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The Science of Preserving and Processing of Milk

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Abstract

Milk processing is a critical aspect of the dairy industry, encompassing a series of steps aimed at preserving its quality, safety, and nutritional integrity. This article provides an in-depth examination of key milk processing techniques, including collection, chilling, standardization, pasteurization, UHT treatment, homogenization, and bactofugation. Each stage is meticulously dissected to elucidate its role in enhancing milk's shelf-life, flavour, texture, and microbial safety. Furthermore, the article explores the technological advancements and innovations driving the evolution of milk processing, emphasizing the importance of continuous research and development in meeting consumer demands for high-quality milk and milk products. By comprehensively understanding and optimizing these processing methods, stakeholders in the dairy industry can uphold rigorous standards of excellence while meeting the diverse needs of global markets. This review serves as a valuable resource for dairy professionals, researchers, and enthusiasts seeking to deepen their understanding of milk processing techniques and their implications for product quality and safety.

Introduction

Milk, a nutrient-rich fluid produced by mammals, has been a staple in human diets for centuries. From its initial collection to its journey through various processing techniques, ensuring its safety, quality, and longevity has been a primary concern for dairy industries worldwide.

The journey of milk from farm to table involves several critical stages, each playing a vital role in maintaining its freshness, nutritional value, and safety. Understanding these processes is crucial not only for dairy producers but also for consumers who rely on milk as a staple food item. The collection of milk marks the beginning of the processing

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journey, where it is harvested from dairy animals and transported to processing facilities under controlled conditions to prevent contamination and maintain freshness. Chilling the milk immediately after collection helps inhibit bacterial growth and preserve its quality during storage and transportation. Standardization is the process of adjusting the fat content of milk to meet specific regulatory or consumer preferences. This step ensures consistency in product quality and allows dairy producers to create various milk products with different fat concentrations to cater to diverse consumer needs. Pasteurization, a widely adopted heat treatment method, involves heating milk to a specific temperature for a predetermined time to eliminate harmful pathogens while preserving its nutritional content and sensory properties. Similarly, Ultra-High Temperature (UHT) treatment involves heating milk at an even higher temperature for a shorter duration, extending its shelf life without the need for refrigeration. Homogenization is a mechanical process that breaks down fat globules in milk to create a uniform texture and prevent cream separation. This step enhances the mouthfeel and stability of milk products, particularly those with higher fat content. Bactofugation, a relatively newer technique, involves removing bacteria and spores from milk using centrifugal force, further enhancing its microbiological safety and extending its shelf life.

Collection of milk:

In many developed dairy-producing nations, milk production typically occurs in rural regions, while the demand predominantly arises from urban areas. Consequently, the milk must be gathered and transported from its production sites in the rural milkshed regions to processing and distribution centres located in cities.

The common systems of milk collection in India are:

- By Co-operative organization
- By contractors
- By individual producers

The main objective of this collection step is to preserve the quality and ensure easy transport of milk to processing plants. The location of milk collection centres in based on presence of adequate milk supply, water and electricity facility, sewage disposal facility and proximity to good road or railway station etc. Upon arrival to milk collection centre, the milk undergoes a series of steps including grading for acceptance or rejection, weighing, sampling for testing, cooling, and storage at a low temperature until it is ready for dispatch to the processing facility.

Chilling:

Chilling milk involves quickly lowering its temperature to inhibit the growth of microorganisms present in the milk. Ideally, the temperature of the milk should be reduced to below 10 degrees Celsius, preferably between 3 to 4 degrees Celsius. While milk within the udder is nearly sterile, once it is exposed to the atmosphere during extraction, microorganisms can enter it. Chilling serves as the most efficient method for regulating the growth of microorganisms in milk without altering its physicochemical properties and nutritional value. This process doesn't eliminate microorganisms but rather inhibits their growth, acting as a temporary measure to control microbial proliferation.

Methods of chilling:

- Can Immersion
- In can cooling
- Surface Cooler
- Tubular cooler
- Plate chiller
- Bulk milk cooler

Standardization:

The process of standardizing milk involves modifying the fat and/or solids-not-fat percentages to meet specific legal or regulatory standards or other predetermined criteria. This adjustment aims to achieve the desired composition of milk while ensuring compliance with relevant requirements. Pearson's square method is commonly used for this process.

Table 1: Commercially available milk types

Class of milk	Min. Milk fat%	Min. SNF%
Standardized milk	4.5	8.5
Toned milk	3.0	8.5
Double toned milk	1.5	9.0
Skimmed milk	Not more than 0.5	8.7
Full cream milk	6.0	9.0

Source: *Food safety and standards regulations (food products standards and food additives, 2011)*

Pasteurization:

The process known as pasteurization was named after Louis Pasteur, a French scientist who demonstrated between 1860-64 that heating wine between 122 to 140 °F could eliminate spoilage organisms and preserve it. Although Pasteur pioneered this technique for wine preservation, the term "pasteurization" became commonly used in technical language. The term pasteurization, as it pertains to market milk today, involves heating every particle of milk to at least 63°C for 30 minutes, or 72°C for 15 seconds, or to any temperature-time combination that achieves equivalent efficiency, using approved and properly operated equipment. Following pasteurization, the milk is promptly cooled to 5°C or lower.

Organisms that are typically eliminated by pasteurization include acid producers like *Streptococci*, *Lactobacilli*, and *Microbacteria*, as well as coliforms, micrococci, gas producers like Coliforms and *Clostridium butyricum*, and those responsible for ropy or stringy fermentation such as Alcaligenes viscolactis and Enterobacter aerogenes. Additionally, proteolytic organisms like Bacillus spp., Pseudomonas spp., Proteus spp., and Streptococcus liquefaciens, as well as lipolytic organisms like *Pseudomonas fluorescens, Achromobactor lipolyticum, Candida lipolytica,* and *Penicillium spp*. are also effectively eradicated by pasteurization.

Heating milk within the temperature range of 72.9-85.2°C showed consistent lethal effects on various bacterial genera. However, psychrotolerant bacteria capable of forming endospores exhibited enhanced growth in pasteurized milk, posing a challenge to prolonging shelf life beyond 14 days. The optimal temperature for spore generation is between 65-75°C. Using higher pasteurization temperatures (80-90°C) led to a decrease in milk shelf life due to spore growth stimulation, reduced effectiveness of antimicrobial compounds, and increased production of growth factors. Milk treated at 76°C displayed the slowest bacterial growth rate and longest shelf life, while elevating pasteurization temperatures to 84.0 and 92.2°C did not improve shelf life, as maximal bacterial growth occurred at 86.0°C.

Methods of pasteurization:

- **In bottle pasteurization:** The process involves placing bottles filled with raw milk and sealed with special caps in a controlled environment at a temperature between 63-66°C for 30 minutes. Following this, the bottles are subjected to water sprays to reduce the temperature, effectively cooling both the product inside and the bottles themselves. The advantage of this method is that it ensures the prevention of post-pasteurization contamination and disadvantages are increased risk of bottle breakage, slow heat transfer and the method is considered outdated.
- **Batch or holding pasteurization (LTLT-low temperature long time):** The process of pasteurization involves heating milk to 63°C for 30 minutes followed by rapid cooling to 5°C. Pasteurizers come in three types:
  - ✓ Water-jacketed vat: This type consists of a double-walled container where hot water or steam circulates around the sides and bottom for heating, and cold water is used for cooling. The milk is agitated by paddles or propellers. During heating, the vat cover is left open to allow escape of off-flavors, and it's closed during holding. One advantage is its flexibility in use.

- ✓ Water spray type: Here, a film of water is sprayed over the surface of the tank holding the product.
- ✓ Coil vat type: In this method, the heating/cooling medium is pumped through a coil placed horizontally or vertically, agitating the product as it circulates through.

- **High Temperature Short Time (HTST) pasteurization:** This method is widely adopted for processing large volumes of milk efficiently. This technique involves heating the milk to 72°C for 15 seconds and rapidly cooling it to 5°C or lower, ensuring effective pasteurization while maintaining the quality of the product.

facilitate the operation of the raw milk pump, while also accepting any milk below optimal temperature redirected by the flow diversion valve (FDV).

- ✓ Pump: A positive pump can be employed to maintain flow between the regenerative heating section and heater, or alternatively, a centrifugal pump equipped with a flow control mechanism can be utilized post-FCBT to guarantee a consistent flow.
- ✓ Regenerative heating: In the HTST process, the incoming raw milk is partially and indirectly heated by the hot outgoing milk, contributing to the overall efficiency and cost-

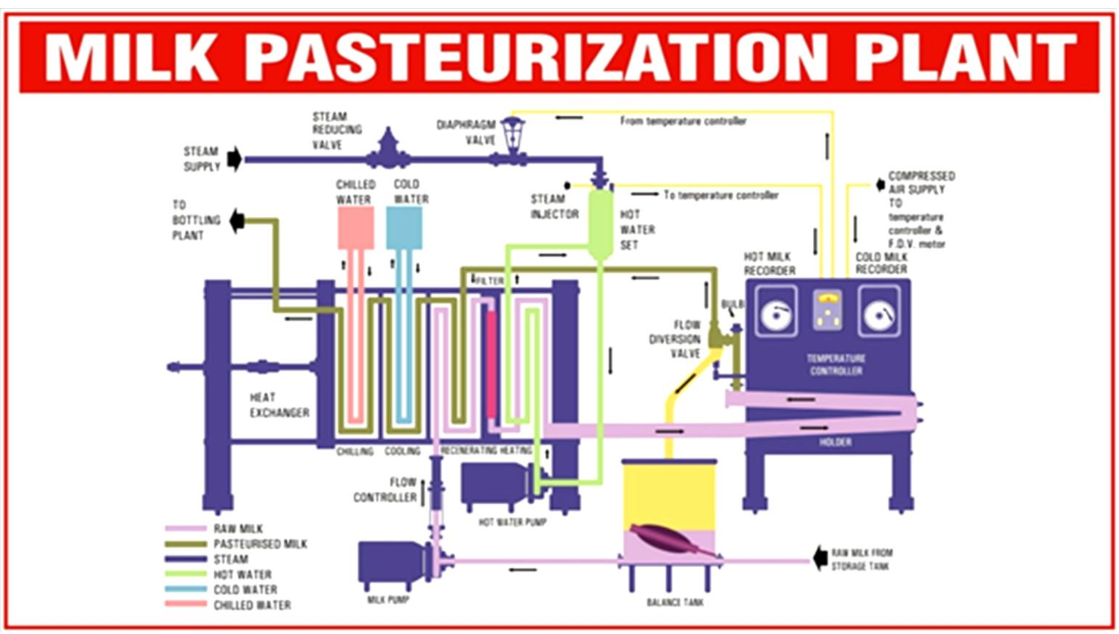

Figure 1: HTST milk pasteurization process

The steps involved are:

- ✓ Float controlled balance tank: Keeps a consistent milk head pressure to

effectiveness of the system.

- ✓ Heating: steam or hot water is used for heating and plate heat exchangers are used which ensure a consistent turbulent flow of the product to facilitate rapid heat transfer uniformly throughout the process.

- ✓ Holding: Milk is held for not less than 15 seconds in holding plates or tubes at 72°C
- ✓ Flow diversion valve: It automatically redirects unpasteurized milk back to the FCBT for reprocessing.
- ✓ Regenerative cooling: The pasteurized hot outgoing milk undergoes partial and indirect cooling by the incoming raw cold milk, further enhancing the cost-effectiveness of the operation.
- ✓ Cooling by chilled water.

- **Electric pasteurization:** This pasteurizer is characterized by a rectangular, vertical design, standing at 2 feet in height and approximately 2 inches in cross-section. It consists of two sides with carbon electrodes and intervening walls constructed of plate glass. In operation, the cold milk undergoes preheating in the regenerative section, achieving temperatures of around 120 °F through contact with the hot outgoing milk. Following this, it enters the electric heating chamber, where resistance to a 110-volt alternating current raises its temperature to 161 °F to 163 °F. The milk remains at this temperature for 15-20 seconds before proceeding to the cooling phase.
- **Vacuum pasteurization:** This process involves pasteurizing milk or cream under reduced pressure using direct steam, known as "vacreation." The equipment utilized is called a "vacreator," comprising three interconnected stainless steel chambers for steam heating and vacuum treatment with continuous product flow.

In operation, the product enters the first chamber of the vacreator as droplets, where pasteurization occurs under a vacuum of 5 inches Hg, maintaining a temperature of 90-95 °C. Steam is introduced from the top and descends by gravity to the chamber's bottom. The product and free steam are then removed from the bottom of the first chamber to the top of the second chamber. In the second chamber, maintained at a temperature of 71-82 °C under a vacuum of 15-20 inches Hg, some of the tainting substances and off-flavors are eliminated through heat and vacuum treatment. The product proceeds to the third chamber at 43 °C under a vacuum of 26-28 inches of Hg, where additional water and off-flavors are removed.

A multistage centrifugal pump extracts the product from the third chamber, completing the process in approximately 10 seconds as it passes through the three chambers.

UHT Treatment:

UHT treatment involves subjecting milk to temperatures between 135°C to 150°C for a brief duration without holding. The effectiveness of UHT heat treatment relies on promptly packaging the milk in an aseptic environment. It extends the shelf life of the milk without the need of refrigeration. When comparing UHT (Ultra High Temperature) milk to pasteurized milk, one notable distinction is the flavor profile. UHT milk often exhibits a more cooked taste due to the intense heating it undergoes. Additionally, over time, various changes in the physical and chemical properties of milk can occur during storage, leading to undesirable effects such as off-flavors, browning, fat separation, sedimentation, or gelation. Several factors contribute to the quality and consumer acceptance of milk, including processing conditions, storage parameters like time-temperature abuse, and the type of packaging used.However, the impact of heat treatments on milk proteins is not consistently predictable. During UHT processing, major modifications occur in milk proteins, including denaturation, aggregation, and chemical alterations of amino acids. These changes induced by UHT treatment can influence the digestibility of proteins and alter their overall biological effects upon consumption.

Homogenization:

Homogenized milk undergoes a mechanical process where it's propelled through a narrow passage at high speed, effectively reducing the size of fat globules. This results in a stable emulsion, preventing the fat globules from clustering and forming cream. Homogenized milk offers several benefits: Ensures uniform fat distribution, eliminating the cream layer, Enhances the full-bodied flavor, Provides a whiter, more appealing color, Accelerates coagulation in rennet cheese production.

Homogenization is the mechanical process of creating a stable emulsion of milk fat and milk serum. This process is achieved using a machine called a homogenizer. During homogenization, the size of fat globules in milk, typically ranging from 1 to 20 microns with an average of 4-6 microns, is reduced, with most reduced to 2 microns or less. This reduction prevents the formation of a cream line in milk and inhibits the production of butter granules from homogenized cream through churning. Additionally, homogenization increases the viscosity of milk or cream due to smaller fat globules encountering greater resistance, attributed to a larger proportion of milk protein adsorbed on their surfaces.

The altered clotting properties of homogenized milk result in softer curd formation when rennet or pepsin is added. However, homogenized milk or cream may become rancid more quickly than untreated products due to increased hydrolysis of fat by lipolytic enzymes adsorbed on the surfaces of numerous small fat globules. To mitigate these changes, pasteurization immediately before or after homogenization is recommended. Typically, milk is homogenized following primary heating before pasteurization. During homogenization, heated milk is forced through a small valve against hard surfaces, subjected to high pressures of around 2500 psi initially and 500 psi in a second stage, through an extremely minute aperture with a diameter of 1/10000 inch.

Presently used types of homogenizers are:

- High pressure type
- Low pressure rotary type
- Sonic vibrator or oscillator

To achieve an effective degree of fat dispersion, it's necessary to employ high homogenization pressures. However, these pressures can lead to products with reduced heat stability. The findings suggest several methods to partially counteract this destabilization. These strategies involve implementing a 2-stage homogenization process, applying moderate homogenization pressures, and adding Na phosphates to the milk as stabilizers.

Bactofugation:

Bactofugation is a centrifugal separation process commonly utilized in the dairy industry to improve the microbiological quality of milk by effectively removing bacteria, including spores, as well as somatic cells. It may go upto 60000rpm. It is a process that typically divides milk into a fraction largely free from bacteria and a concentrate known as bactofugate. The bactofugate comprises both spores and general bacteria, constituting up to 3% of the input to the Bactofuge. Bactofugation of raw milk, following preheating to 55°C, led to a noteworthy decrease in thermoduric bacteria levels. This method can effectively diminish microorganisms in raw milk that are resilient to pasteurization, thereby maintaining its quality. It can be combined with other techniques to manage microbiological contamination caused by endospore-forming bacteria in raw milk.

Conclusion:

The comprehensive review of milk processing techniques including collection, chilling, standardization, pasteurization, UHT treatment, homogenization, and bactofugation underscores the critical role these processes play in ensuring milk safety, quality, and shelf-life extension. Each step contributes uniquely to the overall preservation and enhancement of milk's nutritional value, flavor, and texture, while also mitigating potential risks associated with microbial contamination. By understanding and optimizing these processes, stakeholders in the dairy industry can uphold stringent standards of product excellence, thereby fostering consumer confidence and satisfaction. Additionally, ongoing research and technological advancements continue to refine these methods, promising further innovations in the future of milk processing.

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