MILK AND MILK PRODUCTS

1. Introduction

Milk has been a source for food for humans since the beginning of recorded history. Although the use of fresh milk has increased with economic development, the majority of consumption occurs after milk has been heated, processed, or made into butter. The milk industry became a commercial enterprise when methods for preservation of fluid milk were introduced. The successful evolution of the dairy industry from small to large units of production, ie, the farm to the dairy plant, depended on sanitation of animals, products, and equipment; cooling facilities; health standards for animals and workers; transportation systems; construction materials for process machinery and product containers; pasteurization and sterilization methods; containers for distribution; and refrigeration for products in stores and homes.

2. Composition and Properties

Milk consists of 85–89% water and 11–15% total solids (Table 1); the latter comprises solids-not-fat (SNF) and fat. Milk having a higher fat content also has higher SNF, with an increase of 0.4% SNF for each 1% fat increase. The principal components of SNF are protein, lactose, and minerals (ash). The fat content and other constituents of the milk vary with the animal species, and the composition of milk varies with feed, stage of lactation, health of the animal, location of withdrawal from the udder, and seasonal and environmental conditions. The nonfat solids, fat solids, and moisture relationships are well established and can be used as a basis for detecting adulteration with water. Physical properties of milk are given in Table 2.

2.1. Nutritional Content. To assure that milk provides the necessary nutrients it may be fortified with vitamins. Vitamin D [*1406-16-2*] milk has been sold since the 1920s when it was fortified with vitamin D by irradiation or by feeding irradiated yeast to cows. Ergosterol [*57-87-4*] is converted to vitamin D by ultraviolet irradiation. Presently, vitamin D is added directly to the milk to provide 400 *U.S. Pharmacopoeia* (USP) units/L. Vitamin A [*68-26-8*] may be added to low fat skimmed milk to provide 1000 retinol equivalents (RE) per liter. Multivitamin, mineral fortified milk provides the recommended daily requirements. The vitamin content of milk from various mammals is given in Table 3. The daily nutritional needs for an adult are given in Table 4.

2.2. Fat. Milk fat is a mixture of triglycerides and diglycerides. The triglycerides are short-chain, C_{24}–C_{46}; medium-chain, C_{34}–C_{54}; and long-chain, C_{40}–C_{60}. Milk fat contains more fatty acids than those in vegetables. In addition to being classified according to the number of carbon atoms, fatty acids in milk may be classified as saturated or unsaturated and soluble or insoluble. Fat carries numerous lipids (Table 5) and vitamins A, D, E, and K, which are fat soluble. Tables 6–8 give fatty, saturated, and unsaturated acid contents of milk fat.

3. Processing

The processing operations for fluid or manufactured milk products include cooling, centrifugal sediment removal and cream (a mixture of fat and milk serum) separation, standardization, homogenization, pasteurization or sterilization, and packaging, handling, and storing.

3.1. Cooling. After removal from the cow by a mechanical milking machine, (at$\sim$34°C), the milk is rapidly cooled to $\leq$4.4°C to maintain quality. At this low temperature, enzyme activity and microorganism growth are minimized. Commercial dairy production operations usually consist of a milking machine, a pipeline to convey the milk directly to the tank, and a refrigerated bulk milk tank in which the milk is cooled and stored for later pickup. Rancidity is avoided by preventing air from passing through the warm milk, via air leaks and long risers in the pipeline. The pipelines, made of glass or stainless steel, are usually cleaned by a cleaning-in-place (CIP) process. Bulk milk is pumped from the refrigerated bulk milk tank to a tanker and transported to a processing plant.

3.2. Centrifugation. Centrifugal devices include clarifiers for removal of sediment and extraneous particulates, and separators for removal of fat (cream) from milk.

Clarification. A standardizing clarifier removes fat to provide a certain fat content while removing sediment, a clarifixator partially homogenizes while separating the fat, and a high speed clarifier removes bacteria cells in a bactofugation process. Clarifiers have replaced filters in the dairy plant for removing sediment, although the milk may have been previously strained or filtered while on the farm. A clarifier has a rotating bowl with conical disks between which the product is forced. The sediment is forced to the outside of the rotating bowl where the sludge or sediment remains. Some clarifiers have dislodging devices to flush out the accumulated material. The clarified milk leaves through a spout or outlet.

Clarification is usually performed at 4.4°C, although a wide range of temperatures is used. The clarifier may be used in numerous positions in the milk processing system, depending on the temperature, standardization procedure, flow rate, and use of the clarified product. The clarifier may be between the bulk milk tanker and raw milk storage tank, the raw milk receiving tanks and raw milk storage tank, the storage tank and standardizing tank, the standardizing tank and high temperature–short time (HTST) pasteurizer, the preheater or regenerative heater for raw milk and the heating sections of the HTST pasteurizer, or the regenerative cooler for the pasteurized milk side and the final cooling sections of the HTST pasteurizer, which is rarely used because of possible post-pasteurization contamination.

To avoid the accumulation of sediment following homogenization, the clarifier generally is used before homogenization to clarify the incoming raw milk. Clarification at this point provides milk ready for pasteurization, particularly if standardized; permits longer operation of the clarifier without stopping or cleaning, because sediment builds up more rapidly with a warm product; and when used as an operation independent from pasteurization, does not interfere with the pasteurization if maintenance is necessary.

Bactofugation. This process is not used for ordinary fluid milk, but for sterile milk or cheese. Although no longer used in the United States, bactofugation is a specialized process of clarification in which two high velocity centrifugal bactofuges operate at 20,000 rpm in series. The first device removes 90% of the bacteria, and the second removes 90% of the remaining bacteria, providing a 99% bacteria-free product. The milk is heated to 77°C to reduce viscosity. From the centrifugal bowl there is a continuous discharge of bacteria and a high density nonfat portion of the milk (1–1.5%).

Separation. In 1890, continuous-flow centrifugal cream separators using cone disks in a bowl were introduced. Originally, cream separators were basic plant equipment, and dairy plants were known as creameries. The original gravity-fed units incorporated air to produce foam and separators developed 5,000–10,000 times the force of gravity to separate the fat (cream) from the milk. Skimmed milk was discarded or returned to the farm as animal feed, and the cream was used for butter and other fat-based dairy products. Current separators are pressure- or forced-fed sealed airtight units. The separator removes all or a portion of the fat, and the skimmed milk or reduced fat milk is sold as a beverage or ingredient in other formulated foods.

Separation is done between 32 and 38°C, although temperatures as high as 71°C are acceptable. Cold milk separators, which have less capacity at lower temperatures, may be used in processing systems in which the milk is not heated.

Separating fat globules from milk serum is proportional to difference in densities, the square of the radius of the fat globule, and centrifugal force; and inversely proportional to flow resistance of the fat globule in serum, viscosity of the product through which the fat globule must pass, and speed of flow through the separator.

The ease with which the separated products leave the bowl determines the richness of the fat. Fluid whole milk enters the separator under pressure from a positive displacement pump or centrifugal pump with flow control (Fig. 1). The fat (cream) is separated and moves toward the center of the bowl, while the skimmed milk passes to the outer space. There are two spouts or outlets, one for cream and one for skimmed milk. Cream leaves the center of the bowl with the percentage of fat (∼30–40%) controlled by the adjustment of a valve, called a cream or skim milk screw, that controls the flow of the product leaving the field of centrifugal force and thus affects the separation.

3.3. Standardization. Standardization is the process of adjusting the ratio of butterfat and solids-not-fat (SNF) to meet legal or industry standards. Adding cream of high butterfat milk into serum of low butterfat milk might result in a product with low SNF, thus careful control must be exercised.

A standardizing clarifier and separator are equipped with two discharge spouts. The higher fat product is removed at the center and the lower fat product at the outside of the centrifugal bowl. The standardizing clarifier removes sediment and a smaller portion of the fat than the conventional separator that leaves only 0.25% fat. Fat in the milk discharge of a standardizing clarifier is only slightly less than that of the entering milk; the reduction is ∼10% from 4.0–3.6% fat. Accurate standardization is performed by sampling a storage tank of milk and adding appropriate fat or solids, or by putting the product through a standardizing clarifier and then into a tank for adjustment of fat and SNF.

3.4. Homogenization. Homogenization is an integral part of continuous HTST pasteurization. It is the process by which a mixture of components is treated mechanically to give a uniform product that does not separate. In milk, the fat globules are broken up into small particles that form a more stable emulsion in the milk. In homogenized milk, the fat globules do not rise by gravity to form a creamline as with untreated whole milk. The fat globules in raw milk are 1–15 μm in diameter; they are reduced to 1–2 μm by homogenization. The U.S. Public Health Service defines homogenized milk as "milk that has been treated to insure the breakup of fat globule to such an extent that after 48 h of quiescent storage at 45°F (7°C) no visible cream separation occurs in the milk . . ."(6). Most fluid milk is homogenized.

Milk is homogenized in a homogenizer or viscolizer. It is forced at high pressure through the small openings of a homogenizing valve by a simple valve or a seat, or a disposable compressed stainless steel conical valve in the flow stream (Fig. 2). The globules are broken up as a result of shearing, impingement on the wall adjacent to the valve, and to some extent by the effects of cavitation and explosion after the product passes through the valve. In a two-stage homogenizer, the first valve is at a pressure of 10.3–17.2 MPa (1500–2500 psi) and the second valve at ∼3.5 MPa (500 psi). The latter functions primarily to break up clumps of homogenized fat particles, and is particularly applicable for cream and products with more than 6–8% fat.

A homogenizer is a high pressure positive pump with three, five, or seven pistons, that is driven by a motor and equipped with an adjustable homogenizing valve. Smoother flow and greater capacity are obtained with more pistons, which force the product into a chamber that feeds the valve. In design and operation, it is desirable to minimize the power requirements for obtaining an acceptable level of homogenization. At 17.2 MPa (2500 psi) and a volume of 0.91 t/h (2000 lb/h), a 56-kW (75-hp) motor is required.

Several operating factors should be considered: (*1*) before homogenization, milk is heated to break up fat globules and prevent undesirable lipase activity; (*2*) as the temperature of the milk is increased, the size of the globules decreases; (*3*) viscosity of fluid milk is not greatly influenced by homogenization, whereas viscosity of cream is increased; (*4*) clarification before or after homogenization prevents the formation of sediment which otherwise adheres to the fat; and (*5*) it is difficult to separate cream from homogenized milk to make butter.

The homogenizer must be placed appropriately in the system to assure the proper temperature of the incoming product, provide for clarification, and avoid air incorporation that would cause excessive foaming. The homogenizer also may be used as a pump in the pasteurization circuit.

3.5. Pasteurization. Pasteurization is the process of heating milk to kill pathogenic bacteria, and most other bacteria, without greatly altering the flavor. It also inactivates certain enzymes, eg, phosphatase, thus the degree of pasteurization can be determined by measuring the phosphatase present. The principles were developed by and named after Pasteur and his work in 1860–1864. Since then, stringent codes have been developed to assure that pasteurization is done properly. The basic regulations are included in the U.S. Public Health Service Pasteurized Milk Ordinance (6) which has been adopted by most local and state jurisdictions. The quality of milk depends on the care of the animals that produce it, the environment on the farm, and the care of the product throughout.

Pasteurization may be carried out by batch- or continuous-flow processes. In the batch process, each particle of milk must be heated to at least 63°C and held continuously at this temperature for at least 30 min. In the continuous process, milk is heated to at least 72°C for at least 15 s in what is known as high temperature–short time (HTST) pasteurization, the primary method used for fluid milk. For milk products having a fat content above that of milk or that contain added sweeteners, 66°C is required for the batch process and 75°C for the HTST process. For either method, following pasteurization the product should be cooled quickly to ≤7.2°C. Time–temperature relationships have been established for other products including ice cream mix, which is heated to 78°C for 15 s, and eggnog, which must be pasteurized at 69°C for 30 min or 80°C for 25 s.

Another continuous pasteurization process, known as ultrahigh temperature (UHT), employs a shorter time (2 s) and a higher temperature (minimum 138°C). The UHT process approaches aseptic processing (Fig. 3).

Batch Holding. The milk in the batch holding tanks is heated in a flooded tank around which hot water or steam is circulated, or by coils surrounding the liner through which the heating medium is pumped at a high velocity. Two other methods include spraying hot water on the tank liner holding the milk, and pumping hot water through a large-diameter coil that circulates in the milk. A self-acting regulator closely controls the temperature of the water, usually heated with steam. Table 9 gives the overall heat-transfer coefficients (U-values) for these methods.

An airspace heater ejects steam into the airspace above the product and into the foam, maintaining a temperature at least 5°C above the minimum holding temperature of 63°C. The time–temperature exposure is recorded on a chart which must be kept for proof of treatment. If the lid is opened, and the milk temperature falls below 63°C, the exposure is interrupted causing the pasteurization cycle to restart.

Valves are mounted so that the plug of the valve is flush with the tank to avoid a pocket of unpasteurized milk, and a leak detector valve permits drainage of the milk trapped in the plug of the valve. All covers, piping, and tubing must drain away from the pasteurizer.

Agitators provide adequate mixing without churning, assist in heat transfer by sweeping the milk over the heated surface, and assure that all particles are properly pasteurized.

High Temperature–Short Time Pasteurizers. The principal continuous-flow process is the high temperature–short time (HTST) method. The product is heated to at least 72°C and held at that temperature for not less than 15 s. Other features are similar to the batch holding method.

The equipment needed includes a balance tank, regenerative heating unit, positive pump, plates for heating to pasteurization temperature, tube or plates for holding the product for the specified time, a flow-diversion valve (FDV), and a cooling unit (Fig. 4). Often the homogenizer and booster pump also are incorporated into the HTST circuit.

The balance or float tank collects raw milk entering the unit, receives milk returned from the flow-diversion valve that has not been adequately heated, and maintains a uniform product elevation on the pasteurizer intake.

The heat-regeneration system partially heats the incoming cold product and partially cools the outgoing pasteurized product. The regenerator is a stainless steel plate heat exchanger, usually of the product-to-product type. The configuration is so arranged that the outgoing pasteurized product is at a higher pressure to avoid contamination. A pump in the circuit moves the milk from the raw milk side and the discharge to the final heater. Heat regenerators are usually 80–90% efficient. The regeneration efficiency may be improved by increasing the number of regenerator plates, and although this increases the energy for pumping, it also increases the cost for additional heat-exchanger plates.

The final heater increases the regeneration temperature (~60°C) to pasteurization temperature (at least 72°C) with hot water. The hot water is ~1–2°C above the highest product temperature (73°C). Four to six times as much hot water is circulated compared to the amount of product circulated on the opposite side of the plates.

The holder or holding tube is at the discharge of the heater. Its length and diameter assure that fluid milk is exposed to the minimum time–temperature (72°C for 15 s). Glass or stainless steel tubing, or plate heat exchangers, may be used for holders. Holding tubes must be designed for continuous uphill flow (0.64 cm/m) from the start of the tube to the FDV.

On the outlet of the holder tube, the FDV directs the pasteurized product to the regenerator and then to the final cooling section (forward flow). Alternatively, if the product is below the temperature of pasteurization, it is diverted back to the balance tank (diverted flow). The FDV is controlled by the safety thermal-limit recorder.

The final cooling section is usually a plate heat exchanger cooled by water chilled through brine or compression refrigeration. Milk leaves the regenerator and enters the cooling section at ~18–24°C and is cooled to 4.4°C by glycol, or water circulating at 1°C. The relationships of regenerator, heater, and cooler for flow, number of plates, and pressure drop are given in Table 10.

The heat-transfer sections of the HTST pasteurizer, ie, regenerator, heater, and cooler, are usually stainless steel plates ~0.635–0.91 mm thick. Plates for different sections are separated by a terminal that includes piping connections to direct product into and out of the spaces between plates. The plates hang on a support from above and can be moved along with the terminals, for inspection or for closing the unit, and a screw assembly can be operated, manually or mechanically, to hold the plates together during operation. The plates are mounted and connected in such a manner that the product can flow through ports connecting alternate plates. The heat-transfer medium flows between every other set of plates.

The stainless steel plates are separated (ca 3 μm between) by nonabsorbent vulcanized gaskets. Various profiles and configurations, including raised knobs, crescents, channels, or diamonds, provide a rapid, uniform heat-transfer plate surface. During operation the plates must be pressed together to provide a seal, and mounted and connected in such a manner that air is eliminated and that the product drains from the plates without opening.

Various arrangements and configurations are available for the HTST pasteurizer. For regeneration, the milk-to-milk regenerator is most common. A heat-transfer medium, usually water, provides a milk–water–milk system. Both sides may be closed (Fig. 5) or the raw milk supply may be open.

A homogenizer or rotary positive pump may be used as a timing or metering pump to provide a positive, fixed flow through the pasteurization system (Fig. 6). The pump is placed ahead of the heater and the holding section. Various control drives assure that the pasteurized side of the heat exchanger is at a higher (7 kPa (1 psi)) pressure than the opposite side.

The homogenizer can be used as a timing pump as it is homogenizing the product (Fig. 7), or both the timing pump and homogenizer can be used in the same system; in the latter, appropriate connections and relief valves must be provided to permit the product to bypass any unit that is not operating.

Booster Pump. Use of a centrifugal booster pump avoids a low intake pressure, particularly for large, high volume units. A low pressure (>26.6 kPa (200 mm Hg)) on the intake of a timing pump can cause vaporization of the product. The booster pump is in the circuit ahead of the timing pump and operates only when the FDV is in forward flow, the metering pump is in operation, and the pasteurized product is at least 7 kPa (1 psi) above the maximum pressure developed by the booster pump (Fig. 8).

Separator. Fat is normally separated from the milk before the HTST; however, in one system the airtight separator is placed after the FDV, following pasteurization. A restricting device and several control combinations are placed in the line after the FDV to ensure that constant flow is maintained, that vacuum does not develop in the line, that the timing pump stops if the separator stops, and that the legal holding time is met.

Control System. For quality control, a complete record of the control and operation of the HTST is kept with a safety thermal-limit recorder–controller (Fig. 9). The temperature of product leaving the holder tube, ahead of the FDV, is recorded and the forward or diverted flow of the FDV is determined. Various visual indicators, operator temperature calibration records, and thermometers also are provided.

Utilities. Electricity, water, steam refrigeration, and compressed air must be provided to the pasteurizer for heating, cooling, and cleaning of water. The water is heated by steam injection or an enclosed heating and circulating unit. The controller, sensing the hot water temperature, permits heating until the preset temperature is reached, usually 1–2°C above the pasteurization temperature. A diaphragm valve, directed by the controller, maintains the maximum temperature of the hot water by control of the steam. Water is cooled with a direct expansion refrigeration system and may be cooled directly or over an ice bank formed by direct expansion refrigeration. The compressed air should be clean, relatively dry, and supplied at ~138 kPa (20 psi) to operate valves and controls.

Other Continuous Processes. Various pasteurization heat treatments are identified by names such as quick time, vacuum treatment (vacreator), modified tubular (Roswell), small-diameter tube (Mallorizer), and steam injection.

The last three methods are ultrahigh temperature (UHT) processes (see Fig. 3). Higher treatment temperatures with shorter times, approaching two seconds, are preferred because the product has to be cooled quickly to prevent deleterious heat effects.

Vacuum Treatment. Milk can be exposed to a vacuum to remove low boiling substances, eg, onions, garlic, and some silage, which may impart off-flavors to the milk, particularly the fat portion. A three-stage vacuum unit, known as a vacreator, produces pressures of 17, 51–68, and 88–95 kPa (127, 381–508, and 660–711 mm Hg). A continuous vacuum unit in the HTST system may consist of one or two chambers and be heated by live steam, with an equivalent release of water by evaporation, or flash steam to carry off the volatiles. If live steam is used, it must be culinary steam which is produced by heating potable water with an indirect heat exchanger. Dry saturated steam is desired for food processing operations.

Product Heat Treatment. Equivalent heat treatment for destruction of microorganisms or inactivation of enzymes can be represented by plotting the logarithm of time versus temperature. These relationships were originally developed for sterilization of food at 121.1°C, therefore the time to destroy the microorganism is the F_0 value at 121.1°C (250°F). The slope of the curve is z, and the temperature span is one log cycle. The heat treatment at 131°C for one minute is equivalent to 121.1°C for 10 minutes (Fig. 10).

Irradiation. Although no irradiation systems for pasteurization have been approved by the U.S. Food and Drug Administration, milk can be pasteurized or sterilized by β-rays produced by an electron accelerator or γ-rays produced by cobalt-60. Bacteria and enzymes in milk are more resistant to irradiation than higher life forms. For pasteurization, 5000–7500 Gy (500,000–750,000 rad) are required, and for inactivating enzymes at least 20,000 Gy (2,000,000 rad). Much lower radiation, about 70 Gy (7000 rad), causes an off-flavor. A combination of heat treatment and irradiation may prove to be the most acceptable approach.

3.6. Equipment. Equipment is designed according to 3A Sanitary Standards established by a committee of users, manufacturers, and sanitarians in the food industry. The objective of the committee is to provide interchangeable parts and equipment, establish standards for inspection, and provide knowledge of acceptable design and materials, primarily to fulfill sanitary requirements. Sanitary equipment design requires that the material of construction is 18–8 stainless steel, with a carbon content of not more than 0.12%, although equally corrosion-resistant material is acceptable; the metal gauge for various applications is specified; surfaces fabricated from sheets have a No. 4 finish or equivalent; weld areas are substantially as corrosion resistant as the parent material; minimum radii are often specified, eg, for a storage tank, 0.62 cm for inside corners of permanent attachments; no threads are in contact with food; and threads are Acme threads (flat-headed instead of V-shaped).

Materials of Construction. Stainless Steel. The use of stainless steel for flat surfaces, tubing, coils, and castings in milk and dairy equipment has advanced since the 1950s. Previously metal-coated materials such as tinned copper were used for most applications, and copper alloys were used for castings and fittings. The contact surfaces of milk and dairy equipment are primarily stainless steel, which permits cleaning-in-place (CIP), automation, continuous operations, and aseptic processing and packaging.

Many types of stainless steels are available. The type most widely used in the dairy industry is 18–8 (18% chromium, 8% nickel plus iron). Small amounts of silicon, molybdenum, manganese, carbon, sulfur, and phosphorus may be included to obtain characteristics desired for specific applications.

The most important stainless steel [*12597-68-1*] series are the 200-, 300-, and 400-series. The 300-series, primarily 302, 304, and 316, is used in the dairy industry, whereas the 400-series is used for special applications, such as pump impellers, plungers, cutting blades, scrapers, and bearings (Table 11). Surface finishes are specified from No. 1 to No. 8 (highly polished); the No. 4 finish is most commonly used.

Stainless steel develops a passive protective layer ($\leq$5-nm thick) of chromium oxide [*1118-57-3*] which must be maintained or permitted to rebuild after it is removed by product flow or cleaning. The passive layer may be removed by electric current flow across the surface as a result of dissimilar metals being in contact. The creation of an electrolytic cell with subsequent current flow and corrosion has to be avoided in construction. Corrosion may occur in welds, between dissimilar materials, at points under stress, and in places where the passive layer is removed; it may be caused by food material, residues, cleaning solutions, and brushes on material surfaces.

Cleaning. Equipment is cleaned to prevent contamination of subsequent dairy processing operations and damage to the surface. In cleaning stainless steel, surface contaminants are removed that would otherwise destroy the protective passive layer. The surface is dried and exposed to air to rebuild the protective passive chromium oxide layer. Metal adhering to the stainless steel surface should be removed with the least abrasive material, and after cleaning, the surface should be washed with hot water and left to dry. Equipment should be sanitized with 200-ppm chlorine solution within 30 minutes before use, not necessarily after cleaning, to avoid corrosion resulting from chlorine on the surface for an extended period of time. For cleaning-in-place (CIP), the velocity of the cleaning solution over the surfaces should be $\leq$1.5 m/s. Excessive velocities can cause erosion of the surface and reduction of the protective layer. Excessive time of contact of the cleaning solution may cause corrosion, depending on the strength of the cleaning solution.

Piping and Tubing. Piping size is designated by a nominal rather than an exact inside diameter, ie, a pipe of 2.5-cm diameter can have an inside diameter slightly more or less than 2.5 cm, depending on the wall thickness. Tubing size is designated by the outside diameter, ie, a tube of 2.5-cm diameter has an outside diameter of 2.5 cm, and as the thickness of the tubing increases the inside diameter decreases and is always less than 2.5 cm. Both piping and tubing have fixed but different outside diameters for a particular size, and standard fittings can be used with different wall thicknesses.

The food industry uses stainless steel tubing or piping extensively for moving food products; conventional steel, cast iron, copper, plastic, glass, aluminum, and other alloys are used for utilities.

Most piping and tubing systems are designed for in-place cleaning. Classification is based on the type of connections for assembly: welded joints for permanent connections; ground joints with Acme threads and hexagonal nuts having gaskets for connections that are opened daily or periodically; and clamp-type joints.

Corrosion between the support device and the pipeline must be avoided. Drainage is provided by the pipeline slope, normally 0.48–0.96 cm/m of length, and gaskets must be nonabsorbent and of a type that does not affect the food product.

Fittings. Fittings connect pipes and provide for the attachment of equipment to change flow direction. They must be easily cleaned inside and out, have no exposed pipe threads, and, if of the detachable type, have an appropriate gasket. The fittings are constructed of the same or similar materials as the pipeline and are installed on tubing. Standard shapes and sizes are specified by the 3A Standards Committee.

An air valve, sometimes called the air-activated valve, is widely used for automated food handling operations. Although electronic or electric control boxes may be a part of the system, the valve itself generally is air-activated, and is more reliable than other types. Air-operated valves are used for in-place cleaning systems, and for the transfer and flow control of various products.

Plastic. Plastic tubing is used for farm-to-receiving operations rather than for permanent food handling installations. It is widely used to transport water for cleaning and sanitizing.

Pumps. The flow of fluids through a dairy processing plant is maintained by a centrifugal (nonpositive) or a displacement (positive) pump. Positive displacement pumps are either of the piston or plunger type, which are usually equipped with multiple pistons, or of the rotary positive type. The pump is selected on the basis of the quantity of product to be moved against a specified head. Generally, a hardenable 400-series stainless steel is used for the moving parts which chip easily and must be handled carefully during disassembly, cleaning, and assembly.

Centrifugal Pump. The centrifugal pump consists of a directly connected impeller which operates in a casing at high speed. Fluid enters the center and is discharged at the outer edge of the casing. The centrifugal pump is used with for moving products against low discharge heads or where it is necessary to regulate the flow of product through a throttling valve or restriction. Pumps for a CIP system include a self-cleaning diaphragm.

Positive Pumps. Positive pumps employed by the food industry have a rotating cavity between two lobes, two gears that rotate in opposite directions, or a crescent or stationary cavity and a rotor. Rotary positive pumps operate at relatively low speed. Fluid enters the cavity by gravity flow or from a centrifugal pump. The positive pump also may use a reciprocating cavity, and may be a plunger or piston pump. These pumps are not truly positive with respect to displacement, but are used for metering product flow.

Speed Devices. Many displacement pumps are connected by variable speed drives. When these pumps are used as a time device on a homogenizer, the setting is fixed, ie, the maximum speed is limited in order to meet the requirements of pasteurization.

Pump Suction. The net positive suction head required (NPSHR) affects the resistance on the suction side of the pump. If it drops to or near the vapor pressure of the fluid being handled, cavitation and loss of performance occurs

(13). The NPSHR is affected by temperature and barometric pressure and is of most concern on evaporator CIP units where high cleaning temperatures might be used. A centrifugal booster pump may be installed on a homogenizer or on the intake of a timing pump to prevent low suction pressures.

3.7. Cleaning Systems. Both manual and automatic methods are used for cleaning food processing equipment.

Cleaning-In-Place. In dairy plants, the equipment surfaces and pipelines are cleaned in place at least once every 24 hours. Cleaning-in-place (CIP) systems evolved from recirculating cleaning solutions in pipelines and equipment to a highly automatic system with valves, controls, and timers. The results of cleaning in place are influenced by equipment surfaces, time of exposure, and the temperature and concentration of the solution being circulated. Cleaning is a mechanical–chemical operation.

In the CIP procedure, a cold or tempered aqueous prerinse is followed by circulation of a cleaning solution for 10 minutes to one hour at 54–82°C. The temperature of the cleaning solution should be as low as possible, because hot water rinses may harden the food product on the surface being cleaned, but high enough to avoid excess cleaning chemicals. A wide variety of cleaning solutions may be used, depending on the food product, hardness of water, and equipment.

A CIP system includes pipelines, interconnected with valves to direct fluid to appropriate locations, and the control circuit, which consists of interlines to control the valves that direct the cleaning solutions and water through the lines, and air lines which control and move the valves. A programmer controls the timing and the air flow to the valves on a set schedule. The 3A Standards for CIP components, equipment, and installation have been developed. A simple CIP system circuit is shown in Figure 11.

4. Economic Aspects

4.1. Production. In 2000, U.S. milk production was 76.0×10^6 t from nearly 9.2×10^6 cows. In 2007 production is estimated at 83.1×10^6 t. In the United States there has been an increase in quantity of production with a decrease in the number of dairy cows. According is the FAO, the world production of milk in 2002 was 598.7×10^6 t. Milk was produced in all 50 of the United States. The top five states producing approximately 52.5% of total milk production in decreasing order are California, Wisconsin, New York, Pennsylvania, and Minnesota.

The dairy industry in the United States underwent dramatic restructuring the last 50 years. The number of farms with milk cows as well as the number of specialized diary farms decreased dramatically, while herd size grew. The noticeable changes in the number and size of dairy farms were not matched by any major changes in business organization. Commercial dairy farms continue to be owned and operated mainly by individuals or families (14). These changes have occurred as dairy farmers adopted technological innovations and have come to a better understanding of the biology of dairy cows.

On-farm refrigerated bulk milk tanks, improved milking equipment, modern and efficient milking parlors, changes in animal housings, and improved feed handling and waste disposal systems are examples of technological innovations widely adopted by dairy farmers. Advances in animal nutrition and breeding techniques and advance management skills have added to the change.

Table 12 lists the U.S. milk supply and use for the years 1999–2007 (15). A small amount is kept for farm use; most is sold for commercial use.

4.2. Consumption. Table 13 lists the U.S. per capita availability of milk and other dairy products for 1999–2005 (15).

4.3. Organic Milk. U.S. retail sales of organic milk have been growing steadily since the mid-1990s. Sales of organic milk and cream edged over $\$1 \times 10^9$ in 2005, up 25% from 2004. At the same time, overall sales of milk have remained constant. Organic milk and cream account for 6% of retail sales. Rising consumer interest in organic products has been accompanied by a widespread availability of the product in conventional food venues. Shortages of organic milk occurred in 2005 and 2006.

As of 2007, Organic Valley and Horizon are the two major suppliers of organic milk in the U.S. In 2003, Aurora Dairy began operating as a private label processor. It has been reported that these three dairies are trying to increase the organic milk supply by recruiting conventional milk suppliers to switch to organic production. Supply responses, lag since it takes three years to convert a conventional system to an organic system (16).

Organic food consumers perceive that the organic food provides environmental and health benefits, and are, thus, willing to pay a higher price for the product.

Table 14 gives comparisons of conventional and organic milk prices by U.S. region in 2004 (16).

5. Storage, Cooling, Shipping, and Packaging

5.1. Bulk Milk Tanks. Commercial dairy production enterprises generally employ tanks in which the milk is cooled and stored. In some operations, the warm milk is first cooled and then stored in a tank; 3A Standards have been established for their design and operation. Among other requirements, the milk must be cooled to 4.4°C within two hours after milking. The temperature must not be permitted to increase above 10°C when warm milk from the following milking is placed in the tank. Bulk milk tanks are classified according to method of refrigeration, ie, direct expansion (DX) or ice bank (IB); pressure in tank, ie, atmospheric or vacuum; regularity of pickup, ie, every day or every other day; capacity, in liters, when full or at amount which can be received per milking; shape, ie, cylindrical, half-cylindrical, or rectangular; position, ie, vertical or horizontal; and method of cooling refrigeration condenser, ie, by water, air, or both.

5.2. Cooling. A compression refrigeration system, driven by an electric motor, supplies cooling for either direct expansion or ice bank systems (Fig. 12). In the former, the milk is cooled by the evaporator (cooling coils) on the bulk tank liner opposite the milk side of the liner. The compressor must have the capacity to cool the milk as rapidly as it enters the tank.

In the ice bank system, ice is formed over the evaporator coils. Water is pumped over the ice bank and circulated over the inner liner of the tank to cool the milk. The water is returned to the ice bank compartment. This system provides a means of building refrigeration capacity for later cooling; therefore a smaller compressor and motor can be used, although the unit operates two to three times as long as a direct expansion system for the same cooling capacity. Off-peak electricity might be used for the ice bank system, thus reducing operating costs.

Important features of bulk milk tanks include a measuring device, generally a calibrated rod or meter; cleaning and sanitizing facilities; and stirring with an appropriate agitator to cool and maintain cool milk temperatures.

Surface Coolers. Milk coming from cows may be rapidly cooled over a stainless steel surface cooler before entering a bulk tank. The cooler may either use compression refrigeration or have two sections, one using cold water followed by a section using compression refrigeration.

5.3. Shipping. Bulk milk is hauled to the processing plant in insulated tanks using truck tanks or trailer tankers. The milk is transferred from the bulk tank to the tanker with a positive or centrifugal-type pump. For routes of some distance, pick-up every other day reduces handling costs.

Receiving Operations. Bulk milk-receiving operations consist primarily of transferring milk from the tanker to a storage tank in the plant. Practically all Grade A milk is handled in bulk. The handling of milk in 38-L cans requires equipment and space for quality and quantity check of the product, washing of cans, and conveyors for moving and storing the cans.

A computer system that covers much collection and distribution has been reported (18).

5.4. Packaging. Aseptic packaging was developed in conjunction with high temperature processing and has contributed to make sterilized milk and milk products a commercial reality.

The objective in packaging cool sterilized products is to maintain the product under aseptic conditions, to sterilize the container and its lid, and to place the product into the container and seal it without contamination. Contamination of the head space between the product and closure is avoided by the use of superheated steam, maintaining a high internal pressure, spraying the container surface with a bactericide such as chlorine, irradiation with a bactericidal lamp, or filling the space with an inert sterile gas such as nitrogen.

A noncontaminating sale system for milk container spouts that avoids human contact has been reported (19).

6. Analysis and Testing

Milk and its products can be subjected to a variety of tests to determine composition, microbial quality, adequacy of pasteurization, contamination with antibiotics and pesticides, and radioactivity (20).

A sampling and testing system during milking where a portion of the stream goes to a test extractor is discussed in Ref. 21

6.1. Microbial Quality. The microbial quality of dairy products is related to the number of viable organisms present. A high number of microorganisms in raw milk suggests that it was produced under unsanitary conditions or that it was not adequately cooled after removal from the cow. If noncultured dairy products contain excessive numbers of bacteria, post-pasteurization contamination probably occurred or the product was held at a temperature permitting substantial microbial growth. Raw milk, as well as other milk products, is commonly examined for its concentration of microorganisms by a dye reaction test, ie, the methylene blue or resazurin [*635-78-9*] methods, the agar plate test, or the direct microscopic method.

The methylene blue and resazurin reduction methods indirectly measure bacterial densities in milk and cream in terms of the time interval required, after starting incubation, for a dye–milk mixture to change color (methylene blue, from blue to white; resazurin, from blue through purple and mauve to pink). In general, reduction time is inversely proportional to bacterial content of the sample when incubation starts.

The agar [*9002-18-0*] plate method consists of adding a known quantity of sample, usually 1.0 or 0.1 mL, depending on the concentration of bacteria, to a sterile petri plate and then mixing the sample with a sterile nutrient medium. After the agar medium solidifies, the petri plate is incubated at 32°C for 48 hours after which the bacterial colonies are counted and the number expressed in terms of a 1 mL or 1 g sample. This procedure measures the number of viable organisms present and able to grow under test conditions, ie, 32°C.

The direct microscopic count determines the number of viable and dead microorganisms in a milk sample. A small amount (0.01 mL) of milk is spread over a 1.0 cm^2 area on a microscope slide and allowed to dry. After staining with an appropriate dye, usually methylene blue, the slide is examined with the aid of a microscope (oil immersion lens). The number of bacterial cells and clumps of cells per microscopic field is determined and, by appropriate calculations, is expressed as the number of organisms per milliliter of sample.

Coliform Bacteria. Pasteurized products are tested for numbers of coliform bacteria in order to detect significant bacterial recontamination resulting from improper processing, damaged or poorly sanitized equipment, condensate dripping into pasteurized milk, and direct or indirect contamination of equipment by insects or hands or garments of workers. Coliform bacteria are detected by using the agar plate method and a selective culture medium (violet-red bile agar). A liquid medium (brilliant green lactose bile broth) can also be used to detect this group of organisms. Coliform bacteria are not present in properly processed products that have not been recontaminated.

Thermoduric, Thermophilic, and Psychrophilic Bacteria. Thermoduric bacteria survive but do not grow at pasteurization temperatures. They are largely nonspore-forming, heat-resistant types that develop on surfaces of unclean equipment. These bacteria are determined by subjecting a sample to laboratory pasteurization and examining it by the agar plate method.

Thermophilic bacteria are able to grow at 55°C. They are spore-forming bacilli that can enter milk from a variety of farm sources. Thermophiles grow in milk held at elevated temperatures. Their presence in milk is determined by means of the agar plate method and incubation at 55°C.

Psychrophilic bacteria can grow relatively rapidly at low temperatures, commonly within a range of 2–10°C. They are particularly important in the keeping quality of products held at refrigerator storage temperatures, and their growth is associated with the development of fruity, putrid, and rancid off-flavors. These bacteria can be detected and counted by the agar plate method with incubation at 7°C for 10 days.

6.2. Inhibitory Substances. When antibiotics or other chemicals appear in milk, starter culture growth in such milk may be inhibited. To test for the presence of such chemicals, an agar medium is inoculated with spores of *Bacillus stearothermophilus*. A thin layer of the medium is poured into a petri dish and allowed to harden. Filter disks (1.25-cm in diameter) are dipped into milk samples and placed on the surface of the agar medium. After appropriate incubation, plates are examined for a zone of growth inhibition surrounding the disks; the presence of such a zone suggests that the milk contains an antibiotic or other inhibitory agent.

6.3. Sediment. The sediment test consists of filtering a definite quantity of milk through a white cotton sediment test disk and observing the character and amount of residue. Efficient use of single-service strainers on dairy farms has reduced the use of sediment tests on milk as delivered to receiving plants. Although the presence of sediment in milk indicates unsanitary production or handling, its absence does not prove that sanitary conditions always existed.

6.4. Phosphatase Test. The phosphatase [*9001-78-9*] test is a chemical method for measuring the efficiency of pasteurization. All raw milk contains phosphatase and the thermal resistance of this enzyme is greater than that of pathogens over the range of time and temperature of heat treatments recognized for proper pasteurization. Phosphatase tests are based on the principle that alkaline phosphatase is able, under proper conditions of temperature and pH, to liberate phenol [*108-95-2*] from a disodium phenyl phosphate substrate. The amount of liberated phenol, which is proportional to the amount of enzyme present, is determined by the reaction of liberated phenol with 2,6-dichloroquinone chloroimide and colorimetric measurement of the indophenol blue formed. Under-pasteurization as well as contamination of a properly pasteurized product with raw milk can be detected by this test.

6.5. Pesticides. Chlorinated hydrocarbon pesticides are often found in feed or water consumed by cows (22,23); subsequently, they may appear in the milk, where they are not permitted. Tests for pesticides are seldom carried out in the dairy plant, but are most often done in regulatory or private specialized laboratories. Examining milk for insecticide residues involves extraction of fat, because the insecticide is contained in the fat, partitioning with acetonitrile, cleanup (Florisil [*26686-77-1*] column) and concentration, saponification if necessary, and determination by means of paper, thin-layer, microcoulometric gas, or electron capture gas chromatography.

6.6. Fat Content of Milk. Raw milk as well as many dairy products are routinely analyzed for their fat content. The Babcock test, or one of its modifications, has been a standard direct measure for many years and is being replaced by indirect means, particularly for production operations. The Babcock test employs a bottle with an extended and calibrated neck, milk plus sulfuric acid [*7664-93-9*] to digest the protein, and a centrifuge to concentrate the fat into the calibrated neck. The percentage of fat in the milk is read directly from the neck of the bottle with a divider or caliper, reading to ±0.05% (24).

Other direct tests for measuring the fat in milk and dairy products include the Mojonnier method, which employs thermostatically controlled vacuum drying ovens and hot plates together with desiccators whose temperature is controlled by circulating water; the Gerber test, developed and used extensively in Europe (24,25), which employs sulfuric acid to dissolve solids other than fat, amyl alcohol [*71-41-0*] to prevent charring of fat, and centrifuging to separate the fat into the calibrated neck of the Gerber test bottle; and the DPS detergent test, based on the principle that the selected detergent(s) dissolves readily in both fat and water phases of milk and then leaves the solution upon application of heat and/or salt, thereby liberating the accumulated fat for measurement. The official AOAC Te Sa test, a rapid detergent method using alkaline buffering agents and test bottles fitted with a side arm and plunger, is essentially a chemical extraction method applicable to a variety of animal and vegetable fat products. These fat tests are described (26).

Indirect methods for determination of fat and solids-not-fat include infrared spectroscopy and turbidity or light scattering. An infrared spectroscopy unit can measure fat (5.73 μm), protein (6.46 μm), and lactose (9.6 μm) and print out results at 180 samples per hour (25). Light scattering methods include extensive homogenization of milk before passing light through the material to minimize the effect of different sizes of fat globules.

6.7. Protein Content. The protein content of milk can be determined using a variety of methods including gasometric, Kjeldahl, titration, colorimetric, and optical procedures. Because most of the techniques are too cumbersome for routine use in a dairy plant, payment for milk has seldom been made on the basis of its protein content. Dye-binding tests have been applied to milk for determination of its protein content; these are relatively simple to perform and can be carried out in dairy plant laboratories. More emphasis will be given to assessing the nutritional value of milk, and the dependence on fat content as a basis for payment will most likely change.

In dye-binding tests, milk is mixed with excess acidic dye solution where the protein binds the dye in a constant ratio and forms a precipitate. After the dye–protein interaction takes place, the mixture is centrifuged and the optical density of the supernatant is determined. Utilization of the dye is thus measured and from it the protein content determined. Several methods for application of dye-binding techniques to milk are given (27,28).

7. Health and Safety Factors

7.1. Food Safety on the Farm. The first step in ensuring a safe supply of milk is to ensure the dairy cows are healthy. Working with the U.S. Food and Drug Administration and the U.S. Department of Agriculture rigorous and far-reaching safety programs have been put into place. Dairy farmers supply their cows with a range of preventative health care including vaccinations and check ups. Sick cows are removed from the population. Dairy cows are also provided with specialized bedding and comfortable, ample space in which to live protected from the weather. Bovine nutritionists give advice on the proper diets for the dairy cows. Today's dairy cows are milked by sterilized machines. The milk goes directly to specialized refrigerated stainless-steel tanks that keep the raw milk at or below 45°F. The milk is then transferred to a processing plant at least on a daily basis (29).

7.2. Food Safety at the Dairy. The Federal Pasteurized Milk Ordinance (PMO) is a set of requirements for milk production, hauling, pasteurization, product safety, equipment sanitation, and labeling. It is an effective tool for ensuring food safety. Less than 1% of foodborne illness in the U.S. involve dairy products. Milk may be a carrier of disease from cows to humans (see Table 15), but pasteurization is the best means of prevention. Proper farm safety procedures and proper refrigeration also help in avoiding disease. Pasteurization is strongly supported by many organizations including the U.S. FDA and the Center for Disease Control.

The Hazard Analysis and Critical Control Point (HACCP) system is a structured and scientific process used throughout the food industry to ensure food safety. Processing plants identify critical steps throughout manufacturing processes and establish plans to monitor and minimize risks.

Every tank load of milk entering a dairy processing plant is strictly tested for animal drug residues. The U.S. dairy industry conducts more than 3.5×10^6 tests to ensure antibiotics are kept out of the milk supply. Any tanker loads that test positive are disposed of (29).

7.3. Food Safety at the Grocery Store and at Home. Once it is pasteurized, milk must be kept refrigerated at 38–40°F both at the grocery store and at home. Milk kept at temperatures of 41–14°F can serve as a breeding place for harmful bacteria. Cartons of milk in the U.S. are to be marked with a "sell by" or "use by" date. Use by date shows how long the product can be kept at home. Special care should be taken in the summar. Avoid cross contamination by washing hands and keeping milk products separated from all other foods (29).

7.4. Lactose Intolerance. Lactose maldigestion occurs when digestion of lactose is reduced as a result of low activity of the enzyme lactase. Lactose intolerance refers to gastrointestinal symptoms resulting from consuming too much lactose relative to the body's ability to break it down. Lactose maldigestion does not mean one is allergic to milk and dairy products and a severe restrictive diet is not necessary (30). Dairy products provide key nutrients such as calcium, vitamins A and D, riboflavin and phosphorus. It has been shown that there have been misdiagnosis of these problems and could present long-term ill effects by unnecessary avoidance of dairy foods (31,32). Avoidance usually leads to calcium deficiencies, which in turn, effects bone health (33).

8. Manufactured Products

8.1. Evaporated and Condensed Milk. Evaporated milk is produced by removing moisture from milk, under a vacuum, followed by packaging and sterilizing in cans. The milk is condensed to half its volume in single- or multiple-effect evaporators. The final product has a fat to solids-not-fat ratio of 1:2.28, and is standardized before and after evaporation. It must have at least 7.9% fat and 25.9% total milk solids, including fat. The process for making evaporated skim milk is similar. A key operation is sterilization in the container at 116–118°C for 15–20 minutes; subsequent cooling with cold water should be completed in 15 minutes. The cans are continuously turned and moved through the sterilizing unit. Sterilization in the can imparts a distinct cooked flavor to the product. Higher temperatures and shorter treatment (ie, UHT) lessen this effect. Standards and definitions for evaporated and condensed milk have been set by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations (34).

Evaporated milk is a liquid product obtained by the partial removal of water only from milk. It has a minimum milk-fat content of 7.5 mol % and a minimum milk-solids content of 25.0 mol %. Evaporated skimmed milk is a liquid product obtained by the partial removal of water only from skimmed milk. It has a minimum milk-solids content of 20.0 mol %. Sweetened condensed milk is a product obtained by the partial removal of water only from milk with the addition of sugars. It has a minimum milk-fat content of 8.0 mol % and a minimum milk-solids content of 28.0 mol %. Skimmed sweetened condensed milk is a product obtained by the partial removal of water only from skimmed milk with the addition of sugars. It has a minimum milk-solids content of 24.0 mol %. All may contain food additives as stabilizers, in maximum amounts, including sodium, potassium, and calcium salts of hydrochloric acid at 2000 mg/kg singly; citric acid, carbonic acid, orthophosphoric acid, and polyphosphoric acid at 3000 mg/kg in combination, expressed as anhydrous substances; and in the evaporated milk carrageenin may be added at 150 mg/kg.

In addition to sections 1, 2, 4, and 6 of the General Standards for the Labeling of Prepackaged Foods (Ref. No. CAC/RS 1-1969), the following specific provisions apply. The name of the product shall be "Evaporated milk," "Evaporated whole milk," "Evaporated full cream milk," "Unsweetened condensed whole milk," "Unsweetened full cream condensed milk," "Evaporated skimmed milk," "Unsweetened condensed skimmed milk," "Sweetened condensed milk," "Sweetened condensed whole milk," "Sweetened full cream condensed milk," "Skimmed sweetened condensed milk," or "Sweetened condensed skimmed milk," as appropriate. Where milk other than cow's milk is used for the manufacture of the product or any part thereof, a word or words denoting the animal or animals from which the milk has been derived should be inserted immediately before or after the designation of the product, except that no such insertion need be made if the consumer would not be misled by its omission. In sweetened milks, when one or several sugars are used, the name of each sugar shall be declared on the label (34).

Vitamin A (845 RE/L) and vitamin D (913 RE/L) may be added to fortify evaporated milk. Other possible ingredients are sodium citrate, disodium phosphate, and salts of carrageenan. Phosphate ions maintain an appropriate salt balance to prevent coagulation of the protein (casein) during sterilization. The amount of phosphate added depends on the amount of calcium and magnesium present.

Large quantities of evaporated milk are used to manufacture ice cream, bakery products, and confectionery products. When used for manufacturing other foods, evaporated milk is not sterilized, but placed in bulk containers, refrigerated, and used fresh. This product is called condensed milk. Skimmed milk may be used as a feedstock to produce evaporated skimmed milk. The moisture content of other liquid milk products can be reduced by evaporation to produce condensed whey, condensed buttermilk, and concentrated sour milk.

Sweetened Condensed Milk. For sweetened condensed milk, unlike evaporated milk that is sterilized, sugar is added as a preservative and provides keeping quality. The equipment is similar to that used for evaporated milk, except that sugar is added in a hot well before condensing (evaporating) the liquid. Preheating pasteurizes the product and no sterilization is needed. According to standards, sweetened condensed milk must contain a minimum of 8.5% fat and 28% total milk solids, including fat (fat to solids-not-fat ratio = 1:2.3). The final product contains 43–45% sugar. Sweetened condensed skimmed milk has not less than 24% total milk solids, but up to 50% sugar may be added.

Age-thinning and age-thickening defects occur in sweetened condensed products because of the preheating temperature before evaporation of the water. A low temperature can result in thinning, a high temperature in thickening. The optimum preheating temperature is in the range of 60–81°C.

8.2. Dry Milk. Dry milk provides long-term storage capabilities, supplies a product that can be used for food manufacturing operations, and because of its reduced volume and weight, transportation and storage costs are reduced. Dry milk has been used for manufactured products, but is used to a much greater extent for beverage products. Its properties are listed in Table 16.

Dry milk is generally made using the spray process or the so-called roller drum process. These processes generally follow condensing of milk in an evaporator. The moisture content for nonfat dry milk, the principal dry product, is less than 5.0% for standard grade and less than 4.0% for extra grade. Dry whole milk contains less than 3.0% moisture. Other drying methods include the use of foam sprays, jet sprays, freeze-drying, and tall towers.

Clarification and homogenization precede evaporating and drying. Homogenization of whole milk at 63–74°C with pressures of 17–24 MPa (2500–3500 psi) is particularly desirable for reconstitution and the preservation of quality.

Standards and definitions for whole milk powder, partly skimmed milk powder, and skimmed milk powder have been set by WHO. This standard applies exclusively to dried milk products as defined, having a fat content of not more than 40 mol %.

Dry milk was referred to as milk powder until the mid-1960s, when the designation was changed by the American Dry Milk Institute to dry milk in the United States. Milk powder, having a milk-fat content of 26–40 mol %, is a product obtained by the removal of water only from milk, partly skimmed milk (powder having a milk-fat content of 1.5–26 mol %), or skimmed milk (powder having a maximum milk-fat content of 1.5 mol %). All have a maximum water content of 5 mol %. All may contain food additives as stabilizers, in maximum amounts, including sodium, potassium, and calcium salts of hydrochloric acid, citric acid, carbonic acid, orthophosphoric acid, and polyphosphoric acid at 5000 mg/kg singly or in combination expressed as anhydrous substances. Emulsifiers in instant milk powders include monoglycerides and diglycerides at 2500 mg/kg and lecithin at 5000 mg/kg. Anticaking agents in milk powders intended to be dispensed in vending machines include tricalcium phosphate, silicon dioxide (amorphous), calcium carbonate, magnesium oxide, magnesium carbonate, magnesium phosphate, and silicates of aluminum, calcium, magnesium, and sodium–aluminate, at 10 g/kg singly or in combination (34).

Dry whole milk should be vacuum or gas packed to maintain the quality while in storage. Products with milk fats deteriorate in the presence of oxygen, giving oxidation off-flavor. Several factors may be involved in oxidative deterioration, such as preheating of product, storage temperature, presence of metallic ions, particularly copper and iron, presence of oxygen (air) in product, and light. Antioxidants of many kinds have been used with various degrees of success, but a universally acceptable antioxidant which meets the requirements for food additives has not been found.

Drum Drying. The drum or roller dryers used for milk operate on the same principles as for other products. A thin layer or film of product is dried over an internally steam-heated drum with steam pressures up to 620 kPa (90 psi) and 149°C. Approximately 1.2–1.3 kg of steam are required per kilogram of water evaporated. The dry film produced on the roller is scraped from the surface, moved from the dryer by conveyor, and pulverized, sized, cooled, and put into a container.

The operating variables for a drum or roller dryer include condensation of incoming product in an evaporator, temperature of incoming product, steam pressure (temperature) in drum, speed of drum, and height of product over drum. The capacity of the dryer is increased by increasing the steam pressure, the temperature of the milk feed, the height of milk over the drums, the gap between drums (double), and the speed of rotation of the drums. Increasing the capacity is limited by the effect on the product quality.

Drum-dried products are more affected by heat than spray-dried products. Drying in a vacuum chamber decreases the temperature and thus the heat effect on the product, although the atmospheric dryers are used more widely.

Drum-dried products, mostly nonfat, make up only 5–10% of dried milk products. Because of the high temperature and longer contact time, considerable protein denaturation occurs. Drum-dried products are identified as high heat dry milk and as such have a lower solubility index, lower protein nitrogen content, and a darker color.

Spray Drying. The spray dryer provides a chamber in which the milk or milk product is atomized in a heated air stream that removes most of the moisture. The dry product is separated from the air stream and removed from the chamber. The process involves condensing the product from 3 to 2:1, preheating or reheating at 63–74°C, pumping at 17.2–20.7 MPa (2500–3000 psi), atomizing, spray drying with an outlet air temperature of 82–85°C, separating air and product, cooling product at 32–38°C, sifting, packaging (vacuum plus nitrogen for whole milk), and storing.

In spite of the higher energy requirements, the spray dryer has gained in popularity because of the reduced heat effect on the product as compared to the drum dryer. Modifications such as foam spraying are being developed to reduce the heat effect further.

In the manufacture of dry milk by the spray process, a condensed product is pumped to an atomizer in order to produce a large surface area to enhance drying. A high pressure nozzle or centrifugal device, such as a rotating disk or wheel, is used for atomization. The air is filtered, heated to 149–260°C and moved over the atomizing product, saturated with water, and exhausted from the dryer. The dry product is removed from the air in a mechanical centrifugal separator and filtered outside the drying chamber. In order to minimize heat effects, the dried product is removed as rapidly as possible from the chamber and cooled. Considerable variation exists in the operation of spray dryers, depending on the product and the dryer. A low heat, nonfat dry milk product is obtained by minimizing heating before and after drying.

Foam spray drying consists of forcing gas, usually air or nitrogen, into the product stream at 1.38 MPa (200 psi) ahead of the pump in the normal spray dryer circuit. This method improves some of the characteristics of dried milk, such as dispersibility, bulk density, and uniformity. The foam–spray dryer can accept a condensed product with 60% total solids, as compared to 50% without the foam process. The usual neutralization of acid whey is avoided with the foam–spray dryer.

Agglomeration. The process of treating dried products, particularly nonfat products, in order to increase speed and ability to reconstitute those products, is known as instantizing or agglomeration. Particles are agglomerated into larger particles which dissolve more easily than small particles. In this process the dry particle surface is first wetted; this is followed by agglomeration and drying. Instantized products can also be obtained by foam–spray drying. Instantized products have a lower density, are more fragile than conventional products, and must be handled with extra care. They are of particular importance to the fast-food market. The process is also used for various beverage and milk products.

Packaging. Dry milk is packaged in large bulk or small retail containers. A suitable container keeps out moisture, light, and air (oxygen). For dry whole milk, oxygen is removed by vacuum, and an inert gas, such as nitrogen, is inserted in the heat space. An oxygen level of $\leq$2.0% is required by U.S. standard for premium quality.

8.3. Cream. Cream is a high fat product which is secured by gravity or mechanical separation through differential density of the fat and the serum. Fat content may range from 10 to 40%, depending on use and federal and state laws. The U.S. Public Health Service (6) milk ordinance defines cream as a product that contains not less than 18% milk fat. Whipping cream has a fat content of 30–40%, and light cream has a fat content of 18–30%. Half-and-half, suggesting a mixture of cream and milk, has not less than 10.5% milk fat, and in some states up to 12%. Cream is standardized in the same manner as milk, following separation. The addition of whole milk rather than serum is preferred.

The sale of fresh cream as a table item for serving has decreased greatly since the 1970s, primarily as a result of changing customer demand based on diet. A variety of cream and fat substitutes are available for spreads, toppings, whiteners, and cooking.

8.4. Anhydrous Milk Fat. One high milk-fat material is butter oil (99.7% fat), also called anhydrous milk fat or anhydrous butter oil if less than

0.2% moisture is present. Although the terms are used interchangeably, anhydrous butter oil is made from butter and anhydrous milk fat is made from whole milk. For milk and cream there is an emulsion of fat-in-serum, for butter oil and anhydrous milk fat there is an emulsion of serum-in-fat, such as with butter. It is easier to remove moisture in the final stages to make anhydrous milk fat with the serum-in-fat emulsion.

8.5. Butter. In the United States about 10 wt% of edible fats used are butter. Butter is defined as a product that contains 80% milk fat with not more than 16% moisture. It is made of cream with 25–40% milk fat. The process is primarily a mechanical one in which the cream, an emulsion of fat-in-serum, is changed to butter, an emulsion of serum-in-fat. The process is accomplished by churning or by a continuous operation with automatic controls. Some physical properties are given in Table 17.

Butter, fresh and salted, was once a primary trade commodity, but is no longer in as high a demand. There has been a shift in emphasis from fat content to the protein, mineral, and vitamin content of milk and milk products, particularly in developed countries.

8.6. Buttermilk. Buttermilk is drained from butter (churn) after butter granules are formed; as such, it is the fluid other than the fat which is removed by churning. Buttermilk may be used as a beverage or may be dried and used for baking. Buttermilk from churning is $\sim$91% water and 9% total solids. Total solids include lactose [*598-82-3*], 4.5%; nitrogenous matter, 3.4%; ash, 0.7%; and fat, 0.4%. Table (18) gives the U.S. specifications for dry buttermilk (DBM) and whey.

Cultured buttermilk is that which is produced by the fermentation of skimmed milk, often with some cream added. The principal fermentation organisms used are *Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp. *lactis*, and *Leuconostoc citrovorum*. The effect of the high processing temperature and the lactic acid provide an easily digestible product.

Dried buttermilk is made by either the drum or spray process. Buttermilk is usually pasteurized before drying, even though the milk was previously pasteurized before churning. Dried buttermilk is used primarily for baking, confectionery, and dairy products.

8.7. Cheese. The making of cheese is based on the coagulation of casein from milk, and to a minor extent the proteins of whey. The casein is precipitated by acidification which can be accomplished by natural souring of milk. The procedures for making cheese vary greatly and cheese products are countless. The composition and handling of the original milk, bacterial flora, and starter culture are the basis variables, which along with heat treatments, flavoring, salting, and forming, affect the final product.

Membrane Separation. The separation of components of liquid milk products can be accomplished with semipermeable membranes by either ultrafiltration or hyperfiltration, also called reverse osmosis (38). With ultrafiltration (UF) the membrane selectively prevents the passage of large molecules such as protein. In reverse osmosis (RO) different small, low molecular weight molecules are separated. Both procedures require that pressure be maintained and that the energy needed is a cost item. The materials from which the membranes are made are similar for both processes and include cellulose acetate, poly(vinyl chloride), poly(vinylidene difluoride), nylon, and polyamide. Membranes are commonly used for the concentration of whey and milk for cheesemaking (39). For example, membranes with 100 and 200 μm are used to obtain a 4:1 reduction of skimmed milk.

Four configurations for membranes are plate, hollow fine fiber, spiral wound, and tubular (40). With a variety of shapes, sizes, and materials many options exist for meeting the various needs in the dairy industry.

Ultrafiltration. Membranes are used that are capable of selectively passing large molecules (>500 daltons). Pressures of 0.1–1.4 MPa ($\leq$ 200 psi) are exerted over the solution to overcome the osmotic pressure, while providing an adequate flow through the membrane for use. Ultrafiltration has been particularly successful for the separation of whey from cheese. It separates protein from lactose and mineral salts, protein being the concentrate. Ultrafiltration is also used to obtain a protein-rich concentrate of skimmed milk from which cheese is made. The whey protein obtained by ultrafiltration is 50–80% protein which can be spray dried.

Reverse Osmosis. Membranes are used for the separation of smaller components (<500 daltons). They have smaller pore space and are tighter than those used for ultrafiltration. High pressure pumps, usually of the positive piston or multistage centrifugal type, provide pressures up to 4.14 MPa (600 psi).

Following ultrafiltration of whey, the permeate passes over a reverse osmosis membrane to separate the lactose from other components of the permeate. Reverse osmosis can be used to remove water and concentrate solids in a dairy plant, giving a product with 18% solids and thus decreasing the difficulty of waste disposal. Concentration of rinse water gives a product with 4–5% total solids. Proper maintenance of the membrane allows for use up to two years. Membranes are available for use up to 100°C with pH ranges from 1 to 14; the usual temperature range is 0–50°C.

Cheddar Cheese. Milk is heated to 30°C and a lactic acid-producing starter is added. The milk is held for about one hour, during which time the acidity increases. Rennet extract is mixed with the milk that produces a curd in approximately 30 minutes. The curd is cut into cubes and the whey expressed. The curd solidifies and is stirred and heated slowly. The heating is continued until the curd becomes completely firm, and the whey is drained and separated by forming channels. With the development of lactic acid and the removal of whey, the curd becomes a solid mass and is cut, with the pieces moved to continue the removal and drainage of the whey. The whey increases from 0.1% acid at the time of cutting, to 0.5% acid at the end of drainage. Cheddared cheese is put through a curd mill to reduce the curd sizes.

Cottage Cheese. Cottage cheese is made from skimmed milk. As compared to most other cheeses, cottage cheese has a short shelf-life and must be refrigerated to maintain quality, usually $\leq$4.4°C to provide a shelf-life of three weeks or more. Cottage cheese is a soft uncured cheese which contains not more than 80% moisture.

Several procedures can be used for making cottage cheese. In general, pasteurized skim milk is inoculated with lactic acid culture and rennet starter to coagulate the protein. The coagulated material is divided or cut and the resulting curd cooked to expel the whey. The whey is drained and the curd washed with water. Mechanized operations are used for large-scale production. The conditions for manufacture are given in Table 19.

Horizontal vats are employed for manual and mechanized operations. The starter may be blended with the incoming product or added at the vat. The setting temperature of the treated whey is typically 30°C and is held for 4.5–5 hours. The curd is cut when the titratable acidity is 0.52% for lactic acid milk with 9.0% nonfat milk solids, or pH 4.6–4.7. The acidity controls the calcium level of the casein that determines many of the characteristics of the curd; low acidity causes a rubbery curd, and high acidity causes a tender curd that shatters easily. The curd is cut by moving a knife first horizontally, then vertically, and finally crosswise through the vat. The cut curd is cooked about 30 minutes after cutting is finished. The temperature is gradually increased in increments of 0.5–1.0°C every 3–5 minutes to avoid the formation of a hardened protein layer that would inhibit moisture removal. After cooking, the whey is drained off and the curd is washed successively with cooler water, pasteurized or treated with chlorine, and rinsed at 4.4°C for firmness. Curd pumps move the curd to the blender where salt, cream, and stabilizer may be added. Creamed cottage cheese that has a fat content of at least 4% is produced by mixing in 12–14% fat cream.

8.8. Yogurt. Yogurt is a fermented milk product that has rapidly increased in consumption in the United States. Milk is fermented with *Lactobacillus bulgaricus* and *Streptococcus thermophilous* organisms that produce lactic acid. Usually some cream or nonfat dried milk is added to the milk in order to obtain a heavy-bodied product.

Yogurt is manufactured by procedures similar to buttermilk. Milk with a fat content of 1–5% and solids-not-fat (SNF) content of 11–14% is heated to ca 82°C and held for 30 minutes. After homogenization the milk is cooled to 43–46°C and inoculated with 2% culture. The product is incubated at 43°C for three hours in a vat or in the final container. The yogurt is cooled and held at $<$4.4°C. The cooled product should have a titratable acidity of not less than 0.9% and a pH of 4.3–4.4. The titratable acidity is expressed in terms of percentage of lactic acid [*598-82-3*], which is determined by the amount of 0.1 *N* NaOH/100 mL required to neutralize the substance. Thus 10 mL of 0.1 *N* NaOH represents 0.10% acidity. Yogurts with less than 2% fat are popular. Fruit-flavored yogurts are also common in which 30–50 g of fruit are placed in the carton before or with the yogurt.

8.9. Frozen Desserts. Ice cream is the principal frozen dessert produced in the United States. It is known as the American dessert and was first sold in New York City in 1777. Frozen yogurt is also gaining in acceptance as a dessert. The composition of various frozen desserts is given in Table 20.

Ice Cream. Ice cream is a frozen food dessert prepared from a mixture of dairy ingredients (16–35%), sweeteners (13–20%), stabilizers, emulsifiers, flavoring, and fruits and nuts (qv). Ice cream has 10–20% milk fat and 8–15% nonfat solids with 38.3% (36–43%) total solids. These ingredients can be varied, but the dairy ingredient solids must total 20%. The dairy ingredients are milk or cream, and milk fat supplied by milk, cream butter, or butter oil, as well as SNF supplied by condensed whole or nonfat milk or dry milk. The quantities of these products are specified by standards. The milk fat provides the characteristic texture and body in ice cream. Sweeteners are a blend of cane or beet sugar and corn syrup solids. The quantity of these vary depending on the sweetness desired and the cost.

Stabilizers to improve the body of the ice cream include gelatin, sodium alginate (alginic acid sodium), certain pectins, guar gum, locust bean gum, and carboxymethylcellulose. Emulsifiers such as lecithin, monoglycerides, and diglycerides assist the incorporation of air and improve the whipping properties. The mixture of components for making ice cream is called ice cream mix and is often sold as a commercial product to those who make ice cream. Ice cream mix in dry powder form is also available. The properties of ice cream are given in Table 21.

Preceded by a blending operation and pasteurization, the ingredients are mixed in a freezer that whips the mix to incorporate air and freezes a portion of the water. Freezers may be of a batch or continuous type. Commercial ice cream is produced mostly in continuous operation.

The incorporation of air decreases the density and improves the consistency. If one-half of the final volume is occupied by air, the ice cream is said to have 100% overrun, and 4 L will have a weight of 2.17 kg. Ice cream from the freezer is at ca -5.5°C with one-half of the water frozen, preferably in small crystals.

Containerized ice cream is hardened on a stationary or continuous refrigerated plate-contact hardener or by convection air blast as the product is carried on a conveyor or through a tunnel. Air temperatures for hardening are -40 to -50°C. The temperature at the center of the container as well as the storage temperature should be $\leq -26^{\circ}$C. Approximately one-half of the heat is removed at the freezer and the remainder in the hardening process.

Other Frozen Desserts. Although ice cream is by far the most important frozen dessert, other frozen desserts such as frozen yogurt, ice milk, sherbet, and mellorine-type products are also popular. The consumption of frozen yogurt has been increasing rapidly.

Ice milk is a frozen product which has less fat (2–7%) and slightly more nonfat milk solids than ice cream. Stabilizers and emulsifiers are added. About half of ice milk produced is made as a soft-serve dessert, produced in freezers with an overrun of 40–100%.

Sherbets have a low fat content (1–2%), low milk solids (2–5%), and a sweet but tart flavor. Ice cream mix and water ice can be mixed to obtain a sherbet. The overrun in making sherbets is about 40–60%.

Mellorine is similar to ice cream except that the milk fat is replaced with vegetable fat (6% min). The total solids in mellorine are 35–39%, of which there are 10–12% milk solids.

Other frozen desserts are parfait, souffle, ice cream pudding, punch, and mousse. These are often classified with the sherbets and ices.

8.10. By-Products From Milk. Milk is a source for numerous by-products resulting from the separation or alteration of the components. These components may be used in other so-called nondairy manufactured foods, dietary foods, pharmaceuticals, and as a feedstock for numerous industries, such as casein for glue.

Lactose. Lactose [*63-42-3*] (milk sugar), $C_{12}H_{22}O_{11}\cdot H_2O$, makes up about 5% of cow's milk. Lactose is a disaccharide composed of D-glucose and D-galactose. Compared to sucrose, lactose has about one-sixth the sweetening strength (see

SUGAR). Because of its low solubility, lactose is limited in its application; however, it is soluble in milk serums and can be removed from whey. Upon fermentation by bacteria lactose is converted to lactic acid [*598-82-3*], and is therefore of particular importance in producing fermented or cultured dairy products, such as buttermilk, cheeses, and yogurt.

The ratio of α-lactose [*10039-26-6*] and β-lactose in dry milk and whey varies according to the speed and temperature of drying. An aqueous solution at equilibrium at 25°C contains 35% α- and 63% β-lactose. The latter is more soluble and sweeter than DL-lactose and is obtained by heating an 80% DL-lactose [*63-42-3*] solution above 93.5°C, followed by drying on a drum or roller dryer. Lactose is used for foods and pharmaceutical products.

8.11. Casein. Milk contains proteins and essential amino acids lacking in many other foods. Casein is the principal protein in the skimmed milk (nonfat) portion of milk (3–4% of the weight). After it is removed from the liquid portion of milk, whey remains. Whey can be denatured by heat treatment of 85°C for 15 minutes. Various protein fractions are identified as α-, β-, and γ-casein, and δ-lactoglobulin; and blood–serum albumin, each having specific characteristics for various uses. Table 22 gives the concentration and composition of milk proteins.

Casein is used to fortify flour, bread, and cereals. Casein also is used for glues and microbiological media. Calcium caseinate is made from a pressed casein, by rinsing, treating with calcium hydroxide [*1305-62-0*], heating, and mixing followed by spray drying. A product of 2–4% moisture is obtained.

Casein hydrolyzates are produced from dried casein. With appropriate heat treatment and the addition of alkalies and enzymes, digestion proceeds. Following pasteurization, evaporation, and spray drying, a dried product of 2–4% is obtained. Many so-called nondairy products such as coffee cream, topping, and icings utilize caseinates. In addition to fulfilling a nutritional role, the caseinates impart creaminess, firmness, smoothness, and consistency of products. Imitation meats and soups use caseinates as an extender and to improve moistness and smoothness.

8.12. Nutritional Value of Milk Products. Milk is considered one of the principal sources of nutrition for humans. Some people are intolerant to one or more components of milk so must avoid the product or consume a treated product. One example is intolerance to lactose in milk. Fluid milk is available in which the lactose has been treated to make it more digestible. The consumption of milk fat, either in fluid milk or in products derived from milk, has decreased markedly in the 1990s. Whole milk sales decreased 12% between 1985 and 1988, whereas the sales of low fat milk increased 165%, and skimmed milk sales increased 48% (43). Nutritionists have recommended that fat consumed provide no more than 30 calories, and that consumption of calories be reduced. Generally, a daily diet of 2000–3000 cal/d is needed depending on many variables, such as gender, type of work, age, body responses, exercise, etc. Further, there is concern about cholesterol [*57-88-5*] and density of fat consumed. Complete information on the nutritive value of milk and milk products is provided on product labels (44) (see also Table 4).

The concern by consumers about cholesterol has stimulated the development of methods for its removal. Three principal approaches are in the pilot-plant stages: use of enzymes, supercritical fluid extraction, and steam distillation.

Using known techniques, it is not possible to remove all cholesterol from milk. Therefore, FDA guidelines identify cholesterol-free foods as containing less than 2 mg cholesterol per serving, and low cholesterol foods as containing from 2 to 20 mg (45).

9. Biotechnology

Biotechnology is being applied in the dairy industry. A significant and controversial development is the technique of producing transgenic animals, ie, animals in which hereditary deoxyribonucleic acid (DNA) has been augmented by DNA from another source, using recombinant DNA (rDNA) techniques.

One technology uses bovine somatotropin (bST) produced by recombinant technology (46). Somatotropin [*9002-72-6*] is a growth hormone. The bST-supplemented cows provide an increase in milk output per cow or an increased feed efficiency. Recombinant bST, also known as recombinant bovine growth hormone (rBGH) is the synthetic analogue of a natural hormone that increases milk production in cows (47). The use of recombinant technology was approved by the FDA in 1993.

There are several reasons why bST, which is naturally present in cow's milk, does not have any physiological effect on humans consuming the milk. bST is species-specific, which means that it is biologically inactive in humans. Also, pasteurization destroys 90% of bST in milk. The remaining, trace amounts of bST in milk are broken down into inactive fragments (ie, constituent amino acids) by enzymes in the human gastrointestinal tract, just like any other protein (48,49).

New biotechnology products are also being developed for food processing. Genetically engineered enzymes have been approved by FDA for cheese manufacturing. Engineering microorganisms will be available to produce enzymes to be added to curd for ripening cheese. Various applications of biotechnology include production of milk that can be ingested by lactose-intolerant people, improved fermented products, production of natural preservatives in milk, and methods for treating and processing waste products for further use or nondamaging disposal (46).

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Dairy Science Abstracts
Food Science and Technology Abstracts (U.K.)

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Table 1. **Constituents of Milk from Various Mammals, Average, wt%**

Species	Water	Fat	Protein	Lactose	Ash	Nonfat solids	Total solids
human	87.4	3.75	1.63	6.98	0.21	8.82	12.57
cows							
Holstein	88.1	3.44	3.11	4.61	0.71	8.43	11.87
Ayrshire	87.4	3.93	3.47	4.48	0.73	8.68	12.61
Brown Swiss	87.3	3.97	3.37	4.63	0.72	8.72	12.69
Guernsey	86.4	4.5	3.6	4.79	0.75	9.14	13.64
Jersey	85.6	5.15	3.7	4.75	0.74	9.19	14.34
goat	87.0	4.25	3.52	4.27	0.86	8.65	12.90
buffalo (India)	82.76	7.38	3.6	5.48	0.78	9.86	17.24
camel	87.61	5.38	2.98	3.26	0.70	6.94	12.32
mare	89.04	1.59	2.69	6.14	0.51	9.34	10.93
ass	89.03	2.53	2.01	6.07	0.41	8.49	11.02
reindeer	63.3	22.46	10.3	2.50	1.44	14.24	36.70

Table 2. **Physical Properties of Milk**

Property	Value
density at 20°C with 3–5% fat, average, g/cm^3	1.032
weight at 20°C, kg/L[a]	1.03
milk serum at 20°C, 0.025% fat	
density, g/cm^3	1.035
weight, kg/L[a]	1.03
freezing point, °C	−0.540
boiling point, °C	100.17
maximum density at °C	−5.2
electrical conductivity, $S(=\Omega^{-1})$	$45–48 \times 10^{-8}$
specific heat at 15°C, kJ(kg·K)[b]	
skim	3.94
whole	3.92
40% cream	3.22
fat	1.95
relative volumes	
4% milk at 20°C = 1, volume at 25°C	1.002
40% cream at 20°C = 1.0010, volume at 25°C	1.0065
viscosity at 20°C, mPa·s(= cP)	
skim	1.5
whole	2.0
whey	1.2
surface tension of whole milk at 20°C, mN/m(= dyn/cm)	50
acidity, pH	6.3–6.9
titratable acid, %	0.12–0.15
refractive index at 20°C	1.3440–1.3485

[a]To convert kg/L to lb/gal, multiply by 8.34.
[b]To convert kJ/(kg·K) to Btu/(lb·°F), divide by 4.183.

Table 3. **Vitamin Content of Milk from Various Mammals, mg/L**[a]

	Vitamins									
Species	A, RE[b]	B_6	B_{12}	C	Thiamine	Riboflavin	Nicotinic acid	Pantothenic acid	Biotin	Folic acid
cow	312	0.48	0.0056	16	0.42	1.57	0.85	3.50	0.035	0.0023
goat	415	0.07	0.0006	15	0.40	1.84	1.87	3.44	0.039	0.0024
sheep	292		0.0064	43	0.69	3.82	4.27	3.64	0.093	0.0024
horse	160	0.21	0.0012	100	0.30	0.33	0.58	3.02	0.022	0.0012
human	380	0.10	0.0003	43	0.16	0.36	1.47	1.84	0.008	0.0020
pig	207	0.40	0.0016	140	0.70	2.21	8.35	5.28	0.014	0.0039
whale	1439	1.10	0.0085	70	1.16	0.96	20.40	13.10	0.050	

[a]Ref. 1.

[b]Ref. 2. Vitamin A is reported as retinol [68-26-8] equivalents/L. RE = 1 μg of all *trans*-retinol, 6 μg of all *trans*-β-carotene, and 12 μg of other provitamin A cartenoids, with older definitions giving 3.33 IU vitamin A from retinol and 10 IU vitamin A activity from β-carotene.

Table 4. **Nutritional Content (for Adults) of Cow Milk**[a]

Nutrient	Recommended daily allowance	Supplied by 1 L, %
energy, kJ[b]	11,720	96
protein, g	56	49
calcium, g	0.8	155
phosphorus, g	0.8	115
iron, mg	10	4.5
vitamin A, RE[c]	1,000	31
thiamine, mg	1.4	30
riboflavin, mg	1.7	92
niacin, mg	18.5	5
ascorbic acid, mg	60	27
vitamin D, IU	200	200[d]

[a]Ref. 2.
[b]To convert kJ to kcal, divide by 4.184; 1 food Calorie = 1 kcal.
[c]RE = retinol equivalent, the standard for vitamin A; 1 RE = 1 μm of all *trans*-retinol.
[d]Fortified milk.

Table 5. **Composition of Lipids in Cow Milk**[a]

Class of lipid	Range of occurrence
triglycerides of fatty acids, %	97.0–98.0
diglycerides, %	0.25–0.48
monoglycerides, %	0.016–0.038
keto acid glycerides, %	0.85–1.28
aldehydrogenic glycerides, %	0.011–0.015
glyceryl ethers, %	0.011–0.023
free fatty acids, %	0.10–0.44
phospholipids, %	0.2–1.0
cerebrosides, %	0.013–0.066
sterols, %	0.22–0.41
free neutral carbonyls, ppm	0.1–0.8
squalene, ppm	70
carotenoids, ppm	7–9
vitamin A, ppm	6–9
vitamin D, ppm	0.0085–0.021
vitamin E, ppm	24
vitamin K, ppm	1

[a]Ref. 3.

Table 6. **Fatty Acids in Samples of Milk Fat for Cows Fed Normal Rations**

	Acid content[a]	
Fatty acid	Range	Average
butyric (4:0)[b]	2.4–4.23	2.93
hexanoic (6:0)	1.29–2.40	1.90
octanoic (8:0)	0.53–1.04	0.79
decanoic (10:0)	1.19–2.01	1.57
lauric (12:0)	4.53–7.69	5.84
myristic (14:0)	15.56–22.62	19.78
oleic (18:1)	25.27–40.31	31.90
palmitic (16:0)	5.78–29.0	15.17
stearic (18:0)	7.80–20.37	14.91

[a]Percent of total acids.
[b]A shorthand designation for fatty acids is used. For example, 18:0 = saturated C_{18}; 18:1 = C_{18} acid with one double bond; 18:2 = C_{18} acid with two double bonds; 18:0 br = branched-chain saturated C_{18} acid; etc.

Table 7. **Saturated Acids as % of Total Acids of Milk Fat[a]**

Even		Odd	
Acid[b]	%	Acid[b]	%
4:0	2.79	5:0	0.01
6:0	2.34	7:0	0.02
8:0	1.06	9:0	0.03
10:0	3.04	11:0	0.03
12:0	2.87	13:0	0.06
14:0	8.94	13:0 br	0.04
14:0 br	0.10	15:0	0.79
16:0	23.80	15:0 br A[c]	0.24
16:0 br	0.17	15:0 br B[c]	0.38
18:0	13.20	17:0	0.70
18:0 br	trace	17:0 br A[c]	0.35
20:0	0.28	17:0 br B[c]	0.25
20:0 br	trace	19:0	0.27
22:0	0.11	21:0	0.04
24:0	0.07	23:0	0.03
26:0	0.07	25:0	0.01

[a]Ref. 4.
[b]See footnote *b* in Table 6.
[c]A and B designate isomers.

Table 8. **Unsaturated Acids as % of Total Acids of Milk Fat**[a]

Even				Odd	
Acid	%	Acid	%	Acid	%
10:1[b]	0.27	20:2	0.05	15:1	0.07
12:1[c]	0.14	20:3	0.11	17:1	0.27
14:1[c]	0.76	20:4	0.14	19:1	0.06
16:1[d]	1.79	20:5	0.04	21:1	0.02
18:1[d]	29.60	22:1	0.03	23:1	0.03
18:2	2.11	22:2	0.01		
18:2*c,t* conj[e]	0.63	22:3	0.02		
18:2 *t,t* conj[e]	0.09	22:4	0.05		
18:3	0.50	22:5	0.06		
18:3 conj	0.01	24:1	0.01		
20:1	0.22				

[a]Ref. 4.
[b]Terminal double bond.
[c]Includes cis, trans, and terminal double-bond isomers.
[d]Includes cis and trans isomers.
[e]*c,t* = cis–trans isomer; *t,t* = trans–trans isomer; conj = conjugated.

Table 9. **U-Values**[a] **for Holding Methods of Batch Pasteurization**

Method	$kW/(m^2{\cdot}K)$[b]	Remarks
water spray[c]	0.350	heat from 10–63°C in 25 min, hot water at 71°C
coil vat[c]	0.350	coils turns at 130 rpm, water through coil at 100 rpm
flooded	0.350	gravity circulation, agitator
high velocity	0.525	requires more energy to pump heating fluid

[a]Overall heat-transfer value.
[b]To convert $kW/(m^2{\cdot}K)$ to $Btu/(h{\cdot}ft^2{\cdot}{}^{\circ}F)$, multiply by 571.2.
[c]No longer used in the United States.

Table 10. **Representative Capacities of HTST Plate Pasteurizers**[a]

Capacity, L/h	3,800	7,600	11,360	15,140	18,930
regenerator, 84%[b]					
plates, number	31	51	71	91	111
pressure drop milk, kPa[c]	62	90	103	103	117
heater[d]					
plates, number	9	15	21	29	33
water, L/min	261	522	587	787	492
pressure drop milk, kPa[c]	55	76	76	69	96
pressure drop water, kPa[c]	83	117	76	69	165
cooler[e]					
plates, number	9	17	31	41	49
water, L/min	326	662	462	643	772
pressure drop milk, kPa[c]	55	55	117	117	145
pressure drop water, kPa[c]	131	131	165	165	179
total, 84% regeneration					
plates, number	49	83	123	161	193
pressure drop, milk, kPa[c]	172	221	296	289	358
size of frame, m	1.22	1.52	1.83	2.13	2.13
total, 90% regeneration					
plates, number	73	109	147	189	239
pressure drop, milk, kPa[c]	131	200	214	221	207
size of frame, m	1.52	1.83	1.83	2.13	2.44

[a]Courtesy of Crepaco, Inc. (now APV Crepaco).
[b]Up temperature = 4–65°C; down temperature, 77–16°C.
[c]To convert kPa to mm Hg, multiply by 7.5.
[d]Milk temperature = 65–77°C; water temperature, 79–77°C.
[e]Milk temperature = 16–3°C; water temperature, 1–4°C.

Table 11. **Stainless Steels Used in Food Processing Equipment**

Identification	Alloy content, wt % Chromium[a]	Nickel[a]	Characteristics	Uses
		300 Series[b]		
301	16–18	6–8	ductile; lower resistance to corrosion, particularly as temperature increases	
302	17–19	8	good corrosion resistance; can be cold worked and drawn; anneal following welding to avoid intergranular corrosion in corrosive environment	general-purpose, used widely
304	18–20	8–12	better corrosion resistance than 302	most widely used for food
310	24–26	19–22	scale-resisting properties at elevated temperatures	high temperature applications
316	16–18, 2–3% Mb	10–14	superior corrosion resistance of all stainless steels	in contact with brine and various acids; gaining importance in food industry
		400 Series[c]		
410	11.5–13.5, 0.15% C	0.15	basic martensitic alloy hardenable by heat treatment	roofing, siding, blades on freezers
416	12–14 C	0.15 C	easily machinable	valve stems, plugs, and gates
420	12–14		hardenable by heat treatment	cladding over steel; high spring temper
430	14–18		nonhardenable, good corrosion resistance	trim, structural, and decorative purposes
440	16–18 C	0.60 C	harder than others; generally not recommended for welding	pumps, plungers, gears, seal rings, cutlery, bearings

[a]Or as indicated.
[b]Nonmagnetic or slightly magnetic.
[c]Magnetic.

Table 12. **U.S. Milk Supply and Use**[a,b]

			Commercial				Commerical				CCC net removals	
Year	Production	Farm use	Farm marketing	Beg. stocks	Imports	Total commercial supply	CCC net removals	Ending stocks	Disappearance	All milk price $/*cwt*	Skim solids basis	Total solids basis[c]
1999	162.6	1.4	161.3	5.3	4.7	171.3	0.3	6.1	164.8	14.36	6.5	4.0
2000	167.4	1.3	166.1	6.1	4.4	176.7	0.8	6.9	169.0	12.40	8.6	5.5
2001	165.3	1.2	164.1	6.8	5.7	176.7	0.1	7.0	169.5	15.04	5.8	3.5
2002	170.1	1.1	168.9	7.0	5.1	181.1	0.3	9.9	170.9	12.18	9.7	6.0
2003	170.4	1.1	169.3	9.9	5.0	184.2	1.2	8.3	174.7	12.55	8.1	5.4
2004	170.9	1.1	169.8	8.3	5.3	183.4	−0.1	7.2	176.4	16.05	1.3	0.7
2005	177.0	1.1	175.9	7.2	4.6	187.7	0.0	8.0	179.7	15.14	−1.0	−0.6
2006	182.0	1.1	180.9	8.0	4.5	193.4	0.0	8.6	184.8	12.75	0.8	0.5
2007	183.2	1.0	182.2	8.6	5.1	195.9	0.0	7.7	188.5	13.40	1.2	0.7

[a]Ref. 15.
[b]Arbitrarily weighted average of milkfat basis (40 percent) and skim solids basis (60 percent).
[c]Units in 10^9 lb, milkfat basis unless otherwise noted.

Table 13. **Dairy Products; U.S. Per Capita Availability**[a,b]

			Cheese					Frozen dairy products						Evaporated and condensed milk: Bulk and canned			Dry dairy products: Dry milks				
			Whole and part-skim milk cheese			Cottage cheese															
Year	Fluid milk and cream	Butter	American	Other	Total	Lowfat	Total	Ice cream	Lowfat ice cream	Sherbet	Frozen yogurt	Other frozen products	Total	Whole milk	Skim milk	Total	Whole milk	Nonfat milk	butter-milk	Total	Dried whey
1996	219.8	4.2	11.8	15.5	27.3	1.2	2.6	15.6	7.5	1.3	2.5	1.2	28.2	2.3	4.0	6.3	0.36	3.73	0.18	4.26	3.2
1997	216.4	4.1	11.8	15.7	27.5	1.3	2.6	16.1	7.8	1.3	2.0	1.1	28.2	2.5	3.9	6.5	0.37	3.33	0.18	3.88	3.2
1998	213.3	4.4	11.9	15.9	27.8	1.3	2.7	16.3	8.1	1.3	2.1	1.3	29.0	2.0	4.1	6.1	0.43	3.20	0.18	3.81	3.2
1999	213.1	4.7	12.6	16.4	29.0	1.3	2.6	16.7	7.5	1.3	1.9	1.2	28.6	2.1	4.4	6.5	0.40	2.82	0.17	3.39	3.1
2000	210.1	4.5	12.7	17.1	29.8	1.3	2.6	16.7	7.3	1.2	2.0	0.9	28.0	2.0	3.8	5.8	0.28	2.62	0.19	3.10	3.8
2001	207.6	4.4	12.8	17.2	30.0	1.3	2.6	16.3	7.3	1.2	1.5	0.7	27.0	2.0	3.5	5.4	0.16	3.25	0.17	3.58	3.7
2002	206.7	4.4	12.8	17.6	30.5	1.3	2.6	16.7	6.5	1.3	1.5	0.6	26.6	2.3	3.7	6.0	0.17	3.08	0.19	3.44	3.7
2003	205.9	4.5	12.5	17.9	30.5	1.3	2.7	16.4	7.5	1.2	1.4	0.6	27.1	2.6	3.3	5.9	0.16	3.38	0.18	3.72	3.7
2004	204.9	4.5	12.9	18.3	31.2	1.3	2.7	15.0	7.2	1.1	1.3	0.6	25.3	2.2	3.2	5.4	0.16	4.28	0 16	4.61	3.2
2005	202.5	4.6	12.7	18.7	314	1.3	2.6	15.4	5.9	0.9	1.3	0.6	24.1	2.2	3.6	5.8	0.06	2.96	0.16	3.18	2.9

[a]Ref. 15.
[b]In pounds, tatals are computed from nonrounded data.

Table 14. **Organic and Conventional Milk Prices and Organic Premium by U.S.[a] Region, 2004**

	Milk price per half gallon, $			
Region	Organic	Conventional	Organic premium, $	Percent
East	4.52	2.01	2.52	126
Central	3.81	1.85	1.96	106
South	2.80	2.01	1.79	89
West	3.90	2.27	1.63	72
National average	4.01	2.02	1.99	98

[a]Ref. 16.

[b]Most organic milk is sold by the half gallon. Conventional and organic prices are averages of individual household purchases as reflected in the Nielsen Homescan data, using the Nielsen projection factor to appropriately weight the sample; price premiums and average prices are calculated by ERS. Price premiums in dollar terms are the difference between the price for organic and conventional milk; price premiums in percentage terms equal the premium divided by the conventional price.

Table 15. **Diseases Transmitted by Milk to Humans**

Disease	Microorganism	Carrier
	Direct transmission	
tuberculosis (cow)	*Mycobacterium bovis*	udder and manure of infected cows
brucellosis	*Brucella abortus*	milk
foot-and-mouth	virus	blood to udder
milk sickness	white snakeroot	in forage
anthrax	*Bacillus anthracis*	udder by systemic disease; organisms live in soil
Q fever	*Rickettsiae burneti,* also called *Coxiella burneti*	spread by ticks and inhalation
mastitis	*Streptococcus agalactiae,* plus several other bacteria	manure, soil, forage, udder
gastroenteritis	*Escherichia coli, Bacillus subtilus*, and salmonella of many types	udder
	Indirect transmission	
tuberculosis, human	*Mycobacterium tuberculosis*	sputum, breath droplets
typhoid fever	*Salmonella typhi*	human excreta, flies, polluted water
paratyphoid fever	*Salmonella paratyphi*	feces and urine
scarlet fever	hemolytic streptococcus	udder infection
salmonellosis	salmonella of many types	water, milk, feces, other animals
staphylococcal infections	*Staphylococcus aureus*	udder, human infection
diphtheria	*Corynebacterium diphtheriae*	throat, nose, tonsils[a]
dysentery		
bacillary	*Shigella dysenteriae*	bowel discharge[a]
amoebic	*Entamoeba histolytica*	bowel discharge[a]

[a]Of humans.

Table 16. **Properties of Dry Milk**[a,b]

Property	Value
moisture content, nonfat, wt%	4–5
apparent or bulk density, including voids, g/cm^3	
drum dried, nonfat	0.3–0.5
spray dried, nonfat	0.5–0.6
true density without voids	
dry milk	1.31–1.32
nonfat dry milk	1.44–1.46
coefficient of friction at 20°C, 5 wt% fat	0.64
porosity, spray dried, nonfat, wt%	0.482
solubility index, spray process	1.2
vapor pressure	
5% moisture, nonfat, 38°C, kPa[c]	1.17
5% moisture, 13% fat, 38°C, kPa[c]	0.75
threshold radiation level to produce off-flavor	
dry whole milk, Gy[d]	590
dry nonfat milk, Gy[d]	1280
titratable acidity, wt%	0.15
specific heat, kJ/(kg·K)[e]	1.04
thermal conductivity, k, W/(m·K)[f]	
4.2% at 40°C	0.05
at 65°C	0.06

[a]Approximate values.
[b]Atomization of one liter of condensed product to an average particle size of 50 μm dia equals 341,000 cm^2 surface.
[c]To convert kPa to mm Hg, multiply by 7.5.
[d]To convert Gy to rad, multiply by 100.
[e]To convert kJ/(kg·K) to Btu/(lb·°F), divide by 4.184.
[f]To convert W/(m·K) to Btu/(h·ft·°F), multiply by 1.874.

Table 17. **Physical Properties of Milk Fat and Butter**[a]

Property	Value
fat content, wt%	80
size of fat globules, μm	1–20
melting point of milk fat, °C	31–36
solidification of milk fat, °C	19–24
apparent specific heat, kJ/(kg·K)[b]	
at 0°C	2.14
15°C	2.20
40°C	2.32
60°C	2.42
density of milk fat, g/cm^3	
at 34°C, >mp	0.91–0.95
60°C	0.896
viscosity of milk fat, mPa·s(= cP)	
at 30°C	25.8
50°C	12.4
70°C	7.1
viscosity of butter 21°C, mPa·s(= cP)[c]	3.1×10^5
iodine number, normal butter	30.5
melting point of butter, °C	33.3
spreadability	
at 21°C	good
7–16°C	desirable
4°C	difficult
ratio of firmness to butter:firmness of butterfat	
summer	1.97:1
winter	1.48:1
coefficient of expansion of liquid pure butterfat, at 30–60°C	0.00076
free acidity, fresh butterfat	0.05–0.10%

[a]Refs. 35 and 36.
[b]To convert kJ/(kg·K) to Btu/(lb·°F), divide by 4.184.
[c]Brookfield at 1 rpm.

Table 18. **U.S. Specifications for Dry Buttermilk and Dry Whey**[a]

	Spray process DBM		Roller process DBM		
Property	Extra	Standard	Extra	Standard	Dry whey,[b] extra
moisture, wt%	≤5.0	≤5.0	≤5.0	≤5.0	≤5.0
milk fat, wt%	≥4.5	≥4.5	≥4.5	≥4.5	≤1.25%
solubility index, mL	≤1.25	≤2.0	≤15.0	≤15.0	≤1.25
scorched particles, mg	≤15.0	≤22.5	≤22.5	≤32.5	≤15.0
titratable acidity, wt%	0.10–0.18	0.10–0.20	0.10–0.18	0.10–0.18	≤0.16
bacteria count, per g	≤50,000	≤200,000	≤50,000	≤200,000	≤50,000
ash alkalinity, mL of 0.1 *N* HCl/100 g	≤125	≤125	≤125	≤125	≤125

[a]Ref. 37.
[b]Not applicable to cottage cheese whey.

Table 19. **Manufacture of Cottage Cheese**

Conditions	Value
amount of starter, wt%	0.5–5
setting temperature, °C	21–32
coagulating time, h	4–12
size of curd cubes, cm^3	0.25–2.00
cooking temperature, °C	49–60
rennet extract, g/500 kg milk	0.5–1.0

Table 20. **Composition of Frozen Desserts,[a] %**

	Ice cream					
Component	Premium[b]	Average	Ice milk	Sherbet	Ice	Soft-serve
milk fat[c]	16.0	10.5	3.0	1.5		6.0
milk solids, nonfat	9.0	11.0	12.0	3.5		12.0
sucrose	16.0	12.5	12.0	19.0	23.0	9.0
corn syrup solids		5.5	7.0	9.0	7.0	6.0
stabilizer[d]	0.1	0.3	0.3	0.5	0.3	0.3
emulsifier[d]		0.1	0.15			0.2
total solids, kg/L	41.1	39.9	34.45	33.5	30.3	33.5
	1.09	1.12	1.13	1.14	1.13	1.11
overrun, %	65–70	95–100	90–95	50	10	40
~kg/L, from freezer	0.64	0.55	0.57	0.74	1.01	0.77

[a]Frozen desserts containing vegetable fat (mellorine-type) are permitted in some states. A wide variation of composition exists depending on individual state standards.
[b]To be classified as custard or French, product must contain ≥1.4% egg yolk solids.
[c]Milk-fat content regulated by individual state.
[d]Usage level as recommended by manufacturer.

Table 21. **Properties of Ice Cream and Ice Cream Mix**[a]

Property	Value
structural constituents,[a] particle diameter, μm	
ice crystals	45–56
air cells	110–185
unfrozen materials	6–8
average distance between air cells	100–150
lamellae thickness	30–300
lactose crystals (when apparent to tongue feel)	16–30
individual fat globules	0.5–2.0
small fat globules	$\leq$20
agglomerated fat	$\leq$25
coalesced fat	$\geq$25
weight per 3.9 L, kg, 100% overrun	2.04
specific gravity, 100% overrun, g/cm^3	0.54
specific heat, kJ/(kg·K)[b]	
ice cream	1.88
ice cream mix	3.35
fuel values, kJ[b]	8.70
overrun, %	60–100
temperature at which freezing begins, °C	3.3
water in frozen ice cream	
at -5 to -6°C	50%
−30°C	90%
ice cream mix	
pH	6.3
acidity, %	0.19
specific gravity	1.054–1.123
surface tension, mN/m(=dyn/cm)	50×10^{-3}
composition of SNF of mix, %	
protein	36.7
lactose	55.5
minerals	7.8

[a]Ref. 41; values are approximate.
[b]To convert kJ to Btu, divide by 1.054.

Table 22. **Composition and Concentrations of Milk Protein**[a]

	Casein						Blood		Pseudo-globulin[b]	
	Whole	α-	β-	γ-	β-Lactoglobulin	α-Lactalbumin	serum albumin	Euglobulin	A	B
					Concentration, g/100 mL					
	2.23–8.84	1.4–2.3	0.5–1.0	0.06–0.22	0.20–0.42	0.07–0.15	0.02–0.05	0.03–0.06	0.02–0.05	
Component					Composition, g/100 g					
N	15.63	15.53	15.33	15.40	15.60	15.86	16.07	16.05	15.29	15.9
amino N	0.93	0.99	0.72	0.67	1.24					
amide N	1.6	1.6	1.6	1.6	1.07		0.78			
P	0.86	0.99	0.61	0.11	0.00	0.02	0.00	0.00	0.00	
S	0.80	0.72	0.86	1.03	1.60	1.91	1.92	1.01	1.00	1.1
hexose								2.93	2.96	
hexosamine								1.58	1.45	
Gly	2.7	2.8	2.4	1.5	1.4	3.2	1.8			
Ala	3.0	3.7	1.7	2.3	7.4	2.1	6.2			
Val	7.2	6.3	10.2	10.5	5.8	4.7	5.9	10.4	9.6	8.7
Leu	9.2	7.9	11.6	12.0	15.6	11.5	12.3	10.4	9.6	8.5
Ile	6.1	6.4	5.5	4.4	6.1	6.8	2.6	3.0	3.0	4.2
Pro	11.3	8.2	16.0	17.0	4.1	1.5	4.8			10.0
Phe	5.0	4.6	5.8	5.8	3.5	4.5	6.6	3.6	3.9	3.9
Cys_2	0.34	0.43	0.0–0.1	0.0	2.3	6.4	5.7	3.3	3.0	
Cys	0.0	0.0	0.0	0.0	1.1	0.0	0.3	0.0	0.0	
Met	2.8	2.5	3.4	4.1	3.2	1.0	0.8	0.9	0.9	1.3
Trp	1.7	2.2	0.83	1.2	1.9	7.0	0.7	2.4	2.7	3.2
Arg	4.1	4.3	3.4	1.9	2.9	1.2	5.9	5.1	3.3	5.6
His	3.1	2.9	3.1	3.7	1.6	2.9	4.0	2.0	2.1	2.3
Lys	8.2	8.9	6.5	6.2	11.4	11.5	12.8	6.3	7.1	6.1
Asp	7.1	8.4	4.9	4.0	11.4	18.7	10.9			9.4
Glu	22.4	22.5	23.2	22.9	19.5	12.9	16.5			12.3
Ser	6.3	6.3	6.8	5.5	5.0	4.8	4.2			
Thr	4.9	4.9	5.1	4.4	5.8	5.5	5.8	10.6	10.3	9.0
Tyr	6.3	8.1	3.2	3.7	3.8	5.4	5.1			6.7

[a]Ref. 42.
[b]A, from milk; B, from colostrum.

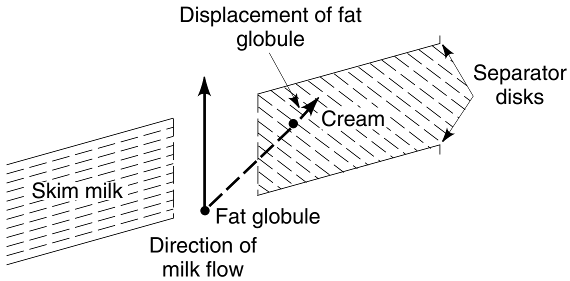


Fig. 1. Diagrammatic representation of fat globule separation in a centrifugal separator (5).

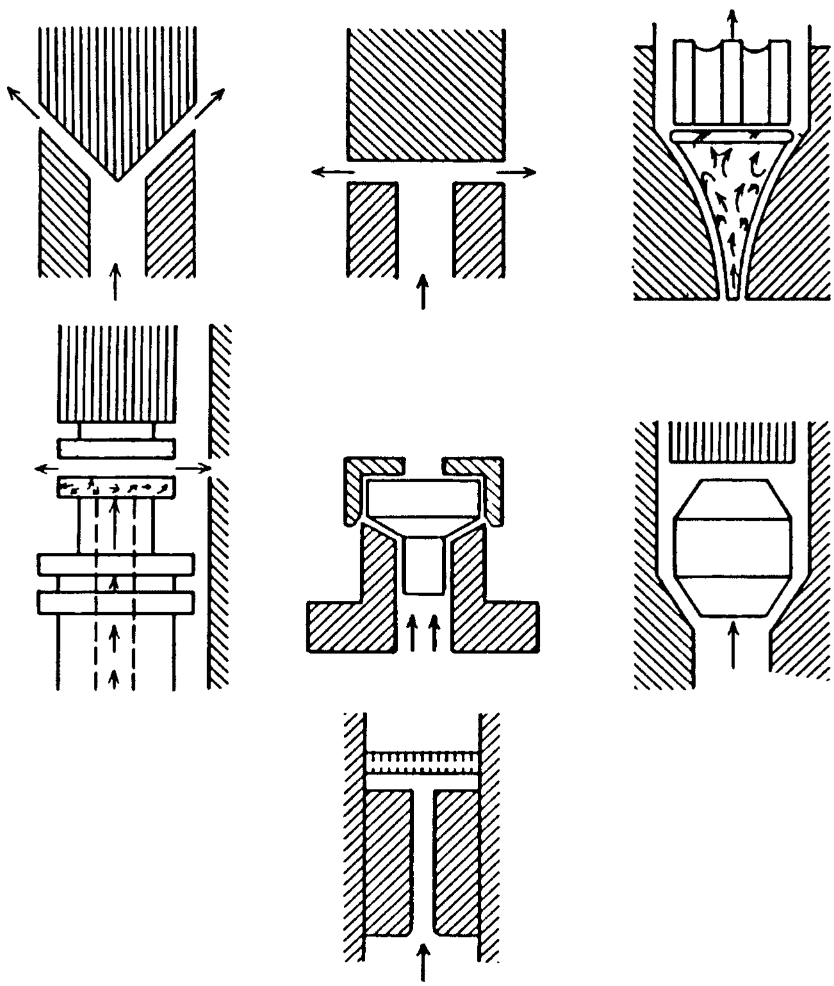


Fig. 2. Types of homogenizer valves based on velocity and impact (7).

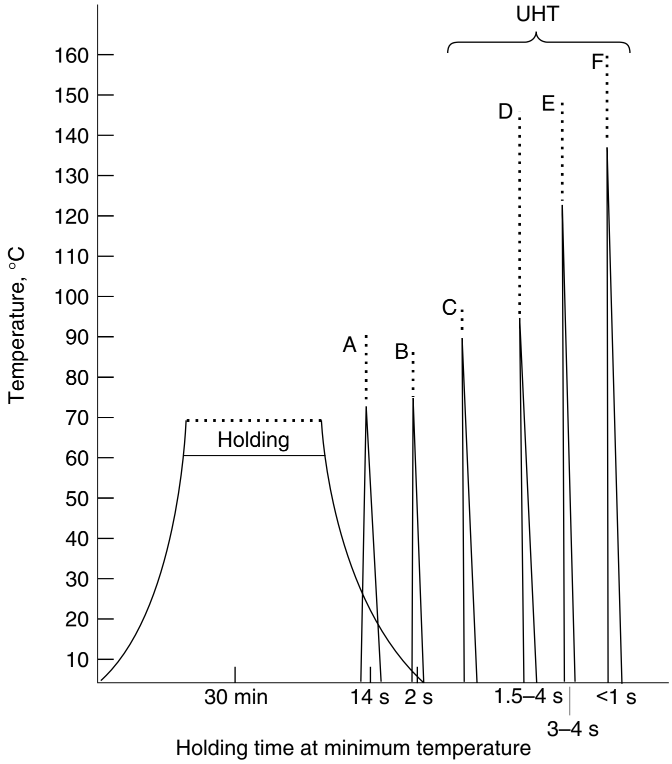


Fig. 3. Pasteurization by various methods (8): A, HTST; B, quick time; C, vacuum; D, modified tubular; E, small-diameter tube; and F, steam injection.

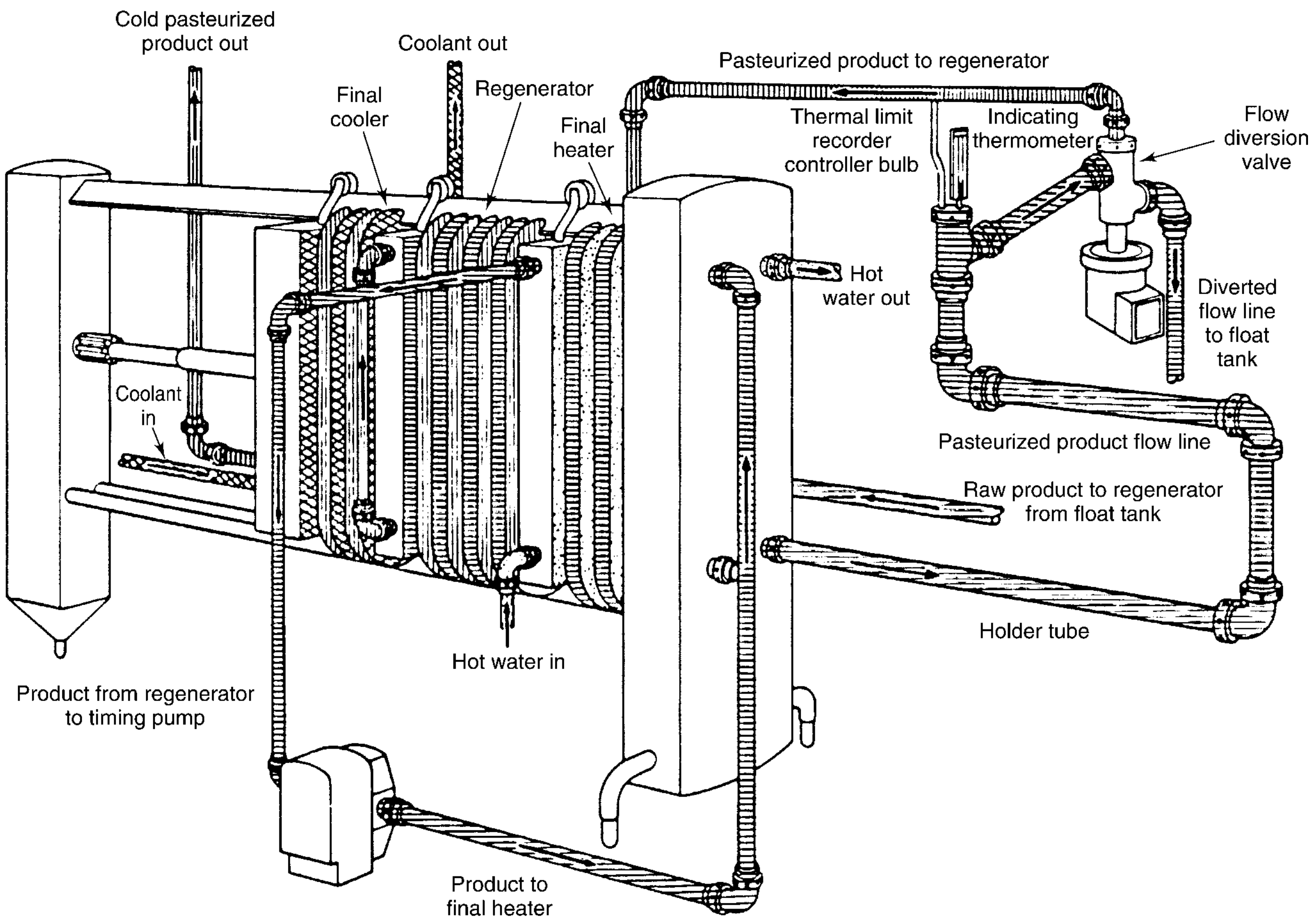


Fig. 4. Flow through a typical HTST plate pasteurizer, where ▤ is raw milk, ▥ pasteurized, ⬚ hot water, and ⊠ coolant. Courtesy of St. Regis Crepaco (now APV Crepaco).

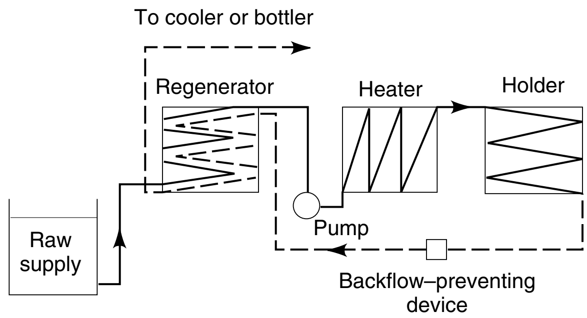


Fig. 5. Milk-to-milk regenerator with both sides closed to atmosphere (9). Courtesy of the U.S. Dept. of Health and Human Services.

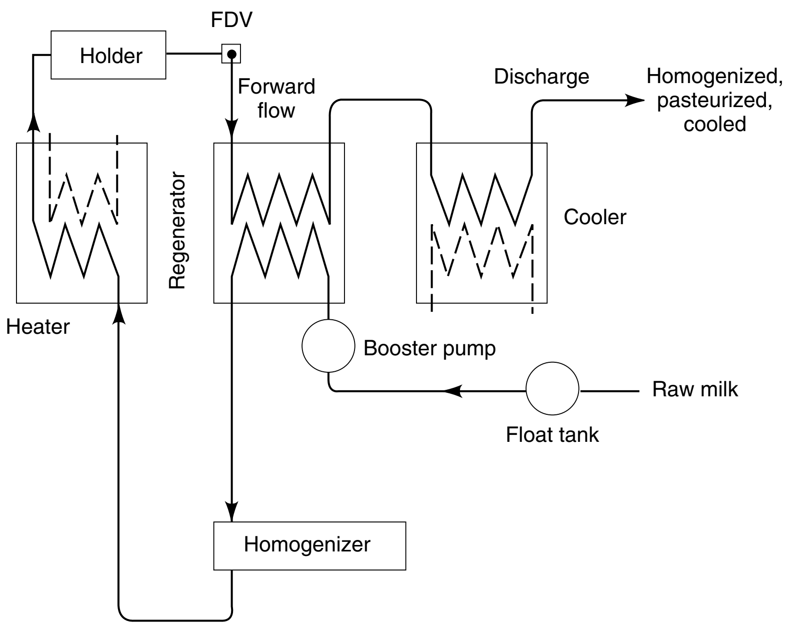


Fig. 6. Homogenizer used as a timing pump for HTST pasteurization. Details of bypass, relief lines, equalizer, and check valves are not included (10).

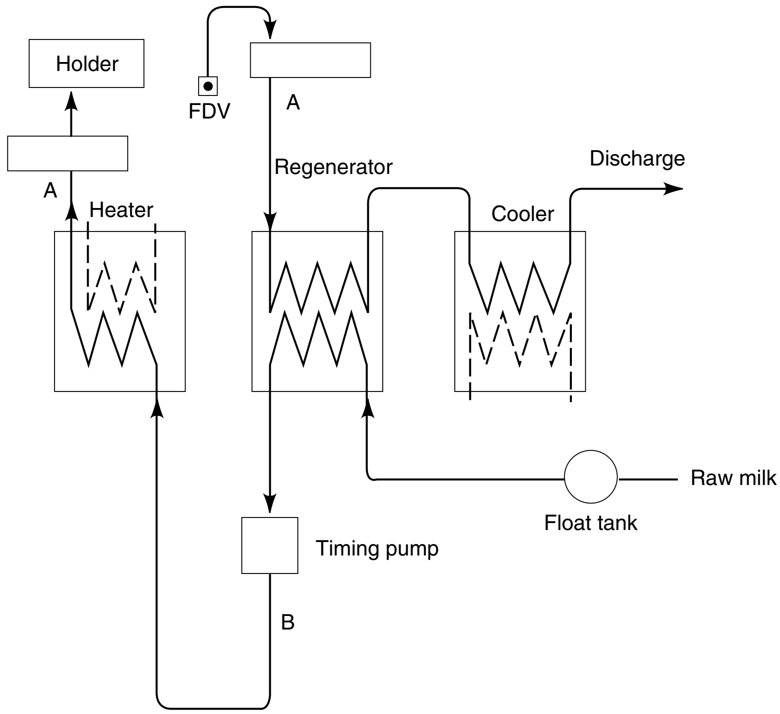


Fig. 7. Homogenization of regenerated milk, A, after HTST heat treatment, and B, before HTST pasteurization. Details of bypass, relief lines, equalizer, and check valves are not included (10).

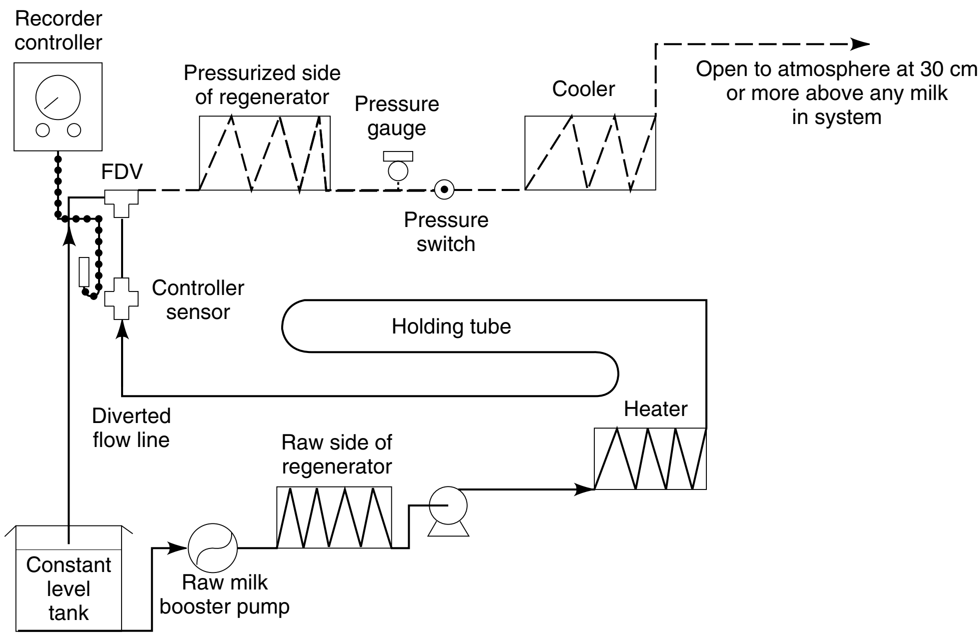


Fig. 8. Booster pump for milk-to-milk regeneration, where (---) is pasteurized milk, (—) is raw milk, and (–●–) is capillary tubing (11).

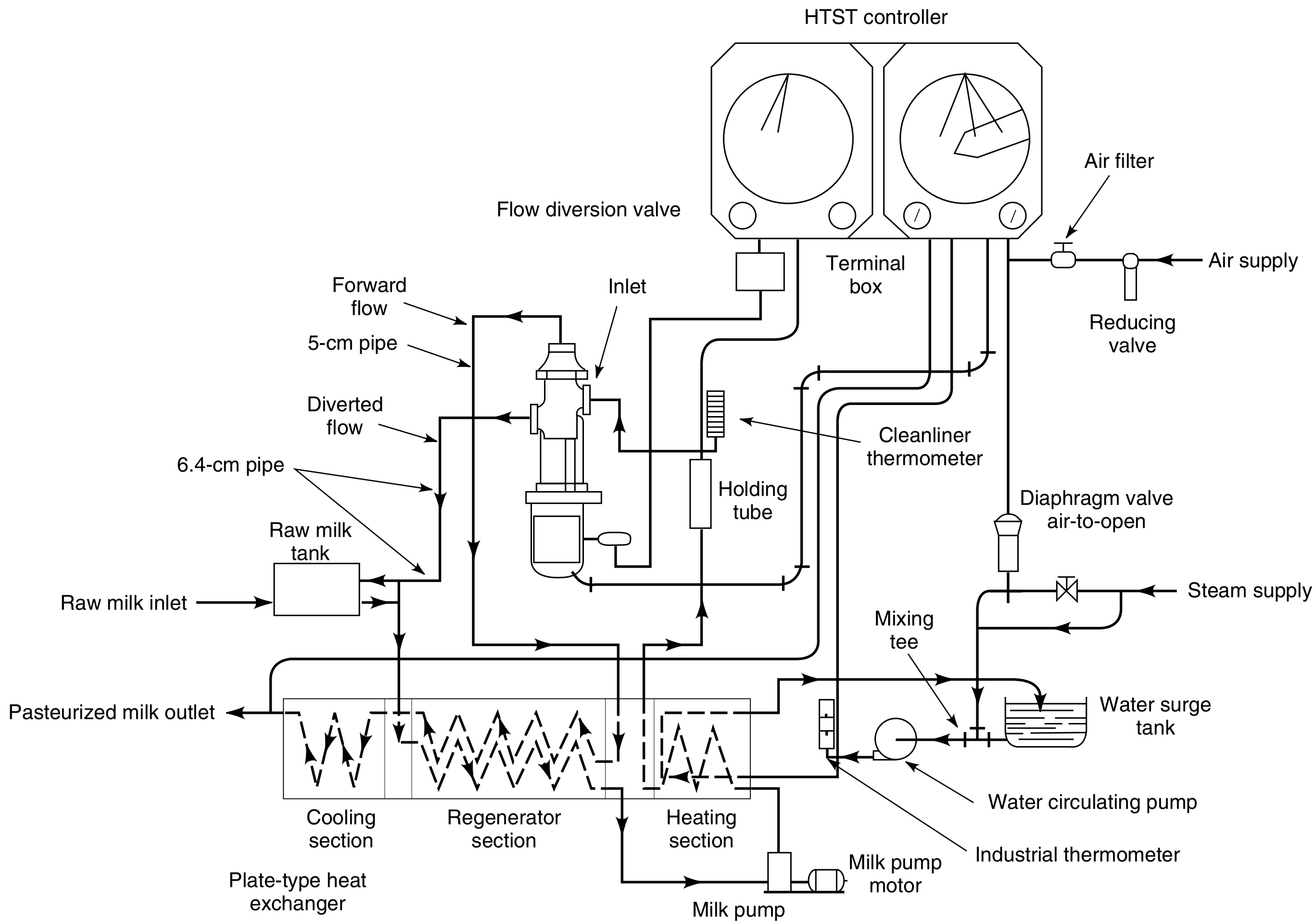


Fig. 9. HTST control system. Courtesy of Taylor Instrument Co. (now Taylor Instrument, Combustion Engineering, Inc.).

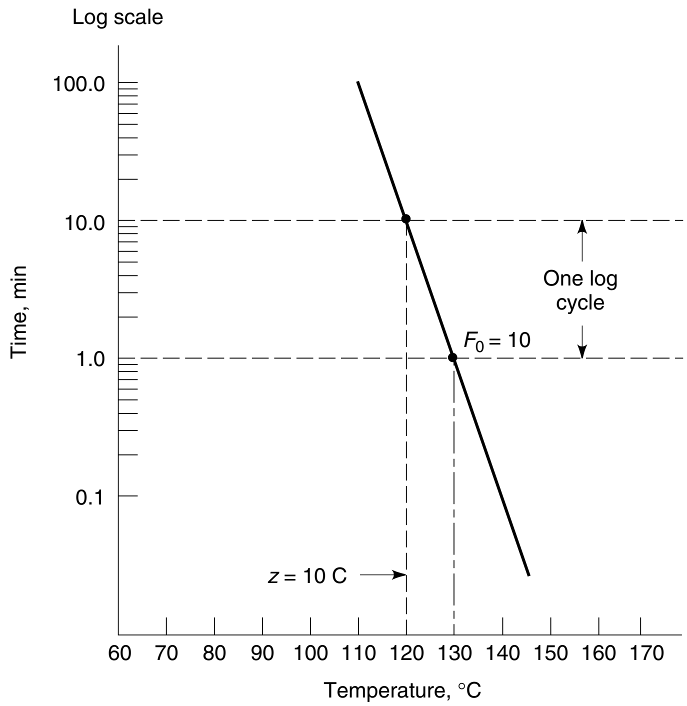


Fig. 10. Representation of z and F values (12). F^0 is the zero point for identifying the sterilization value at 121.1°C (250°F): $F_0 t = e^{2.3/z(T-121.1)} = 10^{(T-121.1)/z}$.

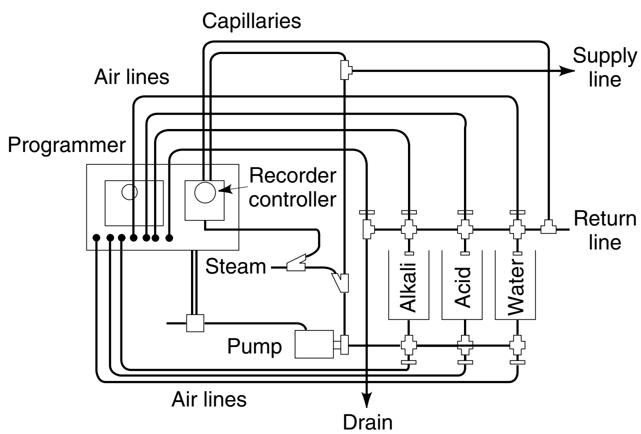
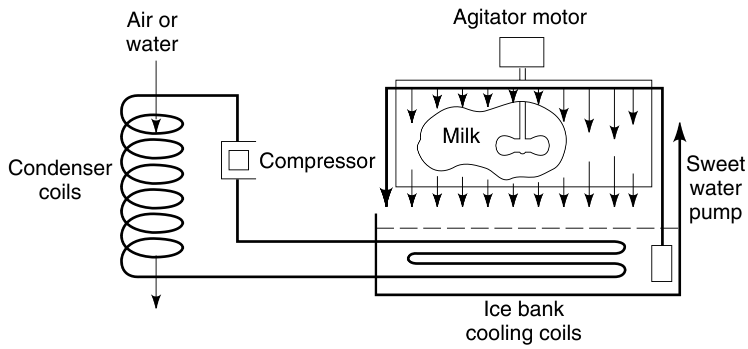


Fig. 11. Simple circuit for CIP system.



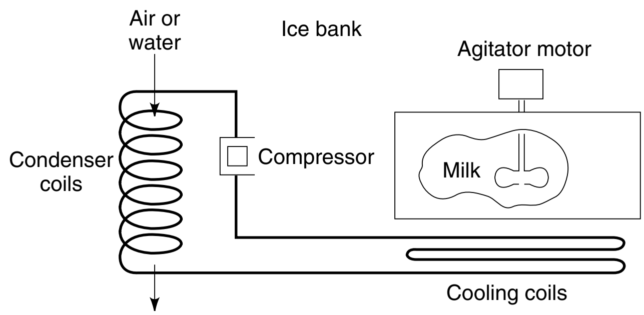


Fig. 12. Compression refrigeration supplying cooling for (**a**) the ice bank, where (↓) represents the flow of sweet water and (---), the water level, or (**b**) the direct expansion systems (17).