniform conditions throughout the room. If these adjustments are not sufficient, or if automatic control of humidity is desired, it is necessary to use reheat coils (electric heaters, steam or hot-water coils, or hot gas from the refrigerating system) in the airstream leaving the units. A heating capacity of 15 to 20% of the refrigerating capacity of the units is usually sufficient to maintain humidity control.

A humidistat may be used to operate the heaters when humidity rises above the desired level. The heater should be wired in series, with a second room thermostat set to shut it off if room temperature becomes excessive. Because of variations in size and shape of drying rooms, it is impossible to generalize about air velocities and capacities. Airflow should be regulated so that the cheese feels moist for the first 24 h and then becomes progressively drier and firmer.

Calculating product refrigeration load for a cheese-curing room involves a simple computation of heat to be removed from the cheese at the incoming temperature to bring it to curing temperature, using 0.65 Btu/lb·°F as the specific heat of cheese. For most varieties, heat given off during curing is negligible.

Although fermentation of lactose to lactic acid is an exothermic reaction, this process is substantially completed in the first week after cheese is made; further heat given off during curing is of no significance. Assuming that average conditions for American cheese curing are approximately 45°F and 70% rh, if 30 to 35°F refrigerant is used in the cooling system, a humidity of about 70% will be maintained.

FROZEN DAIRY DESSERTS

Ice cream is the most common frozen dairy dessert. Legal guidelines for the composition of frozen dairy desserts generally follow federal standards. The amount of air incorporated during freezing is controlled for the prepackaged products by the standard specifying the minimum density, 4.5 lb/gal, and/or a minimum density of food solids, 1.6 solids/gal (21CFR135).

The basic dairy components of frozen dairy dessert are milk, cream, and condensed or nonfat dry milk. Some plants also use butter, butter oil, buttermilk (liquid or dry), and dry or concentrated sweet whey. The acid-type whey (e.g., from cottage cheese) can be used for sherbets.

Ice Cream

Milkfat content (called butterfat by some standards) is one of the principal factors in the legal standards for ice cream. Fats in other ingredients such as eggs, nuts, cocoa, or chocolate do not satisfy the legal minimum. Federal standards set the minimum milkfat content at 8% for bulky flavored ice cream mixes (e.g., chocolate) and 10% or above for the other flavors (e.g., vanilla). Manufacturers, however, usually make two or more grades of ice cream, one being competitively priced with the minimum legal fat content, and the others richer in fat, higher in total solids, and lower in overrun for a special trade. This ice cream may be made with a fat content of 16 or 18%, although most ice cream fat content ranges from 10 to 12%.

Serum solids content designates the nonfat solids from milk. The chief components of milk serum are lactose, milk proteins (casein, albumin, and globulin), and milk salts (sodium, potassium, calcium, and magnesium as chlorides, citrates, and phosphates). The following average composition for serum solids is useful for general calculations: lactose, 54.5%; milk proteins, 37.0%; and milk salts, 8.5%.

The serum solids in ice cream produce a smoother texture, better body, and better melting characteristics. Because serum solids are relatively inexpensive compared with fat, they are used liberally. The total solids content usually is kept below 40%.

The lower limit in the serum solids content, 6 to 7%, is found in a homemade type of ice cream, where the only dairy ingredients are milk and cream. Ice creams with an unusually high fat content are also kept near this serum solids content so that the total solids content will not be excessive. Most ice cream, however, is made with condensed or nonfat dry milk added to bring the serum solids content within the range of 10 to 11.5%. The upper extreme of 12 to 14% serum solids can avoid sandiness (gritty texture) only where rapid product sales turnover or other special means are used.

The sugar content of ice cream is of special interest because of its effect on the freezing point of the mix and its hardening behavior. The extreme range of sugar content encountered in ice cream is from 12 to 18%, with 16% being most representative of the industry. The chief sugar used is sucrose (cane or beet sugar), in either granulated or liquid form. Many manufacturers use dextrose and corn syrup solids to replace part of the sucrose. Some manufacturers prefer sucrose in liquid form, or in a mixture with syrup, because of lower cost and easier handling in tank car lots. In some instances, 50% of the sucrose content has been replaced by other sweetening agents. A more common practice is to replace one-fourth to one-third of the sucrose with dextrose or corn syrup solids, or a combination of the two.

Practically all ice cream is made with a stabilizer to help maintain a smooth texture, especially under the conditions that prevail in retail cabinets. Manufacturers who do not use stabilizers offset this omission by a combination of factors such as a high fat and solids content, the use of superheated condensed milk to help smooth the texture and impart body, and a sales program designed to provide rapid turnover. The most common stabilizing substances are carboxymethylcellulose (CMC) and sodium alginate, a product made from giant kelp gathered off the coast of California. Gelatin is used for some ice cream mixes that are to be batch pasteurized. Other stabilizers are locust or carob bean gum, gum arabic or acacia, gum tragacanth, gum Karaya, psyllium seed gum, and pectin. The amount of stabilizer commonly used in ice cream ranges from 0.20 to 0.35% of the mass of the mix.

Many plants now combine an emulsifier with the stabilizer to produce a smoother and richer product. The emulsifier reduces the surface tension between the water and fat phase to produce a drier-appearing product.

Egg solids in the form of fresh whole eggs, frozen eggs, or powdered whole eggs or yolks are used by some manufacturers. Flavor and color may motivate this choice, but the most common reason for selecting them is to aid the whipping qualities of the mix. The amount required is about 0.25% egg solids, with 0.50% being about the maximum content for this purpose. To obtain the desired result, the egg yolk should be in the mix at the time it is being homogenized.

In frozen custards or parfait ice cream, the presence of eggs in liberal amounts and the resulting yellow color are identifying characteristics. Federal standards specify a minimum 1.4% egg yolk solids content for these products.

Ice Milk

Ice milk commonly contains 3 to 4% fat (but not less than 2% or more than 7%) and 13 to 15% serum solids; formulations with respect to sugar and stabilizers are similar to those for ice cream. The sugar content in ice milk is somewhat higher, to build up the total solids content. The stabilizer content is also higher in proportion to the higher water content of ice milk. Overrun is approximately 70%.

Soft Ice Milk or Ice Cream

Machines that serve freshly frozen ice cream are common in roadside stands, retail ice cream stores, and restaurants. These establishments must meet sanitation requirements and have facilities for proper cleaning of the equipment, but very few blend and process the ice cream mix used. The mix is usually supplied either from a plant specializing in producing ice cream mix only or from an established ice cream plant. The mix should be cooled to about 35°F at the time of delivery, and the ice cream outlet should have ample refrigerated space to store the mix until it is frozen. To be served in a soft condition, this ice cream mix is usually frozen stiffer than would be customary for a regular plant operation with a 30 to 50% overrun. Some mixes are prepared only for soft serve. They are 1 to 2% greater in serum solids and have 0.5% stabilizer/emulsifier to aid in producing a smooth texture. Overrun is limited to 30 to 40% during freezing to the soft-serve condition.

Frozen Yogurt

Hard- or soft-serve frozen yogurt is similar to lowfat ice cream in composition and processing. The significant exception is the presence of a live culture in the yogurt.

Sherbets

Sherbets are fruit- (and mint-) flavored frozen desserts characterized by their high sugar content and tart flavor. They must weigh not less than 6 pounds to the gallon and contain between 1 and 2% milkfat and not more than 5% by mass of total milk solids (21CFR135). Although the milk solids can be supplied by milk, the general practice is to supply them by using ice cream mix. Typically, a solution of sugars and stabilizer in water is prepared as a base for sherbets of various flavors. To 70 lb of sherbet base, 20 lb of flavoring and 10 lb of ice cream mix are added. The sugar content of sherbets ranges from 25 to 35%, with 28 to 30% being most common. One example of a sherbet formula is milk solids, 5%, of which 1.5 is milkfat; sugar, 13%; corn syrup solids, 22%; stabilizer, 0.3%; and flavoring, acid, and water, 59.7%.

In sherbets, and even more so in ices, a high overrun is not desirable because the resulting product will appear foamy or spongy under serving conditions. Overrun should be kept within 25 to 40%. This fact and the problem of preventing bleeding (syrup leakage from the frozen product) emphasize the importance of the choice of stabilizers. If gelatin is selected as the stabilizer, the freezing conditions must be managed to avoid an excessive overrun. The gums added to ice cream are commonly used as the stabilizer in sherbets and ices.

Ices

Ices contain no milk solids, but closely resemble sherbets in other respects. To offset the lack of solids from milk, the sugar content of ices is usually slightly higher (30 to 32%) than in sherbets. A combination of sugars should be used to prevent crusty sugar crystallization, just as in the case of sherbets. The usual procedure is to make a solution of the sugars and stabilizer, from which different flavored ices may be prepared by adding the flavoring in the same general manner as mentioned for sherbets.

Ices contain few ingredients with lubricating qualities and often cause extensive wear on scraper blades in the freezer. Frequent resharpening of the blades is necessary. Where a number of freezers are available, and the main production is ice cream, it is desirable to confine freezing of ices and sherbets to a specific freezer or freezers, which should then receive special attention to resharpening.

Making Ice Cream Mix

The chosen composition for a typical ice cream would be

Fat	12.5%	Sugar	15.0%
Serum solids	10.5%	Stabilizer	0.3%

Mixing and Pasteurizing. Generally, the liquid dairy ingredients are placed in a vat equipped with suitable means of agitation to keep the sugar in suspension until it is dissolved. The dry ingredients are then added, with precautions to prevent lump formation of products such as stabilizers, nonfat dry milk solids, powdered eggs, and cocoa. Gelatin should be added while the temperature is still low to allow time for the gelatin to imbibe water before its dissolving is promoted by heat. Dry ingredients that tend to form lumps may be successfully added by first mixing them with some of the dry sugar so that moisture may penetrate freely. Where vat agitation is not fully adequate, sugar may be withheld until the liquid portion of the mix is partly heated so that promptness of solution avoids settling out.

The mix is pasteurized to destroy any pathogenic organisms, to lower the bacterial count to enhance the keeping quality of the mix and comply with bacterial count standards, to dissolve the dry ingredients, and to provide a temperature suitable for efficient homogenization. A pasteurizing treatment of 155°F maintained for 0.5 h is the minimum allowed. The mix should be homogenized at the pasteurizing temperature. Vat batches should be homogenized in 1 h and preferably less.

Practically all ice cream plants use continuous pasteurization using plate heat exchange equipment for heating and cooling the mix. If some solid ingredients are selected, such as skim milk powder and granulated sugar, a batch is made in a mixing tank at a temperature of 100 to 140°F. This preheated mix is then pumped through a heating section of the plate unit, where it is heated to a temperature of 175°F or higher, and held for 25 s while passing through a holding tube. The mix is then homogenized and pumped to the precooling plate section using city, well, or cooling tower water as the cooling medium. Final cooling may be done in an additional plate section, using chilled water as the cooling medium, or through a separate mix cooler. A propylene glycol medium is sometimes used for cooling to temperatures just above the freezing point.

Large plants generally use all liquid ingredients, especially if the production is automated and computerized. The ingredients are blended at 40 to 60°F. The mix passes through the product-to-product regeneration section of a plate heat exchanger with about 70% regeneration during preheating. The mix is HTST heated to not less than 175°F, homogenized, and held for 25 s. Greater heat treatment is common, and 220°F for 40 s is not unusual. The final heating may be accomplished with plate equipment, a swept-surface heat exchanger, or a direct steam injector or infusor.

Steam injection and infusion equipment may be followed by vacuum chamber treatment, in which the mix is flash-cooled to 180 to 190°F by a partial vacuum. It is further cooled through a regenerative plate section and additionally cooled indirectly to 40°F or less with chilled water. The chief advantage of the vacuum treatment is the flavor improvement of the mix if prepared from raw materials of questionable quality.

Homogenizing the Mix. Homogenization disperses the fat in a very finely divided condition so it will not churn out during freezing. Most of the fat in milk and cream is in globules <2 µm in diameter that form clumps 3 to 7 µm in diameter. Some of the clumps can be 12 µm or larger in diameter, especially if there has been some churning incidental to handling. In a properly homogenized mix, globules are seldom over 2 µm in diameter.

Cooling and Holding Mix. Methods of final cooling of ice cream mix after pasteurization depend on the equipment used and the final mix temperature desired. The mix should be as cold as possible, to about 30°F minimum for greater capacity and less refrigeration load on the ice cream freezers. Smaller plants generally use vat holding pasteurization with either a Baudelot (falling-film) surface cooler or a plate heat exchanger, both with precooling and final cooling sections. Precooling may be done with city, well, or cooling tower water, and mix leaving the precooling section is about 10°F warmer than the entering water temperature. The Baudelot cooler may be arranged for final cooling with chilled water, propylene glycol, or direct-expansion refrigerant. A final mix temperature of 30 to 33°F can be obtained over the surface cooler using propylene glycol or refrigerant. Final mix temperature when using chilled water is about 40°F.

For larger ice cream plants, where low mix temperature is desired and where plate pasteurizing equipment is installed, it may be desirable to use separate equipment for the final cooling. Where the mix is preheated to about 140°F, it will be precooled to about 10°F warmer than the entering precooling water temperature; final cooling can be done in a remote cooler. An ammonia-jacketed, scraped-surface chiller is often selected. Where cold liquid mix is used through a continuous pasteurizing, high-heat vacuum system with regeneration at about 70%, the temperature of the mix to the final cooling unit is 85°F, assuming 40°F original mix temperature and 190°F temperature of mix returning through the regenerating section.

Where plants have ample ice cream mix holding tank capacity (allowing mix to be held overnight), part of the final mix cooling may be accomplished by means of a refrigerated surface built into the tanks. Using refrigerated mix holding tanks, the average rate of cooling may be estimated at 1°F/h. Mixes with gelatin as a stabilizer should be aged 24 h to allow time for the gelatin to fully set. Mixes made with sodium alginate or other vegetable-type stabilizers develop maximum viscosity on being cooled, and can be used in the freezer immediately.

Freezing

The ice cream freezer freezes the mix to the desired consistency and whips in the desired amount of air in a finely divided condition. The aim is to conduct the freezing and later hardening to obtain the smoothest possible texture.

Freezing an ice cream mix means, of course, freezing a mixed solution. The solutes that determine the freezing point are the lactose and soluble salts contained in the serum solids and the sugars added as sweetening agents. 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 (1927) developed a reliable method for computing the freezing points of ice cream mixes from their known composition. He added the lactose and sucrose content of the mix, expressed their concentration in terms of parts of sugar per 100 parts of water, and determined the freezing-point depression caused by the sugars by reference to published data for sucrose. This computation is justified because lactose and sucrose have the same molecular mass.

$$\%\text{ Lactose in mix} = 0.545(\%\text{ Serum solids})$$

$$\frac{(\%\text{ Lactose} + \%\text{ Sucrose})100}{\%\text{ Water in mix}} = \begin{array}{l}\text{Parts lactose + Sucrose}\\ \text{per 100 parts water}\end{array}$$

To the freezing-point depression caused by these sugars, he added the depression caused by the soluble milk salts. The depression caused by the salts is computed as follows:

$$\text{Freezing-point depression caused by salt solids in °F} = \frac{4.27(\%\text{ Serum solids})}{\%\text{ Water in mix}}$$

Table 8 presents the freezing points of various ice creams and a typical sherbet and an ice, as computed by Leighton's method. The freezing point represents the temperature at which freezing

Table 8 Freezing Points of Typical Ice Creams, Sherbet, and Ice

	Composition of the Mix, %					
	Fat	Serum Solids	Sugar	Stabilizer	Water	Freezing Point, °F
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

begins. As in the case of all solutions, the unfrozen portion becomes more concentrated as the freezing progresses, and the freezing temperature therefore decreases as freezing progresses. In a simple solution, containing only one solute, this trend progresses until the unfrozen portion represents a saturated solution of the solute, and thereafter the temperature remains constant until freezing has been completed. This temperature is known as the **cryohydric point** of the solute. In a mixed solution such as ice cream, which contains several sugars and a number of salts, no such point can be recognized.

Sugars remain in solution in a supersaturated state in the unfrozen portion of the product, because, by the time the saturation point has been reached, the temperature is so low and viscosity so high that essentially a glass state exists. In a mixed solution, however, the temperature required for complete freezing must be somewhat below the cryohydric point of the solute with the lowest cryohydric point. In ice cream, that solute is calcium chloride, contained as a component of serum solids. The cryohydric point of calcium chloride is –59.8°F. Therefore, ice cream ranges from 0 to 100% frozen within the approximate range of 27.5 to –67°F.

Therefore, the temperature to which ice cream has been frozen becomes a measure of the degree to which the water has been frozen, as illustrated by Table 9. In the table, the freezing points of the unfrozen portions of the third ice cream listed in Table 8 have been computed when 0 to 90% of the original water has been frozen.

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 (1940), the specific heat of food products may be computed by assuming the following specific heats in Btu/lb·°F for the chief components: carbohydrates, 0.34; proteins, 0.37; fats, 0.40; and water, 1.00. Salts are normally not included. Where they are present in significant amounts, as in ice cream (8.5% of the serum solids), a specific heat of 0.20 is accurate. The value given by Zhadan for fats is apparently for solid fats. For liquid milkfat, Hammer and Johnson (1913) 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 milkfat is about 35 Btu/lb.

The change from liquid to solid fat occurs over a wide temperature range, approximately 80 to 40°F; 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 because milkfat is a mixture of glycerides, and mutual solubility of the glycerides is involved. In any case, the latent heat of fusion of fat is involved in cooling the mix from the pasteurizing and homogenizing temperature down to the aging temperature of 38 to 40°F. Instead of making detailed calculations, a specific heat of 0.80 Btu/lb·°F is assumed for ice cream mix, which is high for mixes ranging from 36 to 40% total solids.

Table 9 Freezing Behavior of Typical Ice Cream*

Water Frozen to Ice, %	Freezing Point of Unfrozen Portion, °F	Water Frozen to Ice, %	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; stabilizer, 0.30; water, 61.7.

In calculating the refrigeration required for freezing and hardening, a single value of a specific heat for frozen ice cream cannot be chosen. As shown in Table 9, 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. Near the initial freezing point, much more latent heat of fusion is involved per degree temperature change than in well-hardened ice cream (e.g., at –10 to –11°F). For this reason, instead of using an overall value of specific heat, freezing load may be computed as follows:

1. First, determine the temperature to which the freezing is to occur; then determine (by calculations such as those used to develop Table 9) 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 mass of water frozen.
2. Compute the sensible heat that must be removed in the desired temperature change, by treating the product as a mix; that is, use the specific heat for ice cream mix. The temperature change times the mass of product times 0.80 = sensible heat to be removed.

In such a calculation, the water present is treated as though it all remained in a liquid form until the desired temperature had been reached, although ice was forming progressively. Because ice has a specific heat of 0.492 Btu/lb·°F instead of 1.00 Btu/lb·°F as for water, this calculation errs in the direction of generous refrigeration. To offset this, the freezer agitation develops friction heat. Approximately 80% 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, power requirements increase, and should be added to the load calculation.

A gallon of ice cream mix weighs from 9 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 mass of a unit volume of ice cream varies with the mix and overrun (volume increase) according to the following relationship:

$$\text{Percentage overrun} = \frac{100(\text{Wt/gal of mix} - \text{Wt/gal of ice cream})}{\text{Wt/gal of ice cream}}$$

Freezing Ice Cream. Both batch and continuous ice cream freezers are in general use. Both are arranged with a freezer cylinder having either an annular space or coils around the cylinder, where cooling is accomplished by direct refrigerant cooling, either in a flooded arrangement with an accumulator or controlled by a thermostatic expansion valve. The freezer cylinder has a dasher, which revolves within the cylinder. Sharp metal blades on the dasher scrape the cylinder's inner surface to remove the frozen film of ice cream as it forms. Some batch freezers use plastic dashers and blades.

Batch freezers range in size 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 special-order quantities. Batch freezers larger than 40 quarts have not been used extensively since the development of the continuous freezer.

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 in the operator’s judgment or by the indication of a meter showing an increase in the current drawn by the motor as the partly frozen mix stiffens. 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 whipping action to produce the desired overrun, which is checked by taking and weighing a sample from the freezer. 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.

Output of a batch freezer varies with blade sharpness, refrigeration supplied, and overrun desired. The average maximum output for commercial batch freezers is 8 batches per hour. This schedule allows 3 to 4 min to freeze, 2 to 3 min to whip, and about 1 min to empty the ice cream and refill with mix. For this time schedule, it is assumed the ice cream is drawn from the freezer at not over 100% overrun, at a temperature of about 24°F and at a refrigerant temperature around the freezer cylinder of about –15°F.

Continuous ice cream freezers range in size from 40 to 2700 gal/h at 100% overrun, and they are 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 semiautomatic packaging or filling machines. In operation, the ice cream mix is continuously pumped to the freezer cylinder by a positive displacement rotary pump. Air pressure within the cylinder is maintained from 20 psig to more than 100 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 because of air pressure and 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% rated capacity by regulating the variable-speed control supplied for the mix pump. Continuous freezers can be used for nearly every flavor of frozen dessert. Where flavors requiring nuts, whole fruits, or candy pellets are run, the base or unflavored 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. Ice cream can be discharged from continuous freezers at temperatures of 25°F, as required for ice cream bar (novelty) operations, up to a very stiff consistency at 20°F, as required for automatic filling of small packages.

Special low-temperature ice cream freezers are available to produce very stiff ice cream for extruded shapes, stickless bars, and sandwiches. Ice cream temperatures as low as 16°F can be drawn with some mixes. When ample refrigerating effect is supplied, ice cream discharge temperature can be varied by regulating the evaporator temperature around the freezer cylinder with 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 gallon 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 in Example 2.

Example 2. Find the weight of mix for the following composition (by percent): milkfat, 12.0; serum solids, 10.5; sugar, 16.0; stabilizer, 0.25; egg solids, 0.25; and water, 61.0.

Solution: The specific gravity of the mix is

$$\frac{100}{\left(\frac{\%\ \text{Milkfat}}{0.93}+\frac{\%\ \text{Solids, not fat}}{1.58}+\frac{\%\ \text{Water}}{1.00}\right)}$$

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

$$\text{Wt per gal of mix} = \text{Wt of 1 gal of water} \times \text{Specific gravity of mix}$$

$$= 8.345 \times 1.099 = 9.17\ \text{lb}$$

The overrun in ice cream varies from 60 to 100%, which affects the required refrigeration. For a continuous freezer, the required refrigeration may be calculated as in Example 3.

Example 3. Assume a typical ice cream mix as listed in Example 2 with 100% overrun. The mix contains 61% water and goes to the freezer at a temperature of 40°F. Freezing would start in this mix at about 27°F, and 48% of the water would be frozen at 22°F.

The weight of mix required to produce 100 gal of ice cream is

$$\frac{100}{100 + \%\ \text{Overrun}} \times 100\ \text{gal} \times \text{Wt mix per gal}$$

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

$$\frac{100}{100+100} \times 100 \times 9.17 = 459\ \text{lb}$$

Calculations of capacity required to freeze 100 gal/h of ice cream are as follows:

$$\begin{aligned}
\text{Sensible heat of mix: } 459 \times (40 - 27) \times 0.80 &= 4{,}770\ \text{Btu/h} \\
\text{Latent heat: } 459 \times 0.61 \times 0.48 \times 144 &= 19{,}350\ \text{Btu/h} \\
\text{Sensible heat of slush: } 459 \times (27 - 22) \times 0.65 &= 1{,}490\ \text{Btu/h} \\
\text{Heat from motors: } 5.5\ \text{hp} \times 2545 &= \underline{14{,}000\ \text{Btu/h}} \\
\text{Total} &= 39{,}610\ \text{Btu/h} \\
\text{5\% losses from freezer and piping (estimated)} &= \underline{1{,}980\ \text{Btu/h}} \\
\text{Total refrigeration} &= 41{,}590\ \text{Btu/h} \\
&= 3.47\ \text{ton}
\end{aligned}$$

Under these conditions, 3.5 tons of cooling capacity per 100 gal/h of 100% overrun ice cream is required.

In continuous freezer operations, heat gain from motors and losses from freezer and piping remains about the same at all levels of overrun, but the necessary refrigerating effect varies with the weight of mix required to produce 100 gal of ice cream, as shown in Table 10.

Hardening Ice Cream. After leaving the freezer, ice cream is in a semisolid state and must be further refrigerated to become solid enough for storage and distribution. The ideal serving temperature for ice cream is about 8°F; it is considered hard at 0°F. To retain a smooth texture in .hardened ice cream, the remaining water content

Table 10 Continuous Freezing Loads for Typical Ice Cream Mix

Overrun, %	Ammonia Refrigeration at 3 psig Suction Pressure, tons per 100 gal/h
60	4.04
70	3.88
80	3.74
90	3.61
100	3.50
110	3.39
120	3.30

must be frozen rapidly, so that the ice crystals formed will be small. For this reason, most hardening rooms are maintained at –20°F, and some as low as –30°F Most modern hardening rooms have forced-air circulation, usually from fan-coil evaporators. With the ice cream containers arranged to allow air circulation around them, the hardening time is about one-half that in rooms having overhead coils or coil shelves and gravity circulation. With forced-air circulation in the hardening room and average plant conditions, ice cream in 2.5 or 5 gal containers (or smaller packages in wire basket containers), all spaced to allow air circulation, hardens in about 10 h. 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/ft^2 of floor area in a 9 ft high room when stacked loose, which includes aisles.

Some larger plants use ice cream hardening carton (carrier) freezers, 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. Containers under one-half gallon are usually hardened in these blast tunnels in about 4 h.

Contact-plate hardening machines are also used. They must continuously and automatically load and unload to introduce packages from the filler without delay. Compared to carton (carrier) freezers, contact-plate hardeners save space and power and eliminate package bulging. They are limited to packages of uniform thickness having parallel flat sides. These freezers are described in Chapter 16.

Temperature in the storage room is held at about –20°F. Space in storage rooms can be estimated at 25 gal/ft^2 when palletized and stacked solid 6 ft high, including space for aisles. Many storage rooms today use pallet storage and racking systems. These rooms may be 30 ft tall or more, some using stacker-crane automation. Freezer storages are described in Chapter 14.

Refrigeration required to harden ice cream varies with the temperature from the freezer and the overrun. The following example calculates the refrigeration required to harden a typical ice cream mix.

Example 4. Assume ice cream with 100% overrun enters the hardening room at a temperature of 25°F. At this temperature, approximately 30% 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 gallon of ice cream at 100% overrun, from a mix weighing 9.18 lb/gal, is 4.59 lb. The mix is assumed to contain 61% water, and the hardening room is at –20°F. Calculate the refrigeration required to harden the ice cream in Btu/gal.

Solution:

Latent heat of hardening: 4.59 × 0.61 × 0.70 × 144	=	282 Btu
Sensible heat: 4.59 × (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 gallon to harden	=	425 Btu

Percent overrun, when calculated on the basis of the quantity of ice cream delivered by the freezer or the quantity placed in the hardening room, would affect the refrigeration required, as shown in Table 11.

Table 11 Hardening Loads for Typical Ice Cream Mix

Overrun, %	Hardening Load, Btu/gal
60	532
70	500
80	470
90	447
100	425
110	405
120	386

Example 5. Calculate the refrigeration load in an ice cream hardening room, assuming 1000 gal of ice cream at 100% overrun are to be hardened in 10 h in a forced-air circulation room at a temperature of –20°F. The hardening room, for three times this daily output, should have 300 ft^2 of floor area measuring approximately 15 by 20 by 9 ft high. The total insulated surface of 1230 ft^2 requires 4 to 6 in. of urethane or equivalent. For this example, the heat conductance through the insulated surface is selected at 0.04 Btu/h·ft^2·°F. The average ambient temperature is assumed to be 90°F.

Solution:

Heat leakage: 1230 × 0.04 × (90 + 20)	=	5,410 Btu/h
Heat from fan motor: 2 hp × 2545/0.85	=	5,990 Btu/h
Heat from lights: 600 W × 3.412	=	2,050 Btu/h
Air infiltration and persons in room (approximately 20% leakage)	=	1,080 Btu/h
Hardening 1000 gal ice cream × 425 Btu/gal in 10 h	=	42,500 Btu/h
Total	=	57,030 Btu/h
	=	4.75 tons

Additional refrigeration load calculation information is located in Chapter 13.

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.

Ice Cream Bars and Other Novelties

Ice cream plants may manufacture and merchandise a limited number of the many novelties. The most common are chocolate-coated ice cream bars, flavored ices, fudge pops, drumsticks, ice cream sundae cups, ice cream sandwiches, and so forth. Small plants freeze most of these products, especially those with sticks, in metal trays containing 24 molds, which are submerged in a special brine tank with a built-in evaporator surface and brine agitation. The product mix is prepared in a tank and cooled to 35 to 40°F. A controlled quantity of mix is poured into the tray molds or measured in with a dispenser. Tray molds are placed in the brine tank for complete freezing. Brine temperature is –30 to –36°F. The freezing rate should be rapid to result in small ice crystals, but it varies with the product and generally is 15 to 20 min. The frozen product is loosened from the molds by momentarily melting the outer layers of the product in a water bath. It is immediately removed from the molds; each is separately wrapped or put in a novelty bag and promptly placed in frozen storage for distribution.

Example 6. Show the refrigeration calculations to freeze 1200 flavored ices per h at 3 oz per pop, based on the mix containing 85% water.

Solution:

Estimated mass flow of mix: 1200 × 3/16 × 1.06 (sp gr)	=	239 lb/h
Cooling mix: 239 × (40 – 27) × 0.87	=	2,700 Btu/h
Freezing: 239 × 0.85 × 144	=	29,250 Btu/h
Subcooling: 239 × (27 + 30) × 0.5	=	6,810 Btu/h
Cooling trays (50/h) 50 × 8 lb × (60 + 30) × 0.12	=	4,320 Btu/h
Heat from agitator: 1 hp × 2545	=	2,550 Btu/h
Leakage through tank, 3 × 12 × 3 ft deep	=	750 Btu/h
Loss, top of tank and piping (assumed)	=	7,500 Btu/h
Total refrigeration load	=	53,880 Btu/h
	=	4.5 tons

In making ice cream, ice milk, and similar kinds of bars, the mix is processed through the freezer and is extruded in a viscous form at about 22°F. Using similar calculations, the estimated refrigeration load to freeze 100 dozen would be 2.2 tons for 3 oz ice cream bars with 100% overrun.

The equipment to make and package novelties in large plants is available in several designs and capacities. Some are limited to the manufacture of one or a few kinds of similar novelties. Other machines have more versatility; for example, they can be used to make novelties with or without sticks, coated or uncoated, and of numerous sizes, shapes, and flavor combinations. Some of these machines include packaging in a bag or wrap, plus placement and sealing in a carton in units of 6, 8, 12, 14, 18, 24, or 48. In other plants, a separate packaging unit may be required. Some units harden the product by air at a temperature within the range of –35 to –46°F. Brine, usually calcium chloride, with a specific gravity of 1.275 or more and a temperature of –28 to –38°F may be the hardening medium. Capacity varies with the shape and size of the specific product, but is commonly in the range of 3500 to 35,000 or more per hour. Novelty equipment in plants may be semiautomatic or automatic in performance of the necessary functions.

An example of a simple novelty machine is one that has two parallel conveyor chains on which the mold strips are fastened. The molds are conveyed through filling, stick inserting, freezing, and defrosting stages. The extractor conveyor removes the frozen product from the mold cups and carries it to packaging or through dipping; it is then discharged at packaging. In the meantime, the molds go through a wash and rinse and back to be filled. The novelty is either bagged or wrapped by machine, grouped and placed into cartons, and conveyed to cold storage.

Refrigeration Compressor Equipment Selection and Operation

Nearly all commercial ice cream plants, particularly larger ones, use ammonia multistage systems. Some smaller plants operate continuous ice cream freezers and refrigerate hardening rooms to acceptable temperatures with single-stage refrigerant compressors. In most cases, these smaller plants operate reciprocating compressors at conditions above the maximum compression ratio recommended by the manufacturer.

For economical operation, and to maintain reasonable limits of compression ratio, ice cream plants normally use multistage compression. For freezing ice cream, producing frozen novelties, and refrigerating an ice cream hardening room to –20°F, one or more booster compressors may be used at the same suction pressure, discharging into second-stage compressors, which also handle the mix cooling and ingredient cold storage room loads. If a carton freezer is used at a temperature of –40°F or below for ice cream hardening, two low-suction pressure systems should be used, the lower one for the carton freezer and the higher one for the ice cream freezers and storage room. Both low-suction pressure systems discharge into the high-stage compressor system. For plants with carton freezers arranged for large volumes, an analysis of operating costs may indicate savings in using three-stage compression with the low-temperature booster compressors used for the tunnel, discharging into the second-stage booster compressor system used for freezers and storage, and then the second-stage booster compressor system discharging into the third- or high-stage compressor system.

High-temperature loads in an ice cream plant usually consist of refrigeration for cooling and holding cream, cooling ice cream mix after pasteurization, cooling for mix holding tanks, refrigeration for the ingredient cold-storage room, and air conditioning for the production areas. If direct refrigerant cooling is used for these loads, then compressor selections for the high stage can be made at about 20°F saturated suction temperature and combined with the compressor capacity required to handle the booster discharge load. Approximately the same high-stage suction temperature can be estimated if ice cream mix and mix holding tanks are cooled by chilled water from a falling-film water chilling system. If an ice builder supplies chilled water for cooling pasteurized ice cream mix, it may be desirable to provide a separate compressor system to handle this refrigerating load rather than meeting all of the high-temperature loads at the reduced suction temperature required to make ice.

Refrigeration is a significant and important cost in an ice cream plant because of the relatively large refrigeration capacity required at low suction pressure (temperature). It is imperative to use efficient two- or three-stage compression systems at the highest suction pressures and lowest discharge pressures practical to achieve the desired product temperatures.

Effectiveness of the heat transfer surfaces is reduced by oil films, excessive ice and frost, scale, noncondensable gases, abnormal temperature differentials, clogged sprays, improper liquid circulation, poor airflow, and foreign materials in the system. Adequate operations and maintenance procedures for all components and systems should be used to ensure maximum performance and safety.

Process operation performance is also critical to the effectiveness of the refrigeration system. Items that adversely affect ice cream freezing rates include dull scraper blades, high mix inlet temperatures, low ice cream discharge temperatures, overrun below specifications, and incorrect mix composition and/or viscosity.

Rooms and storage areas should be well maintained to preserve insulation integrity. This includes doors and passageways, which may be a major source of air infiltration load.

New and updated ice cream plants should be equipped with microprocessor compressor controls and an overall computerized control system for operations and monitoring. When properly used, these controls help provide safe, efficient operation of the refrigeration system.

ULTRAHIGH-TEMPERATURE (UHT) STERILIZATION AND ASEPTIC PACKAGING (AP)

Ultrahigh-temperature sterilization of liquid dairy products destroys microorganisms with a minimum adverse effect on sensory and nutritional properties. **Aseptic packaging** containerizes the sterilized product without recontamination. Sterilization, in the true sense, is the destruction or elimination of all viable microorganisms. In industry, however, the term *sterilized* may refer to a product that does not deteriorate microbiologically, but in which viable organisms may have survived the sterilization process. In other words, heat treatment renders the product safe for consumption and imparts an extended shelf life microbiologically.

Sterilization Methods and Equipment

Retort sterilization of milk products has been a commercial practice for many years. It consists of sterilizing the product after hermetically sealing it in a metal or glass container. The heat treatment is sufficiently severe to cause a definite cooked off-flavor in milk and to decrease the heat-labile nutritional constituents of milk products. UHT-AP has the advantage of causing less cooked flavor, color change, and loss of vitamins while producing the same sterilization effect as the retort method.

UHT-AP has been applied to common fluid milk products (whole milk, 2% milk, skim milk, and half-and-half), various creams, flavored milks, evaporated milk, and such frozen dessert mixes as ice cream, ice milk, milk shakes, soft-serve, and sherbets. UHT-sterilized dairy foods include eggnog, salad dressings, sauces, infant preparations, puddings, custards, and nondairy coffee whiteners and toppings.

UHT sterilization is accomplished by rapidly heating the product to the sterilizing temperature, holding the temperature for a definite number of seconds, and then rapid cooling. The methods have been classified as direct steam or indirect heating. Advantages of direct methods include the following: (1) faster heating, (2) longer processing intervals between equipment cleanings, and (3) the flow rate is easier to change. Advantages of indirect methods include the following: (1) greater regeneration potential, (2) potable steam is not necessary, and (3) viscous products and those with small pieces of solids can be processed with the scraped-surface unit.

The direct steam method is subdivided into injection or infusion. In direct injection, steam is forced into the product, preferably in small streamlets, with enough turbulence to minimize localized overheating of the milk surfaces that the steam initially contacts. In infusion, the product is sprayed into a steam chamber. Advantages of infusion over injection are (1) slightly less steam pressure is required (with exceptions), (2) less localized overheating of a portion of the product, and (3) more flexibility for change of the product flow rate. Vacuum chambers are required for direct steam methods to remove the water added during heating.

The three important indirect systems are tubular, plate, and cylinder with mechanical agitation. In the tubular type, the tube diameter must be small and the velocity of flow high to maximize heat transfer into the product.

Essential components for direct steam injection are storage or balance tank, timing pump, preheater (tubular or plate), steam injector or infuser unit, holding unit, flow-diversion valve, vacuum chamber, aseptic pump, aseptic homogenizer, plate or tubular cooler, and control instruments. The minimum items of equipment for steam infusion are the same, except that the infuser is used to heat the product from the preheat to the sterilization temperature.

The necessary equipment for indirect systems is similar: storage or balance tank, timing pump, preheater (tubular or plate type, and preferably regenerative), homogenizer, final plate or tubular heater, holding tube or plate, flow-diversion valve, cooler (one to three stages), and control instruments. The mechanically agitated heat exchanger replaces the tubes or plates in the final heating stage. Otherwise, the same items of equipment are used for this system of sterilization.

In addition to the basic equipment, many combinations of essential and supplemental items of UHT equipment are available. For example, one variation on the indirect system is to use the pump portion of the homogenizer as a timing pump when it is installed after the balance tank. The first stage of homogenization may occur after preheating, and the second stage may occur after precooling. A vacuum chamber may be placed in the line after preheating, for precooling after sterilization, or installed in both locations. A condenser in the vacuum chamber allows the advantages of deaeration without moisture losses that otherwise would occur in the indirect system. In Europe, some indirect systems have a hold of several minutes after preheating, to reduce the rate of solids accumulation on the final heating surfaces of the tubes or plates. A bactofuge may be included in the line after preheating to reduce a high microbiological content, especially of bacterial spores.

Self-acting controls and other instrumentation are available to ensure automatic operation in nearly every respect. Particularly important is automatic control of temperatures for preheating, sterilizing, and precooling in the vacuum chamber, and to some extent, of the final temperature before packaging. This may include temperature-sensing elements to control heating and cooling and pressure-sensing elements for operating pneumatic valves. The cleaning cycle may be automated, beginning with a predetermined solids accumulation on specific heating surfaces. Timers regulate the various cleaning and rinsing steps.

In some systems, one or more aseptic surge tanks are installed between the UHT sterilizer and the AP equipment. Aseptic surge tanks allow either the sterilizer or AP equipment to continue operation if the other goes off-line. It also makes the use of two or more AP units easier than direct flow from the UHT sterilizer to the AP machines.

When aseptic surge tanks are used, they must be constructed to withstand the steam pressure required for equipment sterilization and be provided with a sterile air venting system. Aseptic surge tanks may be unloaded by applying sterile air to force product out to the AP equipment. The pressure for air unloading can be controlled at a constant value, making uniform filling possible even when one of several AP machines is removed from service.

Aseptic surge tanks make it possible to hold bulk product, even for several days, until it is convenient to package it.

Basic Steps. After the formula is prepared and the product standardized, the processing steps are (1) preheat to 150 to 170°F by a plate or tubular heat exchanger; (2) heat to a sterilization temperature of 285 to 300°F; (3) hold for 1 to 20 s at sterilizing temperature; and (4) cool to 40 to 100°F, depending on product keeping quality needs. Cooling may be by one to three stages; generally, two are used. The direct steam method requires at least two cooling stages. The first is flash cooling in a vacuum chamber to 150 to 170°F to remove moisture equal to the steam injected during sterilization. The second stage reduces the temperature to within 50 to 100°F. A third stage is required in most plants if the temperature is lowered to 35 to 50°F.

Products with fat are homogenized to increase stability of the fat emulsion. The direct method requires homogenization after sterilization and precooling. Homogenization may follow preheating or precooling, but usually follows preheating in the indirect method. Efficient homogenization is very important in delaying the formation of a cream layer during storage.

Sterilized plain milks (such as whole, 2%, and skim milk) are most vulnerable to having a cooked off-flavor. Consequently, the aim is to have low sterilization temperature and time consistent with satisfactory keeping quality. The total cumulative heat treatment is directly related to the intensity of the cooked off-flavor. The total processing time from preheating to cooling varies widely among systems. Most operations in the United States range from 30 to 200 s; in European UHT processes, it may be much longer.

Several factors influence the minimum sterilization temperature and time needed to control adverse effects on flavor and physical, chemical, and nutritional changes. Type of product, initial number of spores and their heat resistance, total solids of the product, and pH are the most important factors. Obviously, the relationship is direct for the number and heat resistance of the spores. Total solids also have a direct relationship, but for an acid pH, it is inverse.

Several terms are used to describe UHT's effect on the microbiological population. **Decimal reduction** refers to a reduction of 90% (e.g., 100 to 10, or one log cycle). An example of a three-decimal reduction is 10,000 to 10. **Decimal reduction time**, or ***D* value**, is the time required to obtain a 90% decrease. **Sterilizing effect**, or **bactericidal effect**, is the number of decimal reductions obtained and expressed as a logarithmic reduction ($\log_{10}$ initial count minus $\log_{10}$ final count). A sterilizing effect of six means one organism remaining from a million per mL (10^6), and seven would be one remaining in 10 mL (a final count of 10^{-1}).

The ***Z* value** is the temperature increase required to reduce the *D* value by one log cycle (90% reduction of microorganisms with the time held constant). The ***F* value** (thermal death time) is the time required to reduce the number of microorganisms by a stated amount or to a specific number. For example, assuming a *D* value of 36 s for *Bacillus substilis* spores at 250°F and a need to reduce the spores from 10^6 per mL to <1 per mL, the thermal treatment time would be 6×36 s = 216 s (*F* value).

Aseptic Packaging

Aseptic fillers are available for coated metal cans, glass bottles, plastic/paperboard/foil cartons, thermoformed plastic containers, blow-molded plastic containers, and plastic pouches. Aseptic can equipment includes a can conveyor and sterilizing compartment, filling chamber, lid sterilizing compartment, sealing unit, and instrument controls. The procedure sterilizes cans with steam at 550°F as they are conveyed, fills them by continuous flow, simultaneously sterilizes the lids, places the lids on the cans, and seals the lids onto the cans. Pressure control apparatus is not used for entry or exit of cans.

A similar system is used for glass bottles or jars. The jars are conveyed into a turret chamber; air is removed by vacuum; the jars are then sterilized for 2 s with wet steam at 60 psi and moved into the filler. The temperature of the glass equalizes to 120°F and the filling takes place. Next, the transfer is to the capper for placement of sterile caps, which are screwed onto the jars. The filling and capping space is maintained at 500°F.

Several aseptic blow-mold forming and filling systems have been developed. Each system is different, but the basic steps using molten plastic are (1) extruded into a parison, (2) extended to the bottom of the mold, (3) mold closed, (4) preblown with compressed air that inflates the plastic film into a bottle shape, (5) parison cut and the neck pinched, (6) final air application, (7) bottle filled and foam removed, (8) top sealed, and (9) mold opened and filled bottle ejected.

The basic steps in the manufacture of aseptic, thermoformed plastic containers are as follows: (1) a sheet of plastic (e.g., polystyrene) is drawn from a roll through the heating compartment and then multistamped into units, which constitute the containers; (2) these units are conveyed to the filler, which is located in a sterile atmosphere, and are filled; (3) a sheet of sterilized foil is heat sealed to the container tops; and (4) each container is separated by scoring and cutting.

One of the two aseptic systems for the plastic/paperboard/foil cartons draws the material from a roll through a concentrated hydrogen peroxide bath to destroy the microorganisms. The peroxide is removed by drawing the sheet between twin rolls, by exposure to ultraviolet light and hot air, or by superheated, sterilized air forced through small slits at high velocity. The packaging material is drawn downward in a vertical, sterile compartment for forming, filling by continuous flow, sealing, separation, and ejection.

In the other plastic/paperboard/foil aseptic system, the prepared, flat blanks are formed and the bottoms are heat sealed. In the next step, the inside surfaces are fogged with hydrogen peroxide. Sterilized hot air dissipates the peroxide. The cartons are conveyed into the aseptic filling and then into top-sealing compartments. Air forced into these two areas is rendered devoid of microorganisms by high-efficiency filters.

Operational Problems. Aseptic operational problems are reduced by careful installation of satisfactory equipment. The equipment should comply with *3-A Sanitary Standards*. Milk and milk products that are processed to be commercially sterile and aseptically packaged must also meet the *Grade A Pasteurized Milk Ordinance* and be processed in accordance with 21CFR113. Generally, the simplest system, with a minimum of equipment for product contact surfaces and processing time, is desirable. It is specifically important to have as few pumps and nonwelded unions as possible, particularly those with gaskets. The gaskets and O rings in unions, pumps, and valves are much more difficult to clean and sterilize than are the smooth surfaces of chambers and tubing. Automatic controls, rather than manual attention, is generally more satisfactory.

Complete cleaning and sterilizing of the processing and packaging equipment are essential. Milk solids accumulate rapidly on heated surfaces; therefore, cleaning may be necessary after 0.5 h of processing for tubular or plate UHT heat exchangers, although cleaning after 3 to 4 h is more common. Cleaning for the sterilizer, filler, and accessory equipment usually involves the CIP method for the rinse and alkali cleaning cycle, rinse, acid cleaning cycle, and rinse. Some plants only periodically acid-clean the storage tanks and packaging equipment (e.g., once or twice a week). Steam sterilization just before processing is customary. At 8 to 10 psig of wet steam, 1.5 to 2.0 h (or a shorter time at higher steam pressure) may be required. Water sterilized by steam injection or the indirect method can be used for rinsing and for the cleaning solution.

Survival of spores during UHT processing, or subsequent recontamination of the product before the container is sealed, is a constant threat. Inadequate sealing of the container also may be troublesome with certain types of containers. Another source of poststerilization contamination is airborne microorganisms, which may contact the product through inadequate sterilization of air that enters the storage vat for the processed product or through air leaks into the product upstream of the sterilized product pumps or homogenizer, if pressure is reduced. During packaging, air may contaminate the inside of the container or the product itself during filling and sealing.

Quality Control

Poor quality of raw materials must be avoided. The higher the spore count of the product before sterilization, the larger the spore survival number at a constant sterilization temperature and time. Poor quality can also contribute to other product defects (off-flavor, short keeping quality) because of sensory, physical, or chemical changes. Heat stability of the raw product must be considered.

A good-quality sterilized product has a pleasing, characteristic flavor and color that are similar to pasteurized samples. The cooked flavor should be slight or negligible, with no unpleasant aftertaste. The product should be free of microorganisms and adulterants such as insecticides, herbicides, and peroxide or other container residues. It should have good physical, sensory, and keeping quality.

Deterioration in storage may be evaluated by holding samples at 70, 89, 98, or 113°F for 1 or 2 weeks. The number of samples for storage testing should be selected statistically and should include samplings of the first and last of each product packaged during the processing day. To identify the source of microbiological spoilage, continuous aseptic sampling into standard-sized containers after sterilization and/or just ahead of packaging may be practiced. Sampling rate should be set to change containers each hour.

The rate of change in storage of sterilized milk products is directly related to the temperature. Commercial practice varies, with storage ranging from 35°F to room temperature, which may reach 95°F or higher. In plain milks, the cooked flavor may decrease the first few days, and then remain at its optimum for 2 to 3 weeks at 70°F before gradually declining. When milk is held at 70°F, a slight cream layer becomes noticeable in approximately 2 weeks and slowly continues until much of the fat has risen to the top. Thereafter, the cream layer becomes increasingly difficult to reincorporate or reemulsify.

Viscosity increases slightly the first few weeks at 70°F and then remains fairly stable for 4 to 5 months. Thereafter, gelation gradually occurs. However, milks vary in stability to gelation, depending on factors such as feeds, stage of lactation, preheat treatment, and homogenization pressure. Adding sodium tetraphosphate to some milks causes gelatin to develop more slowly.

Occasionally, some sterilized milk products develop a sediment on the bottom of the container because of crystallization of complex salt compounds or sugars. Browning can also occur during storage. Usually, off-flavors develop more rapidly and render the product unsalable before the off-color becomes objectionable.

Heat-Labile Nutrients

Results reported by researchers on the effects of UHT sterilization on heat-sensitive constituents of milk products lack consistency. The variability may be attributed to the analytical methods and to the difference in total heat treatment among various UHT systems, especially in Europe. In a review, Van Eeckelen and Heijne (1965) summarized the effect of UHT sterilization on milk as follows: slight or none for vitamins A, B_2, and D, carotene, pantothenic acid, nicotinic acid, biotin, and calcium; and no decrease in biological value of the proteins. The decreases were 3 to 10%, thiamine; 0 to 30%, B_6; 10 to 20%, B_{12}; 25 to 40%, C; 10%, folic acid; 2.4 to 66.7%, lysine; 34%, linoleic acid; and 13%, linolenic acid. Protein digestibility was decreased slightly. A substantial loss of vitamins C, B_6, and B_{12} occurred during a 90 day storage. Brookes (1968) reported that Puschel found that babies fed sterilized milk averaged a gain of 27 g per day, compared to 20 g for the control group.

EVAPORATED, SWEETENED CONDENSED, AND DRY MILK

Evaporated Milk

Raw milk intended for processing into evaporated milk should have a heat stability quality with little (preferably no) developed acidity. As milk is received, it should be filtered and held cold in a storage tank. The milkfat is standardized to nonfat solids at the ratio of 1:2.2785. It is then preheated to 200 to 205°F for 10 to 20 min or 240 to 260°F for 60 to 360 s to reduce product denaturation during sterilization. Moisture is removed by batch or (usually) continuous evaporation until the total solids have been concentrated to 2.25 times the original content.

Condensed product is pumped from the evaporator and, with or without additional heating, is homogenized at 2000 to 3000 psi and 120 to 140°F. It is cooled to 45°F and held in storage tanks for restandardization to not less than 7.9% milkfat and 25.9% total solids. The product is pumped to the packaging unit for filling cans made from tin-coated sheet steel. Filled cans are conveyed continuously through a retort, where the product is rapidly heated with hot water and steam to 245°F and held for 15 min to complete the sterilization. Rapid cooling with water to 80 to 90°F follows. The evaporated milk is agitated while in the retort by the can movement. Application of labels and placement of cans in shipping cartons are done automatically.

Storage at room temperature is common, but deterioration of flavor, body, and color is decreased by lowering the storage temperature to 50 to 60°F. Relative humidity should be less than 50% to reduce can and label deterioration. The recommended inversion of cases during storage to reduce fat separation is shown in Table 12.

Sweetened Condensed Milk

Sweetened condensed milk is manufactured similarly to evaporated milk in several aspects. One important difference, however, is that added sugar replaces heat sterilization to extend storage life. Filtered cold milk is held in tanks and standardized to 1:2.2942 (fat to nonfat solids). The milk is preheated to 145 to 160°F, homogenized at 2500 psi, and then heated to 180 to 200°F for 5 to 15 min or to 240 to 300°F for 30 s to 5 min. The milk is condensed in a vacuum pan to slightly higher than a 2:1 ratio. Liquid sugar (pasteurized) is added at the rate of 18 to 20 lb/100 lb of condensed milk.

As the mixture is pumped from the vacuum pan, it is cooled through a heat exchanger to 86°F and held in a vat with an agitator. Nuclei for proper lactose crystallization are provided by adding finely powdered lactose (200-mesh). The product is cooled slowly, taking an hour to reach 75°F with agitation. Then cooling is continued more rapidly to 60°F. Improper crystallization forms large crystals, which cause sandiness (gritty texture). The sweetened condensed milk is pumped to a packaging unit for filling into retail cans and sealing. Labeling cans and placement in cases is mechanized, similar to the process used for evaporated milk. The product is usually stored at room temperature, but the keeping quality is improved if stored below 70°F.

Condensing Equipment. Both batch and continuous equipment are used to reduce the moisture content of fluid milk products. The continuous types have single, double, triple, or more evaporating effects. The improvement in efficiency with multiple effects is shown in Table 13 by the reduction in steam required to evaporate 1 lb of water.

A simple evaporator is the horizontal tube. In this design, the tubes are in the lower section of a vertical chamber. During operation, water vapor is removed from the top and the product, from the bottom of the unit. For the vertical short-tube evaporator, the chamber design may be similar to the horizontal tube. The long-tube vertical unit may be designed to operate with a rising or falling film in the tubes; the latter is common. For the falling film, the product Reynolds number should be greater than 2000 for good heat transfer. Falling-film units may have a high *k*-factor at low temperature differentials, resulting in low steam requirements per mass of water evaporated per area of heating surface. Falling-film units have a rapid start-up and shutdown. Thermocompressing and mechanical compressing evaporators have the advantage of operating efficiently at lower temperatures, thus reducing the adverse effect on heat-sensitive constituents. Vapors removed from the product are compressed and used as a source of heat for additional evaporation.

Plate evaporators are also used. They are similar to plate heat exchangers used for pasteurization in that they have a frame and a number of plates gasketed to carry the product in a passage between two plates and the heating medium in adjacent passages. They differ in that, in addition to ports for product, they have large ports to carry vapor to a vapor separator. Vapors flow from the separator chamber to a condenser similar to those used for other types of evaporators. Plate evaporators require less head space for installation than other types, may be enlarged or decreased in capacity by a change in the number of plates, and offer a very efficient heat exchange surface.

Equipment Operation. Positive pumps of the reciprocating type are often used to obtain 24 in. Hg vacuum in the chamber. Steam jet ejectors may be used for 25 in. Hg vacuum, for one stage; two stages permit 28 in. Hg vacuum; and three stages, 29.8 in. Hg vacuum. Condensers between stages remove heat and may reduce the amount of vapor for the following stage. Either a centrifugal or reciprocating pump may be used to remove water from the condenser. A barometric leg may also be placed at the bottom of a 34 ft or longer condenser to remove water by gravity.

Dry Milk and Nonfat Dry Milk

There are two important methods of drying milk: spray and drum. Each has modifications, such as the foam spray and the vacuum drum drying methods. Spray drying exceeds by far the other methods for drying milk, and the largest volume of dried dairy product is skim milk.

In the manufacture of spray-dried nonfat dry milk (NDM), cold milk is preheated to 90°F and separated, and the skim milk for low-heat NDM is pasteurized at 161°F for 15 s or slightly higher and/or longer. It is condensed with caution to restrict total heat denaturation of the serum protein to less than 10%. This requires using a low-temperature evaporator or operating the first effect of a regular double-effect evaporator at a reduced temperature. After increasing the total solids to 40 to 45%, the condensed skim milk is continuously pumped from the evaporator through a heat exchanger to increase the temperature to 145°F. The concentrated skim milk is filtered and enters a positive pump operating at 3000 to 4000 psi,

Table 12 Inversion Times for Cases of Evaporated Milk in Storage

Storage Temperature, °F	Time
90	1 month initially and each 15 days
80	1 to 2 months
70	2 to 3 months
60	3 to 6 months

Table 13 Typical Steam Requirements for Evaporating Water from Milk

No. of Evaporating Effects	Steam Required, lb steam/lb water
Single	1.30 to 1.00
Double	0.60 to 0.50
Triple	0.40 to 0.35
Quadruple	0.30 to 0.25

which forces the product through a nozzle with a very small orifice, producing a mist-like spray in the drying chamber. Hot air of 290 to 400°F or higher dries the milk spray rapidly. Nonfat dry milk with 2.5 to 4.0% moisture is conveyed from the drier by pneumatic or mechanical means, then cooled, sifted, and packaged. Packages for industrial users are 50 or 100 lb bags.

High-heat nonfat dry milk is used principally in bread and other bakery products. The manufacturing procedure is the same as for low-heat NDM except that (1) the pasteurization temperature is well above the minimum (e.g., 175°F for 20 s or higher); (2) after pasteurization, the skim milk is heated to 185 to 195°F for 15 to 20 min, condensed; and (3) the concentrate is heated to 160 to 165°F before filtering and then is spray dried, similar to the process for low-heat NDM. Storage of low- or high-heat NDM is usually at room temperature.

Dry Whole Milk. Raw whole milk in storage tanks is standardized at a ratio of fat to nonfat solids of 1:2.769. The milk is preheated to 160°F, filtered or clarified, and homogenized at 160°F and 3000 psi on the first stage and 750 psi on the second stage. Heating continues to 200°F with a 180 s hold. The milk is drawn into the evaporator and the total solids are condensed to 45%. The product is continuously pumped from the evaporator, reheated in a heat exchanger to 160°F, and spray dried to 1.5 to 2.5% moisture. Dry whole milk (DWM) is cooled (not below dew point) and sifted through a 12-mesh screen. For industrial use within 2 or 3 months, the dry whole milk is packaged in 50 lb bags and held at room temperature or, preferably, well below 70°F.

To retard oxidation, the dry whole milk may be containerized in large metal drums or in retail-sized cans unsealed and subjected to 28 in. Hg vacuum. Less than 2% oxygen in the head space of the package after a week of storage is a common aim. Oxygen desorption from the entrapped content in lactose is slow, and two vacuum treatments may be necessary with a 7 to 10 day interval between them. Warm DWM directly from the drier desorbs oxygen more quickly than cooled DWM. Nitrogen is used to restore atmospheric pressure after each vacuum treatment. After the hold period for the first vacuum treatment, the DWM in the drums is dumped into a hopper, mechanically packaged into retailed-sized metal cans, and given the second vacuum treatment.

Foam spray drying allows the total solids to be increased to 50 to 60% in the evaporator before drying. Gas (compressed air or nitrogen) is distributed, by means of a small mixing device, into the condensed product between the high-pressure pump and the spray nozzle. A regulator and needle valve are used to adjust the gas flow into the product. Gas use is approximately 0.5 ft^3/gal of concentrated product. Otherwise, the procedure is the same as for regular drying. Foam spray-dried NDM has poor sinkability but good reconstitutability in water. The density is roughly half that of regular spray-dried NDM. The additional equipment for foam spray drying is limited to a compressor, storage drum, pressure regulator, and a few accessory items. The cost is relatively small, especially if compressed air is used.

Spray driers are made in various shapes and sizes, with one or many spray nozzles. Horizontal-spray driers may be box-shaped or a teardrop design. Vertical spray driers are usually cone- or silo-shaped.

Heat Transfer Calculations. The typical atomization in U.S. spray-drying plants is produced by a high-pressure pump that forces liquid through a small orifice in a nozzle designed to give a spreading effect as it emerges from the nozzle. Single-nozzle driers have an orifice opening diameter of 0.107 to 0.177 in. The diameter for multinozzle driers is 0.025 to 0.052 in. In Europe, the spinning disk is the most common means of atomizing in milk drying plants. Droplet sizes of 50 to 250 μm in diameter are usual. Droplet size has an inverse relationship to the rate of drying at a uniform hot-air temperature. Larger droplets require a higher air temperature and/or longer exposure than the smaller ones.

Other essential steps in spray drying are (1) moving, filtering, and heating the air; (2) incorporating the hot air with the product droplets; and (3) removing the moisture vapors and separating the moist air from the product particles. After passing through a rough or intermediate filter, the air is heated indirectly by steam coils or directly with a gas flame to 250 to 500°F. During the short drying exposure time, the air temperature drops to 160 to 200°F.

Thermal efficiency is the percentage of the total heat used to evaporate the water during the drying process. Efficiency is improved by heat recovery from exhaust air, decreased radiation loss, and high drying air temperature versus a low outlet air temperature. Roughly 2.2 to 3.2 lb of steam are needed to evaporate 1 lb of moisture in the drier.

$$\text{Thermal efficiency} = \frac{(1 - R/100)(t_1 - t_2)}{t_1 - t_0}$$

where

R = radiation loss, percentage of temperature decrease in drier
t_1 = inlet air temperature, °F
t_2 = outlet air temperature, °F
t_0 = ambient air temperature, °F

Most of the dried particles are separated from the drying air by gravity and fall to the bottom of the drier or the collectors. Fine particles are removed by directing the air/powder mixture through bag filters or a series of cyclone collectors. Air movement in the cyclone is designed to provide a centrifugal force to separate product particles. In general, several small-diameter cyclones with a fixed pressure drop will be more efficient for removal of fines than two large units.

The drier has sensing elements to continuously record the hot-air (inlet) temperature and moist-air (outlet) temperature. During drying, these temperatures are adjusted with a steam valve or gas inlet valve.

Drum Drying

Relatively little skim or whole milk is drum-dried. Drum-dried products, when reconstituted, have a cooked or scorched flavor compared to spray-dried products. Heat treatment during drying denatures the protein and results in a high insolubility index. In preparation for drying, skim milk is separated or whole milk is standardized to 1:2.769 [e.g., 3.2 fat and 8.86 solids-not-fat (SNF)]. The product is filtered or clarified, homogenized after preheating, and pasteurized. If the resulting dry product is intended for bakery purposes, the milk is heated to approximately 185°F for 10 min. The fluid product may be concentrated by moisture evaporation to not more than 2 to 1. The product is then dried on the drum(s): skim milk to not more than 4.0%, and whole milk to not more than 2.5% moisture. A blade pressed against the drum scrapes off the sheet of dried product. An auger conveys the dry material to the hammer mill, where it is pulverized and sifted through an 8-mesh screen. Drum-dried milks are usually packaged at the sifter into 50 to 100 lb kraft bags with a plastic liner.

A double-drum drier, with drums spaced 0.02 to 0.043 in. apart, is more common than a single drum for drying milk. Cast iron is used more often in drum construction than stainless steel or alloy steel and chrome plate steel. The knife metal must be softer than the drum. End plates on the drums create a reservoir into which the product, at 185°F, is sprayed the length of the drums. The steam-heated drums boil the product continuously as a thin film adheres to the revolving drums. After about 0.875 of one revolution, the film of product is dry and is scraped off. Drums normally revolve between 10 and 19 rpm. Steam pressure inside the drums is approximately 70 to 90 psi, as indicated by the pressure gage at the inlet of the condensate trap.

Steam pressure is adjusted for drying the product to the desired moisture content. Superheated steam scorches the product. Condensate inside the drums must be continuously removed, while the exterior vapors from the product are exhausted from the building with a hood and fan system. Capacity, dried product quality, and moisture content depend on many factors. Some important ones are steam pressure in drums, rotation speed of drums, total solids of product, smoothness of drum surface and sharpness of the knives, properly adjusted gap between the two drums, liquid level in drum reservoir, and product temperature as it enters the reservoir.

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