Milk and Ice Cream Processing

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17.1 Introduction

Milk products have been consumed by humans since prehistoric times. Archeological records show that humans began milking goats ca. 9000 years ago (Evershed et al., 2008) and manufacturing cheese at least ca. 7000 years ago (Salque et al., 2012). Milk has become an important constituent of our diet for a number of reasons, including but not limited to its high nutritional quality. The annual production/consumption of milk in the world was 749 million metric tonnes and the average per capita consumption of milk was 107.3 kg/person/year in 2011 (IDF, 2012). According to the Food and Agriculture Organization (FAO), the largest producers of milk in the world in 2011 were USA and India (FAO, 2011). The annual US milk production increased from 56 million metric tonnes in 1979 (USDA-NASS, 1980) to 87 million metric tonnes in 2010 (USDA-NASS, 2011). California and Wisconsin are the largest milk-producing states in the US. The availability of fluid milk and cream (half and half, light, heavy, sour cream, and eggnog) in the US in 2009 was 92 kg/person, and for all dairy products about 276 kg (including fluid milk cream, cheese, frozen dairy products, evaporated and condensed milks and dry dairy products) (USDA-ERS, 2011). In order to sustain the growing consumption, the US dairy industry has grown considerably over the years. Along with the amount processed, the variety of dairy products on the market has also increased.

In the present chapter, we focus on fresh milk products including fluid milks and ice cream. Other milk products on the market, including fermented milk products (e.g. yogurt, kefir, and kumiss) and fermented-coagulated products (e.g. cheese), are handled in the next chapter.

17.1.1 Milk – definition and composition

According to the US Code of Federal Regulations (21 CFR Ch. 1, Subpart B, 131.110):

“Milk is the lacteal secretion, practically free from colostrum, obtained by the complete milking of one or more healthy cows. Milk that is in final package form for beverage use shall have been pasteurized or ultrapasteurized, and shall contain not less than 8.25% milk solids not fat and not less than 3.25% milk fat. Milk may have been adjusted by separating part of the milk fat therefrom, or by adding thereto cream, concentrated milk, dry whole milk, skim milk, concentrated skim milk, or nonfat dry milk. Milk may be homogenized.”

Milk intended for interstate shipment and sale requires pasteurization, while intrastate shipment and sale of milk are regulated by states.

The major constituents of milk are shown in Table 17.1. However, bovine milk composition varies with breed, type of milking (time, intervals, procedure, and completeness), season, age of cow, stage of lactation, variations in individual cow, health and condition of cattle, and nutrition provided to the cattle (Jenkins & McGuire, 2006; Laben, 1963; Legates, 1960; Loganathan & Thompson, 1968).

17.2 Physical and chemical properties of milk constituents

17.2.1 Fat

Milk fat is secreted as a fat globule surrounded by a milk fat globule membrane (MFGM), which maintains the integrity of the globule and maintains fat as an emulsion in the surrounding aqueous phase. The interfacial tension between milk fat globule and milk serum is about
2 Nm⁻¹ s⁻¹ and that between non-globular liquid fat and milk serum is about 15 Nm⁻¹ s⁻¹ (Fox & McSweeney, 1998a). This reduction in the interfacial tension by the MFGM stabilizes the fat emulsion in the serum phase. Milk contains a high concentration of saturated fatty acids (62%), followed by lower concentrations of monounsaturated (29%) and polyunsaturated fatty acids (4%). Among saturated fatty acids, short- and medium-chain fatty acids (C4:0 to C18:0) are in abundance. Among short-chain fatty acids, butyric acid (C4:0) is in highest concentration, at 3.8%. Oleic acid is the dominant unsaturated fatty acid residue (27.42%). Milk fat exists

<table>
<thead>
<tr>
<th>Major constituents</th>
<th>Fractions (% of major constituent)</th>
<th>Minor fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (87%)</td>
<td>Triacylglycerides (95.8%)</td>
<td>α₅₁, α₅₂, β, κ, γ caseins</td>
</tr>
<tr>
<td>Lipids (4%)</td>
<td>Di- and monoglycerides (2.4%)</td>
<td>α-Lactalbumin</td>
</tr>
<tr>
<td></td>
<td>Phospholipids (1.1%)</td>
<td>β-Lactoglobulin</td>
</tr>
<tr>
<td></td>
<td>Sterols (0.5%)</td>
<td>Immunoglobulins (Ig) – IgG and IgM</td>
</tr>
<tr>
<td></td>
<td>Free fatty acids (0.3%)</td>
<td>Proteose peptone</td>
</tr>
<tr>
<td>Solids not fat (8.9%)</td>
<td>Casein (78.3%)</td>
<td>Bovine serum albumin</td>
</tr>
<tr>
<td></td>
<td>Whey proteins (17.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Membrane proteins (2%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enzymes</td>
<td></td>
</tr>
<tr>
<td>Carbohydrates (5%)</td>
<td>Lactose (95.8%)</td>
<td>Galactose</td>
</tr>
<tr>
<td></td>
<td>Glucose (2.0%)</td>
<td>Oligosaccharides</td>
</tr>
<tr>
<td></td>
<td>Others (2.2%)</td>
<td></td>
</tr>
<tr>
<td>Organic and inorganic ions (0.7%)</td>
<td>Chloride (27.9%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Citrates* (25.8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phosphates* (23.5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potassium (22.2%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calcium* (18.7%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sodium (9.2%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Magnesium* (1.9%)</td>
<td></td>
</tr>
<tr>
<td>Minor constituents</td>
<td>Organic acid</td>
<td>Vitamin A</td>
</tr>
<tr>
<td></td>
<td>Vitamins</td>
<td>Vitamin B complex: thiamine, riboflavin, niacin, pyridoxine, pantothenic acid, biotin, folic acid, cyanocobalamin</td>
</tr>
<tr>
<td></td>
<td>Non-protein nitrogen</td>
<td>Vitamin C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vitamin D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vitamin E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vitamin K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amino acids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nitrogenous compounds: ammonia, urea, creatine, creatinine, uric acid, nitrogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nucleic acids</td>
</tr>
</tbody>
</table>
mainly as triacylglycerides and other fractions of lipids are mono- and diglycerides, free fatty acids, and compound lipids (phospholipids and cholesterol) (Chandan, 2006).

Most of the fat globules in bovine milk have a size distribution of 0.1–20 μm (Fox & McSweeney, 1998a). The thermal conductivity of cream is about 0.36 W.m⁻¹.K⁻¹ (Sweat & Parmelee, 1978). The specific heat of milk fat is about 2177 kJ.kg⁻¹.K⁻¹, which is temperature dependent. The electrical conductivity is less than 10⁻¹² S/cm and the dielectric constant is about 3.1, depending on frequency (Walstra & Jenness, 1984). The refractive index of milk fat is in the range of 1.3440–1.4552 at 40°C (Fox & McSweeney, 1998a). Milk fat is liquid above 40°C and solid below −40°C. In between these temperatures, it exists as a mixture of crystals and oil. Milk fat has a specific gravity of 0.900, which is less than the rest of milk, with specific gravity close to 1.036 (Mulder & Walstra, 1974). This difference in specific gravity enables the separation of fat from skim milk by centrifugal and gravitational forces.

**17.2.2 Protein**

The protein in milk are primarily caseins (ca. 80%) and whey proteins (ca. 20%). Casein is defined as those proteins in milk that precipitate at or above pH = 4.5. The caseins are phosphoproteins that form a complex quaternary structure (casein micelle), but lack tertiary structure. The five major casein fractions in bovine milk are α₁S₁, α₁S₂, β, γ, and κ fractions. Fragments of β-casein, called γ-casein and proteose peptone, are formed by hydrolysis. The α₁S₁, α₁S₂, β, γ, and κ-caseins are in the approximate ratio of 4:1:3:5:1.5 in milk (Swaisgood, 2003). The casein micelles contain in excess of 20,000 individual protein molecules hydrated with 3–4 g of water per g of protein (Dalgleish, 2011). In these micelles, α₅₆ and β-caseins are extensively phosphorylated and are bound with calcium phosphate. The α₅₆ and β-caseins are highly calcium sensitive (precipitates in the presence of 0.25 M calcium chloride), while κ-casein does not precipitate in the presence of 0.25 M calcium chloride) is calcium insensitive (Fox, 2003). The κ-casein stabilizes the particles by extending the caseinomacropeptide moiety, containing sufficient amounts of hydrophilic amino acids, into the serum. This forms a “hairy” layer on the micelle surface that provides steric and electrostatic stabilization (de Kruif & Zhulina, 1996). The α₅₆ and β-caseins form the internal structure of the micelle, owing to the presence of patches of hydrophobic residues, which enable hydrophobic interactions with other hydrophobic proteins. The internal structure of casein micelles is still being debated. A number of models have been suggested by researchers depicting the internal structure of the casein micelles, including the submicelle (Walstra, 1990), dual binding (Horne, 1998), and nanocluster (Holt et al., 2003) models. They all emphasize the importance of hydrophobic bonds and calcium bridges in holding the micelle together. All these models have been reviewed by Dalgleish (2011).

The size of casein micelles ranges from 80 to 400 nm, with an average of 200 nm (de Kruif, 1998). Its molecular weight is 3.7 × 10⁶ Da. The casein micelles, owing to their colloidal dimensions, are capable of scattering light and are responsible for the white color in milk. The micelles carry an overall negative charge at neutral pH, equivalent to zeta potential of about −20 mV (Dalgleish, 2011). Caseins precipitate close to pH 4.6 (isoelectric pH) and at high temperatures of 140°C for 15–20 min at normal pH of milk.

Whey proteins are globular proteins consisting mainly of α-lactalbumin and β-lactoglobulin, forming approximately 20% of proteins in bovine milk. The globular structure is mainly attributed to the disulfide bonds present in them (Smith & Campbell, 2007). Whey proteins have a net negative charge at pH 6.6 (normal milk pH). β-Lactoglobulin is the major whey protein in bovine milk (50% of total whey proteins). It does not occur in human milk and is one of the primary allergenic protein in bovine milk for human infants. Whey proteins are rich in sulfur amino acids and have high biological value. α-Lactalbumin is a calcium-binding metalloprotein and constitutes 20% of whey proteins.

**17.2.3 Salts**

Milk salts include organic and inorganic salts. The inorganic salts include Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, CO₃²⁻, SO₄²⁻, and PO₄³⁻; organic salts include amines, citrate, carboxylic acid, and phosphoric esters. Salts in milk can be present in the dissolved and undissolved (colloidal) form (as given in Table 17.1). The dissolved salts play an important role in milk protein stability. A part of the colloidal salts is associated as counter ions to the negatively charged casein micelles. The rest of the undissolved salts consist of calcium and phosphate that are integral to the structure of the casein micelles. Salts are the principal buffering compounds in milk, especially soluble calcium phosphate, citrate, and bicarbonate (Fox & McSweeney, 1998a), though proteins also contribute to buffering capacity. The stability of proteins in milk can be associated with the molar ratio of calcium and...
phosphorus (including organic phosphate), which is 0.9 in bovine milk (Walstra et al., 2006). Salts, particularly Na⁺, K⁺, and Cl⁻, are responsible for electrical conductivity of milk. Increase in electrical conductivity may occur due to bacterial fermentation of lactose to lactic acid.

### 17.2.4 Lactose

Lactose is the primary carbohydrate in bovine milk. It is a disaccharide of galactose and glucose units, linked by a β-1-4 glycosidic bond (4-O-β-D-galactopyranosyl-D-glucopyranose). Lactose is a reducing sugar and exists as α and β anomers in solution. In solution, lactose undergoes mutarotation between α and β forms, involving interchanging of OH and H groups on the reducing group. Mutarotation of lactose depends on temperature and pH. The α and β forms vary in solubility, crystal shape, size, hydration of crystal form, specific rotation, and sweetness. The α-lactose crystallizes as α-monohydrate and α-anhydrous forms, while β-lactose crystallizes into β-anhydride crystal. Some of the physical properties of the two common forms of lactose are given in Table 17.2. Lactose crystallizes much faster than other sugars like sucrose. It is confusing to talk about supersaturated solutions and which sugar crystallizes first. Crystallization of lactose leads to formation of large crystals, which are associated with sandy texture defect in sweetened condensed milk and ice cream (Fox & McSweeney, 1998b).

### 17.3 Milk handling

In a typical modern dairy farm, milk is transferred after milking, rapidly cooled to 4°C in bulk tanks (300–30,000 L), and kept for a maximum of 72 h before transportation to the processing facility. Milk is transported in milk trucks with standard capacity of about 25,000 L/truck and distances that vary from industry to industry. For most dairy industries, the milk hauler/sampler is responsible for an initial quality control (e.g. check for appropriate storage conditions, aroma, and visual appearance of milk) and also collects samples from the bulk tank to be tested at a certified state laboratory and after reception in the plant. A bulk milk hauler/sampler

<table>
<thead>
<tr>
<th>Table 17.2 Physical and chemical properties of cow milk</th>
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</thead>
<tbody>
<tr>
<td>Properties</td>
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<tr>
<td>pH (25°C)</td>
</tr>
<tr>
<td>Acidity</td>
</tr>
<tr>
<td>Redox potential</td>
</tr>
<tr>
<td>Specific gravity</td>
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<tr>
<td>Coefficient of viscosity</td>
</tr>
<tr>
<td>Viscosity</td>
</tr>
<tr>
<td>Refractive index ([α]D)</td>
</tr>
<tr>
<td>Specific refractive index</td>
</tr>
<tr>
<td>Electrical conductivity (25°C)</td>
</tr>
<tr>
<td>Surface tension</td>
</tr>
<tr>
<td>Specific heat</td>
</tr>
<tr>
<td>Heat capacity¹</td>
</tr>
<tr>
<td>Thermal diffusivity</td>
</tr>
<tr>
<td>Thermal conductivity</td>
</tr>
<tr>
<td>Ionic strength</td>
</tr>
<tr>
<td>Colligative properties</td>
</tr>
<tr>
<td>Freezing point</td>
</tr>
<tr>
<td>Boiling point</td>
</tr>
<tr>
<td>Osmotic pressure</td>
</tr>
<tr>
<td>Specific electrical conductance (25°C)</td>
</tr>
<tr>
<td>Water activity</td>
</tr>
<tr>
<td>Coefficient of cubic expansion</td>
</tr>
</tbody>
</table>

undergoes a training program and is examined by testing for competency, as prescribed by a regulatory agency, to be licensed. The procedure of milk sampling and care is followed as specified by the Standard Methods for Examination of Dairy Products (SMEM; Graham, 2004).

Milk trucks are weighed at arrival and then milk is transferred to large-capacity storage silos. During pumping, a heat exchanger may be used to assure proper temperature of the milk being transferred to the storage silo. The milk, based on its sanitary, microbial, chemical and handling quality, is graded as A (Grade A) or B (manufacturing grade) milk by the US Department of Agriculture (USDA). The standards for Grade A milk are published in the Grade “A” Pasteurized Milk Ordinance (PMO; FDA, 2011). The details of the grading, standards, and regulating agencies are provided later on in this chapter.

Milk pricing in the US is a complex system which varies between grades of milk and from industry to industry. The base pricing, especially for Grade A milk, is set administratively through the state and federal milk marketing orders. The federal milk marketing orders are not mandatory, but the dairy producers can request and approve them as authorized by the Agricultural Marketing Agreement Act of 1937. The milk marketing orders utilize “classified pricing” to establish minimum prices for milk and milk components based on their use and “pooling” to set uniform pricing regardless of how milk is used. On the other hand, shelf-stable manufactured dairy product pricing is determined either by the market demand and supply or the dairy price support program. The dairy price support program operates through the USDA’s Commodity Credit Corporation (CCC). It maintains the price level and product supply of many manufactured dairy products, including but not restricted to butter, buttermilk, non-fat dry milk, and cheese. A good review of the basic milk pricing concepts has been authored by Jesse and Cropp (2008). Some methods used in base pricing are based on fat and protein content, together with bonuses and/or penalties for milk quality, while more complex pricing systems are adopted by many dairy industries and organizations (Manchester & Blayney, 2001).

17.3.1 Processing of fluid milk

17.3.1.1 Cream separation and standardization

The standard of identity for each dairy product sets different fat and total solids percentage in the final product. Standardization is the process of adjusting the composition, especially the fat content, to the prescribed amount. The process that enables standardization by removing the fat content in milk is cream separation (Figure 17.1). The principle behind cream separation is the lower density of fat compared to the rest of the milk phase. This density difference enables its separation from the rest of the milk by the application of centrifugal force.

The equipment assembly of a cream separator consists of conical disks mounted on top of a bowl (Figure 17.2). The disks are separated by gaps between the plates and have a hole on either side of the cone. Whole milk is pumped from the bottom center of the cone. With centrifugal force produced by the rotation of the disks along with the disk holder, cream moves up to the top and through the holes and skim milk through the sides, to come out of different channels, thus separating them from each other. The cream (approximately 40% fat) can then be used to standardize milk and milk products for fat content. The skim milk stream typically contains less than 0.1% fat.

17.3.1.2 Homogenization

One of the processes that have become standard in the last 50 years for fluid milk and dairy products is homogenization. In the simplest terms, homogenization is subjecting a fluid to extreme mixing energy. This can be done by forcing the fluid through a small hole or gap at high velocity or by very high speed propeller mixing. For fluid milk, homogenization helps control the size of the fat particles this prevents creaming milk fat on storage. Having this control helps prevent the fat particles from agglomerating and floating to the top. Historically, homogenizers were developed early in the 20th century to prevent stealing of valuable fat by whole sellers (Trout 1948). Today most consumers prefer to consume milk products without separation. A few consumers are willing to pay a premium for non homogenized milk, however.

For the most part, homogenizers used in the dairy industry are specialized reciprocating high-pressure pumps with one or two restrictions to flow (valves). Figure 17.3 shows a schematic of a homogenizing valve. The pump propels fluid through the valves at high pressure and volume, causing the fluid to be exposed to very high shear forces and in some cases cavitation. This causes the milk fat globule (MFG) to break apart. Force applied to the valve decreases the size of the gap; Cavitation is the formation and implosion of cavities in a liquid due to rapid changes in pressure. Shock waves due to cavitation are thought to contribute to either the breakdown of the fat globules or to the breaking of clumps of fat globules immediately after the point of maximum shear.
this in turn increases the pressure and velocity of the suspension of fat globules in the gap. The shear forces thus generated causes the fat globule size to decrease.

Most homogenizers have two valves; the purpose of the first valve is to do the actual size reduction of the globules.

The second valve functions to put a little back pressure on the first, this helps separate the clusters of fat globules that quickly form after the first stage. This also gives a little time for the proteins and MFGMs to form a new fat globule membrane (Walstra, 1975). Sometimes this pressure is reduced or eliminated from the second stage, to encourage these agglomerations. This is done to achieve increased viscosity in creams and other dairy products. The first stage of homogenization usually employs 2000–2500 psi (14–17 MPa) and the second stage 300–1000 psi (4–7 MPa) for milk (see Figure 17.1).

For homogenization to work, the fat must be in the liquid state. For dairy fat, the temperature must be greater than 52 °C for fats to be in liquid state. Higher temperatures result in lower fat viscosity and this in turn results in smaller, more uniform globules. Another benefit of homogenizing milk at elevated temperatures is that inactivation of the enzyme lipase occurs. Lipase is an enzyme that cleaves fatty acids from triglycerides, which can lead to rancid off-flavors in milk. When fat globule size is reduced, the amount of surface that the fat globules have is increased. For milk, the average diameter decreases from 3.3 μm without homogenization to 0.2 μm after homogenization, and the total surface area increases from 80 m²/L without homogenization to 1250 m²/L after homogenization. Protein, primarily casein, provides coverage

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**Figure 17.1** Schematic diagram of a typical fluid milk processing unit.

**Figure 17.2** Schematic diagram of a disk bowl cream separator.
for the surface generated by homogenization. When milk is homogenized, the tendency for the fat to cluster together and float to the top of container is reduced. Equation 17.1 describes the relationship between fat globule size and the speed of the globule rising to the top.

\[ v_s = \frac{-a(\rho_p - \rho_f)d^2}{18\eta_p} \]  

Equation 17.1. Stokes velocity, the velocity of a particle of density \( \rho_f \) and diameter \( d \) in a fluid with density \( \rho_p \) and viscosity \( \eta_p \). In the case of creaming due to gravity, \( a \) is equal to the force of gravity (9.8 m/s\(^2\)).

Factors such as agglomeration of fat and other particles, number of particles, fat globule shape, and the nature of the fat globule surface will also affect the velocity. This formula does describe, in a general way, how the size of the fat globule affects the speed of creaming. Decreasing the fat globule size or increasing the serum viscosity will slow creaming and size will have the stronger effect. Since the fat globules are moving violently during homogenization, individual fat globules may bump into each other and agglomerates or clusters of fat globules are formed in these collisions.

### 17.3.1.3 Pasteurization

The primary purpose of pasteurization is to inactivate most pathogens (disease-causing bacteria) in milk to make it safer to consume (at least reduction in five log cycles of population of *Mycobacterium paratuberculosis*; Stabel & Lambertz, 2004). Due to food safety concerns, this process is highly regulated all over the world. There are basically three methods used to pasteurize milk: vat pasteurization (or low-temperature, long-time (LTLT)); high-temperature, short-time (HTST) pasteurization; and ultra-pasteurization (or ultra high-temperature pasteurization (UHT) if aseptically packaged. The times and temperature requirements are listed in Table 17.3 as defined in the CFR (21 CFR 131).

The regulations further state that every particle of product must reach these temperatures, at a minimum, and be maintained at or above the temperature for a minimum of these times. The equipment used in pasteurization must be designed and regularly tested to fulfill this mandate as referred to in Appendix H in the PMO (FDA, 2011). The PMO specifies that Grade A milk raw must contain less than 100,000 colony-forming units per milliliter (CFU/mL) of total aerobic bacteria. Pasteurization is designed to kill 5 logs (100,000 CFU/mL) of heat-susceptible bacteria; pathogenic bacteria are heat susceptible. The reason why pasteurized milk is not sterile, and milk needs to be pasteurized, is that thermoduric bacteria endure HTST processing and can later cause spoilage in milk.

![Diagram of a milk homogenization valve.](image)

Table 17.3 Times and temperatures for the pasteurization of fluid milk as defined in the CFR (7 CFR 58)

<table>
<thead>
<tr>
<th>Common name of treatment</th>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low temperature, long time (LTLT)</td>
<td>63 °C (145 °F)</td>
<td>30 minutes</td>
</tr>
<tr>
<td>High temperature, short time (HTST)</td>
<td>72 °C (161 °F)</td>
<td>15 seconds</td>
</tr>
<tr>
<td>Ultrapasteurization (UP)</td>
<td>138 °C (280 °F)</td>
<td>2 seconds</td>
</tr>
</tbody>
</table>
The primary method used in the fluid milk industry is HTST. In this process, there are three heat exchange sections: regeneration, heating, and cooling (see Figure 17.1). These sections consist of stacks of corrugated (to enable efficiency by increasing the surface area of heat transfer) stainless steel plates, where the heating medium and product flow in separate alternate plates (Figure 17.4). The plates are formed such that they direct the flow of the product evenly across the surface and maximize the surface area of the plates. The flow in the heat exchangers can be concurrent or countercurrent flow. Concurrent flow is where both the heating medium and the product flow in the same direction. This lowers efficiency heat transfer compared to the countercurrent flow, where the heating medium and the fluid product flow in opposite directions. The regenerator section has pasteurized heated product on one side of the plates and unpasteurized cold product on the other. This section recovers much of the heat from the pasteurized product, increasing the efficiency of the pasteurizer. The only energy that needs to be supplied is that lost to the atmosphere and that due to inefficiencies of the heat transfer. Pressures in these plates are arranged so that if there should be a leak between the plates, the flow would always be from the pasteurized product into the unpasteurized product or the other heat exchange fluid.

The heating section is connected to the holding tube (see Figure 17.1). The heating section brings the temperature up such that at the end of the holding tube, the product is at a temperature higher than the stated pasteurization temperature (i.e. 72°C) for at least the minimum time (i.e. 15 sec). The heat transfer fluid for this section of the pasteurizer is most usually hot water. To guarantee that every particle of product is heated and held for the prescribed temperature and time, pasteurizers are provided with a holding tube and timing pump. This tube's length is calculated using the flow rate provided by the timing pump to give, at a minimum, the prescribed hold time. The timing pump's speed is adjustable and the flow rate is tested and sealed by regulatory officials. The holding tubes are mounted with an incline so that they will flow continuously back toward the heating section in the case of a shutdown. Pasteurizers are also provided with a set of valves, arranged to divert the product flow back through the pasteurizer when the product flow or temperature settings are not met, called the flow diversion valve (FDV). The goal for all the machinery involved in pasteurization is to guarantee that every particle passing through the system is subjected to the minimum time and temperature set by the regulatory agencies. In the cooling section, the product cooled by the incoming product or the other heat exchange fluid.

Alternatives to plate heat exchangers can be tube-within-tube heat exchangers, where one fluid passes within a central tube in one direction while the second fluid passes in the other direction in a tube surrounding the central tube. Product can also be heated directly by bringing it into direct contact with steam. The water thus added to the product is removed by vacuum evaporation downstream. Scraped surface heat exchangers are used to

Figure 17.4 Schematic diagram of a plate heat exchanger with end plates and corrugated plates in between. The flow is indicated by the continuous line for fluid product and the dashed line for the heating medium.
heat treat fluids with particulate matter or higher viscosity. They have scrapers that remove the product fouling of the heat exchanger walls.

There are additional methods of pasteurization, including vat, UP, and UHT. Vat pasteurization differs in that the heating fluid passes around the jacket of a specially designed tank. In order to prevent contamination from condensate dripping into the pasteurizing fluid, the temperatures above the fluid in the tank must be above that of the fluid at all times. Since the temperatures are lower for vat pasteurization, the process times are necessarily longer to achieve the same kill of pathogens. The equipment for UP and UHT pasteurization is similar to HTST except for the time and temperatures involved. UP involves higher temperatures (with shorter hold times) than HTST. The primary advantage of UP and UHT is that the product is rendered essentially commercially sterile when combined with aseptic packaging (as with UHT), which allows for shelf stability.

Regulations establish the minimum design and instrumentation for all forms of pasteurization. The sanitary fabrication, construction, and design of dairy equipment have been enforced based on the standards set up by the National Conference on Interstate Milk Shipments (NCIMS) given in the PMO Appendix H (FDA, 2011). Another independent organization that has developed the 3-A standards for the dairy industry is the 3-A Sanitary Stds., Inc. The references to these standards can also be found in the PMO (FDA, 2011).

17.3.1.4 Packaging

At the beginning of the 20th century fluid milk was sold commercially in glass bottles. Glass bottles were replaced by gable topped cardboard containers and by plastic (high-density polyethylene (HDPE)) bottles or jugs and plastic (low-density polyethylene (LDPE)) pouches since the 1960s. A package is defined to protect a food product and preserve its nutritional value. In the dairy industry the package should protect the milk product from mechanical shock, light, and oxygen. The exposure to light and oxygen induces fat oxidation, development of oxidized off-flavors, and loss of vitamins in milk. The different filling systems used in the dairy industry are form fill and seal, aseptic filling, and bottle filling. In the form fill and seal system, the packaging material is made to form a container in the filling machine; the product is filled into this container and then sealed. This method is used for plastic pouches and paper cartons. Aseptic filling is utilized for aseptically packaged milk products where a sterile product is filled into a sterile container under aseptic conditions.

17.4 Dairy product processing

17.4.1 Fluid milk products

There are a variety of fluid milk products available on the US market. These include the following (along with references for standards of identity in the CFR).

17.4.1.0.1 Whole, reduced-fat (2%), low-fat (1%), and fat-free (skim) milk (21 CFR 131.110)

The percentage of milk fat is adjusted in the milks by cream separation and standardization processes, providing these fluid milk varieties. All of the reduced-fat milks are fortified with vitamins A and D because these vitamins are fat soluble. The standards of identity of whole, reduced-fat, low-fat, and fat-free milks require them to contain >3.25%, >2%, >1%, and <0.1% milk fat by weight. The total solid content of all these milk should be at least 11.5% w/v.

17.4.1.0.2 Lactose-free and lactose-reduced milks

Lactose-free and lactose-reduced milks are produced by the complete or partial hydrolysis of lactose in milk. The hydrolysis of lactose into glucose and galactose is accomplished using B-galactosidase (lactase) enzyme. Lactose intolerance or lactose maldigestion is a condition where people are unable to produce B-galactosidase. Milk treated to be reduced in lactose or free of lactose can be a strategy for living with this condition. It is also possible to recombine milk using materials like whey protein isolate, whole milk protein isolate or vegetable proteins such that the product does not contain lactose. Such recombined milks do not have a standard of identity specified by the FDA.

17.4.1.0.3 Light, light whipping, and heavy cream

Cream is a fat-rich dairy product, obtained from the cream separation from milk and pasteurization. The percentage fat distinguishes the different cream varieties, but cream as a whole should contain more than 18% milk fat. The fat percentage requirements of light, light whipping, and heavy cream as in the CFR are given in
Table 17.4 Standards of identity for some fluid milk products (USGPO, 2013)

<table>
<thead>
<tr>
<th>Fluid milk product</th>
<th>Standards for composition</th>
<th>Section of title 21 CFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light cream</td>
<td>&gt;18% and &lt;30%</td>
<td>131.155</td>
</tr>
<tr>
<td>Light whipping cream</td>
<td>&gt;30% and &lt;36%</td>
<td>131.157</td>
</tr>
<tr>
<td>Heavy cream</td>
<td>&gt;36%</td>
<td>131.150</td>
</tr>
<tr>
<td>Half and half</td>
<td>&gt;10.5% and &lt;30%</td>
<td>131.180</td>
</tr>
<tr>
<td>Evaporated milk</td>
<td>&gt;6.5% &gt;23%</td>
<td>131.130</td>
</tr>
<tr>
<td>Concentrated milk</td>
<td>&gt;7.5% &gt;25.5%</td>
<td>131.115</td>
</tr>
<tr>
<td>Sweetened condensed milk</td>
<td>&gt;8% &gt;28%</td>
<td>131.120</td>
</tr>
</tbody>
</table>

Table 17.5 Heat treatment times and temperatures for cream for different purposes (7 CFR 58.334)

<table>
<thead>
<tr>
<th>End use of cream</th>
<th>Heat treatment</th>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cream for butter making</td>
<td>Vat pasteurization</td>
<td>85 °C (165 °F)</td>
<td>30 minutes</td>
</tr>
<tr>
<td></td>
<td>HTST</td>
<td>74 °C (185 °F)</td>
<td>15 seconds</td>
</tr>
<tr>
<td>Cream for frozen and plastic creams</td>
<td>Vat pasteurization</td>
<td>88 °C (170 °F)</td>
<td>30 minutes</td>
</tr>
<tr>
<td></td>
<td>HTST</td>
<td>77 °C (190 °F)</td>
<td>15 seconds</td>
</tr>
</tbody>
</table>

Table 17.4. The processing steps in producing cream involve cream separation, homogenization, and pasteurization. The pasteurization temperatures for cream are higher than for milk (Table 17.5), as the higher fat content is known to offer protection to microorganisms (Senhaji, 1977). Appropriate terms have to be added to the product name on the label if the creams are sweetened or flavored.

17.4.1.0.4 Half and half

Half and half is a mixture of milk and cream. It is produced from a series of processes including standardization, homogenization, and pasteurization. The details of the requirements for this product are given in Table 17.4.

17.4.1.0.5 Flavored milk

Flavored milks are milks with or without coloring, nutritive sweeteners, emulsifiers, stabilizers, and fruit or fruit juice. Chocolate milk is a commonplace example of this genera. They are classified under milks in the CFR. These products undergo the same processing steps as for white milk.

17.4.1.0.6 Concentrated, evaporated, and sweetened condensed milk

These dairy products are obtained by the partial removal of water from milk. While sweetened condensed milk (SCM) contains suitable nutritive carbohydrate sweeteners, they are absent in evaporated and concentrated milks. The difference between evaporated and concentrated milk is the sealing of the product in a container and heating before or after packaging to prevent spoilage in evaporated milks. The details of milk fat and milk solids non-fat regulations for concentrated, evaporated, and sweetened condensed milks are given in Table 17.4.

17.4.2 Ice cream processing

Like most products, on the surface ice cream appears to be a simple entity, but on closer examination it is one of the most complex food products that exist. Most foods have a single phase structure that is either fat or water based, or a simple emulsion of fat and water. Ice cream, on the other hand, contains liquid (both water and fat), crystalline (water, fat, and sugar) and gaseous phases (air and water vapor). All of these are important to its production, distribution, and consumption. It contains fat that, in the same product at the same time, exists in both liquid
and solid phases. Further, the fat can be crystallized into several forms. Processing of ice cream and frozen desserts is, at its most basic level, the management of these phases. If processing is not carried out in such a way that all the phases are correct, the product will have problems during processing, storage, or transportation or at consumption.

Ice cream is a frozen food made from dairy products, sugars, flavorings, and minor amounts of optional ingredients used to improve texture, enhance shipping and aging characteristics and make manufacturing more efficient. In the US, ice cream is defined in the CFR Title 21, Chapter 1, Subchapter B, Part 135, subpart B, “Requirements for specific standardized frozen desserts.” In other countries similar standards exist. It is increasingly important to keep in mind that standardized frozen desserts are a subset of frozen desserts in general. Unstandardized products deviate from standardized products for reasons of expanded creativity, economy, new technology or expedience in manufacture, storage, distribution, marketing, and consumption. A common example of an unstandardized product would be a frozen dessert made in the US using vegetable fat instead of dairy-derived fat.

In the US, people consume about 22 L of ice cream per person per year. In 2013, the global ice cream market is forecast to have a value of $54 billion, an increase of 20.3% since 2008. In 2013, the global ice cream market is forecast to have a volume of 12.7 billion L, an increase of 15.7% since 2008 (Techzone, 2010).

### 17.4.2.1 Raw materials and their storage

The ingredients used in frozen desserts include, but are not necessarily limited to, air, water, whole milk, skim milk, cream, butter, condensed milk, non-fat dry milk, whey, whey protein powders, caseinates, vegetable-derived protein powders, dairy and vegetable-derived fats, sugars, sugar alcohols, high-potency sweeteners, maltodextrin, eggs, egg yolks, hydrocolloid stabilizers, emulsifiers, flavors, and colors. In addition to these, any number of bulk flavors, inclusions and variegates are added after freezing to produce the variety of frozen dessert products found in the marketplace. All ingredients should be analyzed for microbial contamination and for general quality before they are incorporated into the dessert. Many of these ingredients are raw agricultural products. It is vitally important that these be kept under conditions that discourage the growth of pathogenic or spoilage organisms (cold). Liquid dairy ingredients, being composed of sugars, fats and protein, will separate if not kept adequately agitated.

Certain dairy products, like skim milk and cream, have a tendency to form stable foams. Care should be taken to avoid splashing or whipping these products during storage. Not only does foaming make processing difficult, but in some cases this can cause a severe loss of quality in the final product.

Ingredients that contain fat or other components that are prone to oxidation should be packaged or stored in such a way that they are exposed to the minimum possible oxygen, care should be taken to use these products quickly enough to preclude the oxidation of their components. Raw milk is prone to rancidity, caused by the presence of enzymes (i.e., lipase) in the raw milk. The fat in raw milk is protected from the enzyme by the MFGM. However, this membrane can be damaged by high shear processes such as pumping, violent agitation, splashing, and any other high shear process. Therefore, raw milk should be handled as carefully and gently as possible. Powdered products should be kept under conditions that will maintain them as free flowing as possible. This usually entails keeping the powders as cool and dry as possible and not stacking the bags too high. Frozen ingredients should be kept as cold as possible, with as little temperature fluctuation as possible. When frozen ingredients are thawed, this should be done so that the entire product is maintained at a temperature that discourages microbial growth or it should be done quickly enough that microbial growth is not significant. It should be assumed that microbial growth will happen any time the temperature exceeds 0°C. It is also good practice to assume that all products containing more than 4% water have the ability to support the growth of pathogenic or spoilage organisms or at least maintain their numbers. It is therefore vitally important to pasteurize and/or freeze all ingredients into finished products as soon as possible. Good ingredient rotation will not only result in a superior product but it will minimize the risks involved in processing raw agricultural products into frozen desserts.

### 17.4.2.2 Preparation for processing

Frozen dessert mixes are made to specifications determined by the product line and regulations (specifications are provided in the CFR; USGPO, 2013). These specifications are called a formula. The formula expresses the components as dry percent and Table 17.6 shows a typical formula for a 10% ice cream mix. For “ice cream,” 10% fat is the minimum fat content; ice cream must also weigh at least 4.5 lb/gallon (539.2 grams/L) to comply with US regulations.
The formula is converted daily into a recipe using the specifications and test results of the ingredients that will be used in the product. Table 17.7 shows a recipe developed from this formula. Since the milk solids non-fat and milk fat for dairy ingredients vary considerably depending on the milk supply, the amounts needed in a recipe can vary considerably. If these are not taken into account, variation in the final product will result. Consistency is very important for consumer satisfaction.

In general, specifications for powdered products do not vary as significantly as do many manufactured ingredients, such as sugar or corn syrup. Nonetheless, even if all the ingredients are manufactured to a constant specification, it is good practice to maintain a constant formula and calculate recipes from the formula for each batch. Changes in the form of the ingredients needed for a formula can be based on price and availability. Calculating recipes maintains flexibility in the form of the ingredients used on a day-to-day basis. It is always good practice to analyze and monitor ingredient characteristics in case they change and need to be taken into account in the recipe. A traditional method of calculation of ice cream mix composition is by the serum point method (description in textbooks including Hyde & Rothwell (1973) and Marshall et al. (2003)). There are many computer programs and spreadsheets that can calculate recipes from a formula. These range from relatively complex systems that can monitor inventories as well as calculate batch sheets to simple single-purpose spreadsheets.

### 17.4.2.3 Processing steps

The vast majority of frozen desserts are made using the same methods. In order to avoid repetition, the process for ice cream will be described here. The general steps in the process are shown in Figure 17.5.

#### 17.4.2.3.1 Blending

The first step in producing frozen desserts is the production of a pasteurized “mix.” In producing a mix, the liquid and dry ingredients must be brought together in such a way that all ingredients are dispersed completely prior to heat treatment. There are several problems that must be overcome in this process. Each ingredient will have different density. The tendency will be for these ingredients to float or sink depending on their density. Ingredients that float to the top or sink to the bottom may not be incorporated into the final mix. This will cause inconsistency in the final product. Some ingredients are so hydroscopic that they have a tendency to clump. In extreme cases, such as with some hydrocolloids and proteins the material will form insoluble clumps that are difficult or impossible to break up. If this happens, these ingredients may not be able to pass through filters or screens and will not be incorporated into the mix, causing quality and consistency issues. The blend of ingredients can have a

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Milk fat</th>
<th>Milk solids</th>
<th>Total solids</th>
<th>Pounds for 100 gal batch (928 lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cream</td>
<td>41.50%</td>
<td>5.27%</td>
<td>46.77%</td>
<td>184.16</td>
</tr>
<tr>
<td>Milk</td>
<td>3.65%</td>
<td>8.65%</td>
<td>12.30%</td>
<td>443.60</td>
</tr>
<tr>
<td>Non-fat dry milk</td>
<td>0.50%</td>
<td>96.50%</td>
<td>97.00%</td>
<td>172.00</td>
</tr>
<tr>
<td>Whey powder</td>
<td>0.00%</td>
<td>97.00%</td>
<td>97.00%</td>
<td>19.15</td>
</tr>
<tr>
<td>Sugar syrup</td>
<td>0.00%</td>
<td>0.00%</td>
<td>67.50%</td>
<td>58.05</td>
</tr>
<tr>
<td>36 DE corn syrup</td>
<td>0.00%</td>
<td>0.00%</td>
<td>80.00%</td>
<td>4.69</td>
</tr>
</tbody>
</table>

DE, dextrose equivalent.

### Table 17.6 Typical formula for a 10% ice cream mix

<table>
<thead>
<tr>
<th></th>
<th>Percent by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk fat</td>
<td>10.0%</td>
</tr>
<tr>
<td>Milk solids non-fat</td>
<td>10.0%</td>
</tr>
<tr>
<td>Whey solids</td>
<td>2.0%</td>
</tr>
<tr>
<td>Sugar solids</td>
<td>12.5%</td>
</tr>
<tr>
<td>36 DE corn syrup solids</td>
<td>5.0%</td>
</tr>
<tr>
<td>Emulsifier stabilizer blend</td>
<td>0.5%</td>
</tr>
<tr>
<td>Total solids</td>
<td>40.0%</td>
</tr>
</tbody>
</table>

DE, dextrose equivalent.
tendency to form stable foams (this is desirable in the final product but undesirable in mixes). The order of addition and the equipment used for blending are designed to minimize or eliminate these problems.

Blending is usually preceded by some method of measuring out the ingredients. This is accomplished, for the liquid ingredients, by weighing or metering the ingredients into a blend tank. This tank should not be violently agitated to prevent the development of rancidity in raw milk. The dry ingredients are most often weighed on scales.

After the dry ingredients are weighed out, they are mixed with the liquid ingredients. As mentioned above, some dry ingredients are so hydrophilic that they form clumps, with very high viscosity or gelled outer layers and essentially dry powder in the interior. In order to keep this from happening, these materials need to be as widely dispersed as possible. There are four basic ways in which this can be done; the most popular and efficient way is using a high shear mixer. A small amount of liquid is brought into the blender, a high shear mixing head is started and the powder is fed, slowly, into the blender. Another method feeds the powder slowly into a stream of liquid; the powder is fed into the stream through an open funnel. Sometimes a modified pump further mixes the powder and liquid. Perhaps the oldest method and least efficient is to simply add the powder to the top of the tank of liquid ingredients with strong agitation. This tank is often provided with a recirculation pump to aid in distributing the powder while it hydrates. Hard-to-handle products like stabilizer blends containing hydrocolloids can be first dispersed in an ingredient that does not tend to form clumps, like granulated sugar. The mixture can then be added to the blender slowly; the sugar helps keep the particles of the viscous ingredient separated, keeping them from forming clumps. A similar method used is to disperse the powder in liquid sugar in a high shear blender. Since the amount of water in liquid sugar is low, the particles are able to disperse within the syrup before they hydrate. In each case the strategy is to keep the individual particles of dry ingredients far apart from one another in order to wet the entire surface of each particle separately and therefore to disperse all the particles as uniformly as possible in the blend before they fully hydrate.

It is important to be aware that during blending and subsequent storage before pasteurization, many of the ingredients are not dissolved in the liquid but are only dispersed. If given the chance (insufficient agitation, for instance), they will segregate at the top and bottom of the blend tanks. This can prevent important components from being included in the final product. If this problem exists, the final product will be inconsistent. It may also cause the mistaken conclusion that the settled component is underdosed, which in turn may cause loss of money due to adding too much of that ingredient in the future.

As blending is the first step in making ice cream, it is very important that it be carried out correctly.

17.4.2.3.2 Pasteurization and homogenization

Similar to fluid milk, the primary purpose of pasteurization is to eliminate the pathogens in the ice cream mix to make the product safe to consume; freezing does not kill pathogens. The times and temperatures for ice cream, which are higher than for fluid milk, are listed in Table 17.8 as defined in the CFR. Temperatures of treatment are higher compared to fluid milk because higher amount of solids in ice cream provide a protective effect to bacteria.

Many frozen dessert mixes are viscous. This can cause the product’s flow to be laminar, as opposed to turbulent, for lower viscosity products such as milk. Since the
residence time for particles near the tube walls is longer for laminar flow than it is for turbulent flow, holding tubes for frozen desserts are designed to hold the product for a longer time (Marshall et al., 2003). Tubular and scraped surface heat exchangers are almost never used in ice cream production. Plate heat exchangers are far more common as are batch pasteurizers. The heating of frozen dessert mixes not only accomplishes the required destruction of pathogens and the reduction in the numbers of spoilage organisms; in products containing fat, the heating melts both the fat and the emulsifiers and allows them to interact. This will become critically important during the aging and freezing of these mixes. Heating aids in the dispersion and hydration of hydrocolloids, allowing for these ingredients to become functional. Proteins can be denatured and they can interact with other proteins, stabilizers and other ingredients with heat. This can help increase viscosity. Exposure of protein and sugars to heat can result in browning reactions that can add flavor to mixes. Heating regimes are often increased above the legal limits for this reason alone.

Homogenization’s effects on the fat structure in frozen desserts are the primary reason for its use. The secondary benefit of homogenization includes dispersion of the particles of some stabilizers (primarily microcrystalline cellulose). It can have detrimental effects as well; protein and some hydrocolloids may also be broken down by high shear and temperature. This can cause loss of viscosity, especially when the product is repeatedly homogenized as in reprocessing.

### 17.4.2.3.3 Aging

Once the product has been pasteurized and cooled, it is placed into a chilled tank for aging. During aging, the following structural changes happen.

- Hydrocolloids and protein become fully hydrated.
- Milk protein desorption from the milk fat globules occurs.
- Fats crystallize.

It is obvious that it would be desirable for production efficiency to be able to freeze the product directly after pasteurization. However, aging improves the quality of the final product. The various arrangements in the emulsion structure of the ice cream mix ensure an acceptable texture for the final product. However, a clear picture of the emulsion rearrangements occurring during aging is still not known. The stabilizers and emulsifiers (hydrocolloids) added to the mix during the blending stage are completely hydrated during the aging step.

The cooling to less than 4 °C also causes fat crystallization. The surfactants (emulsifiers) will then adsorb to the partially crystallized fat phase. The proteins forming the MFGM after homogenization are desorbed from the fat surface due to the lowering of the hydrophobic forces at lower temperatures but this is a very minor effect at 10 °C. The main effect is the movement of emulsifiers from the fat on to the surface during fat crystallization thus displacing the protein (Bradford et al., 1991; Danisco 2010; Iversen & Pedersen, 1982; Marshall et al., 2003) and displacement by emulsifiers moving from the fat to the surface of the globule due to fat crystallization. The fat crystals also partially rupture or distort the MFGM, enabling interglobular contact and forming the new stabilized structure (van Boekel & Walstra, 1981).

Since the hydration of protein and hydrocolloids is relatively fast, for products without fat the aging step is less important than it is for products containing fat. In non-fat products, some further hydration of stabilizers and some relaxation of protein can occur; these can make minor improvements in the final product and for processing. In products containing fat, a lack of aging can cause products to be difficult to whip, have poor extrusion properties and to melt improperly. During aging, the fat and emulsifiers (primarily monoglycerides) crystallize. This can be observed in a non-refrigerated tank as an increase in temperature due to the heat given off during fat crystallization. This process can take several hours. Products made without complete crystallization of the fat are prone to churning of the fat. This is evidenced by churned fat (butter) being found in the finished product and inside the freezer and other equipment handling the incompletely aged product. Liquid and partially liquid fat in the high shear environment of pumps, pipes and in the freezer are much more likely to agglomerate together in even larger particles. This uncontrolled agglomeration results in the deposition of fat in the equipment and loss of quality in the finished product.

Monoglyceride emulsifiers are added to frozen dessert mixes to provide controlled agglomeration. These result

### Table 17.8 Pasteurization – minimum temperature and time for frozen desserts

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>69 °C (155 °F)</td>
<td>30 minutes (vat)</td>
</tr>
<tr>
<td>80 °C (175 °F)</td>
<td>25 seconds (HTST)</td>
</tr>
<tr>
<td>138 °C (280 °F)</td>
<td>&gt;2 seconds (UHT)</td>
</tr>
</tbody>
</table>

in the ability of the product to hold more air, extrude more cleanly, maintain shape during melting, avoid collapse and provide better shelf life characteristics. All of these characteristics are related to how the emulsifier behaves during aging. Prior to the crystallization of the fat, the monoglyceride (emulsifier) is primarily dissolved within the fat. As the fat crystallizes, the emulsifier is moved from the interior of the fat particle to its surface by the crystallizing fat (Danisco, 2010). As this is happening, the protein that has been protecting the fat particles from agglomeration is displaced from the surface (emulsifiers have a stronger affinity for the surface of fat than does protein). The presence of emulsifier at the surface of the fat encourages controlled agglomeration of fat during freezing. Mixes made without aging therefore resemble mixes made without emulsification.

One common question is, how long must a product be aged? The actual time necessary depends on many characteristics of the mix and processing environment. The increase in viscosity of the ice cream mix has been taken as the indicator for deciding the time for aging of mix by some researchers (Chang & Hartel, 2002; Dogan & Kayacier, 2007). Cooling rates, mix temperatures, the amount and type of fat in the mix, the type of emulsifiers used and heat transfer properties of the mix all have an effect on the amount of aging necessary. The process of aging is also not linear. Acceptable aging times can be much shorter than optimal aging times. Decisions on how long to age each mix must therefore be a compromise between production efficiency and quality. In the industry there are many rules of thumb and each manufacturer determines the exact minimum aging time experimentally. A good rule of thumb is 4 h.

17.4.2.3.4 Flavoring

In frozen dessert manufacture there are three points at which the flavor of the product is altered. The first point is during formulation and blending. Chocolate ice cream is most often formulated; the cocoa or chocolate is added at blending and pasteurized. Coffee-flavored ice cream is sometimes made this way. Any flavor that does not contain particulates could be made this way but due to the heat treatment, flavors are altered chemically and combine with the other components, which leads to the loss of volatiles. The biggest advantage in this is microbiological; by pasteurizing, any pathogenic bacteria on the flavoring material will be killed. Another advantage is that powdered flavorings like cocoa are much easier to disperse in the blending process than in the flavor vat. In most frozen dessert operations the mixes are made as white unflavored mix and chocolate mix. These are used as bases for all the flavors made.

The second point where flavor (and color) can be altered is just prior to freezing. This operation is most often done in a flavor vat. A flavor vat is a small tank provided with gentle agitation, placed so that it is convenient to the freezer. These tanks can be provided with refrigeration to maintain temperature while the product awaits freezing. Flavor tanks should be designed to drain completely; this prevents cross-over of one flavor into the next or product loss when rinsing between flavors. Liquid flavorings and colors are most often manually measured into this tank and allowed to mix before sending them to the freezer. Automated metering systems for either dosing flavors into the flavor vat or on line to the freezer have been devised and are used in some operations. This eliminates errors of measurement and, in the case of flavors metered directly to the feed line of the freezer, eliminates a point where product contamination could happen. Flavors added post pasteurization are a contamination risk. It is important that flavorings and colorings be pasteurized or otherwise assured to be free of pathogens. This is especially true of raw agricultural products like strawberry juice.

The third and final place where flavors may be added is just prior to packaging. At this point the flavorings added are most often either large particulate flavors like nuts, fruits and candy or thick syrups like marshmallow or chocolate syrup. The two basic pieces of equipment used at this position are fruit feeders and variegators. Fruit feeders are used to deposit pieces of fruit or nuts into the stream of frozen ice cream. They are designed to be flexible so that they can be switched from one inclusion to another and they are adjustable so that different ingredients can be added at differing rates. These machines distribute the particulates evenly throughout the ice cream flow. Since this equipment is used for many different ingredients, it is especially important that it be kept sanitary and that residue from one flavor is not carried into the next. Since it is used to insert nuts, this equipment must be sanitized to be free of nut particles if it is to be used for non-nut flavors in order to avoid allergen problems.

Variegators are designed to add streams and/or layers of syrups to the ice cream stream. The syrup is pumped from a drum or tote into the variegator. The syrups can be aerated, as with marshmallow, or not, as with chocolate
Ice is the characterizing factor for all frozen desserts. There are two basic methods for making frozen desserts: quiescent freezing, where the liquid product is not stirred during freezing, and active freezing, where the product is stirred. Quiescent freezing is generally used to produce molded novelties like ice pops. In this case, the ice pop mix is simply deposited in a mold; the mold is placed in a cryogenic fluid (cold air, cold brine, glycol, liquid nitrogen or other cryogenic heat transfer fluid) and allowed to freeze (with or without stick insertion before complete freezing). The ice crystals start growth at the mold surface and grow towards the center. As ice freezes, it excludes the material dissolved in it. In products without air bubbles, fat droplets or other obstructions, as in ice pops, the ice will push the solutes toward the center and away from the ice crystal surfaces. Since the freezing point of the liquid decreases when the concentration of solutes increases, there will come a point where the ice and the unfrozen liquid reach equilibrium. The number of sites where ice crystals can form is dependent on the temperature at the point where the ice crystals start to form (Drewett & Hartel, 2007; Russell et al., 1999). At lower temperatures, more crystals will form. Also, if there are a large number of points where ice can start to form, like particles of fat or protein, there will be a large number of ice crystals. Ice pops, for instance, have few particles that can initiate ice formation and therefore have a more coarse (icy) texture than ice cream bars. Products with higher fat or protein (particles) will also result in more numerous (smaller) ice crystals (which makes them feel less cold in the mouth). It is the manipulation of the crystals of ice in these products that gives them their textures.

The second and more complicated method for producing frozen desserts is by freezing while stirring (active freezing). The definition of ice cream in the US includes the statement: “Ice cream is a food produced by freezing, while stirring, a pasteurized mix...” (21 CFR 135.110).

There are two basic types of machines that are used to accomplish freezing while stirring: batch and continuous freezers. Batch freezers, as indicated by their name, freeze a measured amount of mix and air to completion, after which the contents of the freezer are emptied. With continuous freezers, mix and air are pumped into the freezer and frozen product is extracted from the freezer in continuous streams.

The ice cream freezer differs little from the original invention by Nancy Johnson in 1843 (US Patent no. 3254). In its essence, an ice cream freezer consists of two parts: a heat exchange surface and some form of scraper to remove frozen product from the surface. Often a beater or dasher is included to aid in mixing the freezing product. Originally and still today, with home freezers the heat exchange surface is cooled using ice and salt. In industrial freezers, the surface is chilled using the direct expansion of freon or ammonia. In the modern continuous freezers the heat exchange surface takes the shape of a cylinder. This cylinder is surrounded by a space where a coolant like ammonia is evaporated. Carbon dioxide or freon may also be used among alternative coolants. Inside this cylinder (called a barrel) is a series of blades that travel around the inside circumference of the barrel. Supporting the blades is a mechanism (called a dasher) that, in addition to supporting the blades, mixes and beats the freezing product to incorporate air. It is the design of the dasher that characterizes the different freezer designs. In continuous freezers, mix and air are metered and pumped into the freezer. In some designs the frozen product is also pumped out of the freezer.

The active freezing process of ice cream and related products is much more complex than for quiescent freezing. During the freezing process the following changes occur.

- The temperature is brought down from approximately 4°C to −6°C.
- Approximately 50% of the water in the mix is frozen.
- The concentration of the unfrozen mix rises from about 38% to roughly 55%.
- Air is incorporated into the mix to approximately half the volume and the air bubble size is reduced to an average between 10 and 30 μm (Rohenkohl & Kohlus, 1999).
- Fat globules are destabilized and partially agglomerated into a structure that both supports and somewhat contains the ice crystals and the air bubbles.
- Protein is moved to the surface of the air bubbles, helping to stabilize them (Goff et al., 1999).
- Due to the concentration of the liquid portion of the mix due to freezing and to the number of solid particles imbedded in this liquid, the viscosity of the product increases from a liquid to a semi-solid.

As the mix and air enter the freezer barrel and the mix is cooled, air bubbles are subdivided into smaller and smaller sizes. Mix located near the walls of the freezer begins to freeze and the ice formed at the wall is moved into the
center of the volume of the freezer. Initially this melts and gives up the heat of crystallization to the bulk of the mix (Drewett & Hartel, 2007; Hartel, 1996; Russell et al., 1999). At some point the temperature difference between the ice crystals formed at the wall of the freezer and the bulk of the mix is not enough to completely melt the ice crystals being transported into the bulk of the mix. At this point there is both growth of ice crystals in the bulk of the mix and the addition of new ice crystals from the barrel wall. At the same time, air is incorporated and stabilized; this is aided by the shear forces from the dasher, the freeze concentration of the protein, the freeze concentration of the sugars and hydrocolloids, and the increasing concentration of ice and small air bubbles that in turn increases the stiffness of the partly frozen material. The shear forces in the forming product cause fat globules to agglomerate together to form a kind of loose structure with ice crystals, air bubbles and unfrozen mix imbedded within it. This process is similar to the whipping of cream. In frozen desserts, the fat must be concentrated by freezing (for ice cream during freezing the fat concentration in the liquid portion of the product nearly doubles).

17.4.2.3.6 Packaging

Once the product exits the freezer, there is no further formation of new ice crystals. All further ice crystal formation is to existing ice crystals (Drewett & Hartel, 2007). In order to move the frozen product through the lines to packaging, there is a significant pressure placed on the product at the freezer. This can be from the geometry of the dasher or due to a pump (generally called an ice cream pump). This back pressure compresses the air in the air bubbles. The air bubbles will expand somewhat as this pressure is released. Depending on the amount of back pressure, this expansion can be enough to cause air bubble instability in the final product. The amount of air in the final product is expressed as overrun which is calculated using the following formula:

\[
\text{Overrun} = \left( \frac{\text{Weight of mix}}{\text{unit volume}} - \frac{\text{Weight of final product}}{\text{unit volume}} \right) \times 100
\]

Overrun for frozen desserts can range from 0% for quiescently frozen ice pops to around 20% for soft-serve ice cream and super premium ice creams to 100% for hard-pack ice cream to 150% or higher for frozen desserts. The CFR regulations control the overrun in ice creams by mandating not less than 1.6 lb of total solids per gallon (191.7 grams of total solids per liter) and weight of not less than 4.5 lb per gallon (539.2 grams per liter). Batch freezers generally can attain about 50% overrun. As overrun increases, the insulation value of the product increases and the product is perceived as less cold in the mouth. Overrun also affects flavor perception to some extent.

Frozen desserts can be packed in innumerable types and configurations of packages. It is beyond the scope of this chapter to discuss them all. Frozen desserts are subject to all the problems that are found in other similar products. An example of this is when ultraviolet (UV) light from the sun or from display lighting, as with gelato displays or behind clear plastic windows on packaging, affects ice cream quality. The ice cream that is exposed to UV light can develop light oxidized flavors in the areas exposed (Clark et al., 2009).

17.4.2.3.7 Hardening

After packaging, approximately half of the water in the product is not frozen. In this state the product is semi-solid and vulnerable to damage. Hardening is the process of continuing freezing without agitation until the temperature is –18 °C or preferably lower. This process should be done as quickly as possible to avoid the growth of large ice crystals in the product.

As the ice cream exits the freezer there is a distribution of ice crystal sizes (Marshall et al., 2003). The most stable ice crystals are the large ones and the least stable are the smallest ice crystals (Everett, 1988). During hardening ice will form on all the ice crystals available. At any point in time, there is a tendency for the larger ice crystals to grow at the expense of the smaller ones. This process is called Ostwald ripening (Everett, 1988). Further, since water must be supercooled in order to form new crystals (Debenedetti & Stanley, 2003), few ice crystals can form as long as there is other ice present in the liquid portion of the product (at constant, increasing and decreasing temperatures\(^2\)). All the above leads to an increase in ice crystal sizes after the ice cream exits the freezer.

\(^2\) This presumes that the temperature is decreasing at a rate within normal processing capabilities. It is possible to form new ice crystals in the presence of ice crystals if the temperature is dropped at a very high rate. This could be done by dropping a small particle of product in liquid helium. The reason for this is, at high rates of cooling water cannot diffuse through the high viscosity mix fast enough to reach the larger ice crystals.
If hardening is done slowly or is delayed, the smaller (more numerous) ice crystals will have disappeared and ice will form on the larger crystals. The result will be product with larger ice crystals, which are more noticeable (cold, coarse) on the tongue. If hardening is done quickly there will be many smaller ice crystals, resulting in a smoother product.

The rate at which the product cools down during hardening is affected by many properties of the product and process conditions. These include the thermal properties of the packaging, the thermal properties of the product, the temperature differential between the product and the cooling medium (most often air), and the flow properties of the cooling medium (Russell et al., 1999). In practice, maintaining the maximum contact between the product and the heat transfer medium and minimizing the distance between them while maximizing the temperature difference will result in the quickest hardening. Some of the methods used to accomplish this can be by direct product contact through cooling plates, by immersion in cooling medium such as liquid nitrogen or most commonly, by directing high-velocity cold air on the product. Where product is palletized before hardening, it is a good procedure to stack the product in such a way that there is maximum contact with high-velocity cold air.

17.4.2.3.8 Storage and shelf life

Once hardened, the product is generally moved into long-term storage. The temperature in storage is generally held near −23 °C. This temperature cycles up and down by several degrees in a daily cycle (called a defrost cycle) that prevents the build-up of frost on the heat transfer surfaces and other surfaces within the storage area. Each time the product temperature increases, the smallest ice crystals in the product will melt and each time the temperature decreases the water released will refreeze on the larger ice crystals. This effect will depend on the magnitude of the change in temperature. With decreasing temperatures, the amount of ice frozen and melted during temperature cycles is decreased. If the temperature rises from −20 °C (−4 °F) to −15 °C (5 °F), about 5% of the water will melt. If the same 5 °C change starts 5 ° colder, only 3% of water will melt. Over time the result of this will be a steady loss of quality.

17.5 US regulations for milk and milk products

The US federal regulations are all the laws and acts passed by the US Congress. These are published in the Federal Register every working day by the executive departments and agencies of the US federal government. All of them are compiled in the US Code of Federal Regulations (CFR) under various titles (1–50), based on the government agency handling them. The CFR is published by the Office of the Federal Register, an agency of the National Archives and Records Administration (NARA). Examples are Title 21 under Food and Drug Administration (FDA), Title 19 under US Customs Services and Title 7 under United States Department of Agriculture (USDA). The Title 21 section 1 to 199 of CFR not only contains standards for different food products but also good manufacturing practices (21 CFR 110), food labeling regulations (21 CFR 101), recall policy (21 CFR 7.40), and nutritional quality guidelines (21 CFR 104) (www.ecfr.gov). These federal laws and regulations ensure the wholesomeness of food, help to inform consumers about the nutritional composition of foods and eliminate economic frauds by dictating the ingredients in foods, tests to be performed on each food, and procedures of analysis.

A comprehensive collection of federal laws, guidelines, and regulations relevant to food and drugs is published by the Food and Drug Law Institute, under the FDA. These include Food and Drug Act of 1906, Federal Food, Drug and Cosmetics Act of 1938, Food Additives Amendment of 1958, Color Additives Amendment of 1960, Nutrition Labeling and Education Act of 1990, Dietary Supplement, Health and Education Act of 1996, and Food Quality and Protection Act of 1996. All these acts have been chronologically referred to in the book published by the Food and Drug Law Institute (Cooper, 2011).

According to the federal regulations, every milk producer, milk distributor, bulk milk hauler/sampler, milk tank truck, milk transportation company, and dairy plant should have a valid permit. The various agencies that work towards establishing and enforcing the regulations and laws for the production, processing, and marketing of milk and milk products in US are (Hui, 1986; Nielsen, 2010):

- United States Food and Drug Administration (FDA)
- United States Department of Agriculture (USDA)

An example of this effect can be seen in the common event of transporting a package of ice cream in the car to the home, allowing the temperature of the package of ice cream to nearly melt and then refreezing it in the home freezer. The resulting product is often much less smooth than it would have been had the product been kept cold (as in winter).
state regulatory agencies
Environment Protection Agency (EPA)
US Customs Service

17.5.1 FDA

The FDA is a government agency within the Department of Health and Human Services (DHHS). Its function is to regulate the safety of foods, cosmetics, drugs, medical devices, biological products, and radiological products. It enforces laws enacted by the US Congress and regulations developed by it to protect consumers' health, safety, and money. The milk and milk products definitions, standards of identity, quality and fill established by the FDA are published in Title 21 of CFR Section 130–135. These sections of the CFR include descriptions of:

- ingredients the different milk and milk products must contain
- minimum or maximum levels of various ingredients based on their economic value
- list of optional ingredients
- methods of analysis
- nomenclature permitted
- label description.

The FDA is authorized by the Food Drug and Cosmetic Act, Public Health Service Act and Import of Milk Act to regulate the production, procurement, processing, and marketing of milk and milk products. The FDA shares its responsibility with the state regulatory agency, which is the department of health or agriculture to ensure safety, wholesomeness and economic integrity of milk and milk products. The FDA has compiled a model for regulation of sanitation and quality of production and handling of Grade A milk called the Grade “A” Pasteurized Milk Ordinance (PMO), which is a consensus of current knowledge and experiences of milk sanitation (FDA, 2011). It is used as the sanitary regulation for milk and milk products for interstate shipment; it is recognized by the public health agencies, the milk industry and many others as the national standard for milk sanitation.

According to the PMO, all sampling procedures and laboratory examinations should be in compliance with the current edition of SMEM by the American Public Health Association (Wehr & Frank, 2004) and Official Methods of Analysis by the Association of Official Analytical Chemists (FDA, 2011).

All US states have adopted the PMO as the minimum requirements for Grade A standards. The FDA monitors the state agencies, as all the 50 states are bound by the Memorandum of Understanding with the National Conference on Interstate Milk Shipments. The FDA also trains state inspectors and certifies the producers and dairy plants eligible for shipping milk to other states. The certified producers and dairy plants are included in the Interstate Milk Shippers List, as a part of the Interstate Milk Shippers Program. This program is maintained by a voluntary organization including the representatives of each state, the FDA, and USDA.

The FDA reviews all the food and color additives before manufacturers and distributors can market them. It publishes a list of permitted additives given in a database called “Everything” Added to Food in the United States (EAFUS), published at www.fda.gov/food/ingredient-packaginglabeling/foodadditivesingredients/ucm115326.htm. It also publishes a list of food contact substances; a food contact substance is defined as “any substance intended for use as a component of materials used in manufacturing, packing, packaging, transporting, or holding food if such use is not intended to have a technical effect in such food” (amended Food, Drug and Cosmetic Act 1998). The FDA also ensures that food labels are truthful and do not mislead consumers, based on the Nutrition Labeling and Education Act 1990. The FDA has a major role in regulating the import of milk and milk products along with the US Customs Services as authorized by the Import of Milk Act 1927.

17.5.2 USDA

The USDA acts as a voluntary grading service for manufactured or processed dairy products, authorized by the Dairy Quality Programs under the Agricultural Marketing Act of 1946 (details about dairy products published in 7 CFR 58). It assists the FDA in regulating safety and quality of milk and milk products by:

- inspecting dairy plants for conformation to “General Specifications for Dairy Plants Approved for USDA Inspection and Grading Services”
- grading, sampling, testing, and certifying products of approved plants
- establishing regulations for manufacturing-grade milk as given in “Milk for Manufacturing Purposes and Its Production and Processing – Recommended Requirements” which is adopted by state agencies to regulate Grade B milk.

Grade B or manufacturing-grade milk does not meet the standards of PMO and can only be used for the manufacture of cheese, butter, and non-fat dairy milk (Womach, 2005).
17.5.3 State agencies

Every state has an authorized state regulatory agency for enacting safety and quality regulations for milk and milk products. The Department of Health or Department of Health Agriculture of the state usually enforces these regulations. The Grade A PMO of the FDA is usually used as the basis for all regulations of Grade A milk. The USDA “Milk for Manufacturing Purposes and Its Production and Processing – Recommended Requirements” is used as the basis for all regulations for manufacturing-grade milk. The state does not necessarily have to use these guidelines for their regulations as they are only voluntary assistance for states and not mandatory. Sometimes state standards may be even more stringent than the federal standards. However, for interstate commerce, it is mandatory to adhere to the standards specified by the PMO for Grade A milk.

17.5.4 Environmental Protection Agency (EPA)

The main function of the EPA with regard to dairy regulations is the establishment of tolerance levels or allowable limits for certain pesticide residues and effluent management. The enforcement of these regulations is carried out by the FDA by collecting and analyzing milk samples for pesticide residues. The EPA also administers the Safe Drinking Water Act of 1974, although it is enforced by the state regulatory agencies. Apart from these, the EPA administers the Federal Water Pollution and Control Act, which sets effluent guidelines and tests various dairy processing plants. The effluent characteristics that are tested include biochemical oxygen demand (BOD), total soluble solids (TSS), and pH. The Title 40 of the CFR Section 405 includes the effluent guidelines and standards for different sections and products manufactured in a dairy industry.

17.5.5 Federal Trade Commission (FTC)

The FTC is a federal agency that develops and administers the regulations on advertising and sales promotion procedures for foods. It is authorized to protect consumers and business persons from anticompetitive behavior and unfair or deceptive business and trade practices by the Federal Trade Commission Act of 1914. The main functions of the FTC are carried out by the Bureau of Consumer Protection. The FTC administers the Fair Packaging and Labeling Act of 1966; however, it is enforced by the FDA. According to this act, the FTC has guidance and preventive functions and can issue complaints and shutdown orders or sue processing plants for violating the act.

17.5.6 US Customs Service

The US Customs Service ensures that imported products are taxed properly, safe for human consumption and not economically deceptive. It is assisted by the FDA and USDA to carry out its responsibilities and set the various requirements for imported milk and milk products. The regulations under the jurisdiction of the US Customs Service are given in Title 19 of the CFR.

17.6 Sustainability of the dairy industry

A major venture for maintaining sustainability in the dairy industries of the US was put forward by the Innovation Center for US Dairy (affiliated to Dairy Management Inc, a non-profit organization of dairy industry personnel: www.usdairy.com/Sustainability/Pages/Home.aspx). It published the first US dairy sustainability commitment progress report in 2007. Since then, this report had been published in 2010 and 2011. These efforts have been made to achieve environmental, social and economic sustainability in the dairy industry. The sustainability point of view in the dairy industry is providing the consumers with affordable and good-quality products while protecting natural resources and communities. Goals include addressing future issues of resource challenges due to the growing population, environment factors such as water scarcity, greenhouse gas emission, and reduction in available land. Efforts have been made to establish about 11–25% reduction of greenhouse gases associated with the production of 1 gallon of ice cream mix. Also, studies are being initiated to understand the environmental and socio-economic impact of the dairy industry. This broad understanding among the dairy industries should take us a long way in providing economically affordable dairy products while enriching the community and preserving the environment, to create a better tomorrow for future generations.

17.7 Conclusion

The US dairy industry is a pioneer in milk and milk product production and export in the world, with a bright future to look upon. Milk is a highly nutritious addition to the diet, which contains carbohydrates, proteins, fats, minerals, and vitamins. There are a number of processing
technologies involved in the production of fluid milk and milk products, including pasteurization, homogenization, freezing and packaging, that have enabled these products to be distributed worldwide for decades. All the milk products and processing technologies are regulated by a number of federal and state agencies to ensure a good-quality product for the consumer. Additionally, a number of programs have been initiated to improve the sustainability of the dairy industry to ensure dairy products for future generations.

References


