University Center of Abdelhafid Boussouf Mila

CHAPTER I

Milk and Dairy Products

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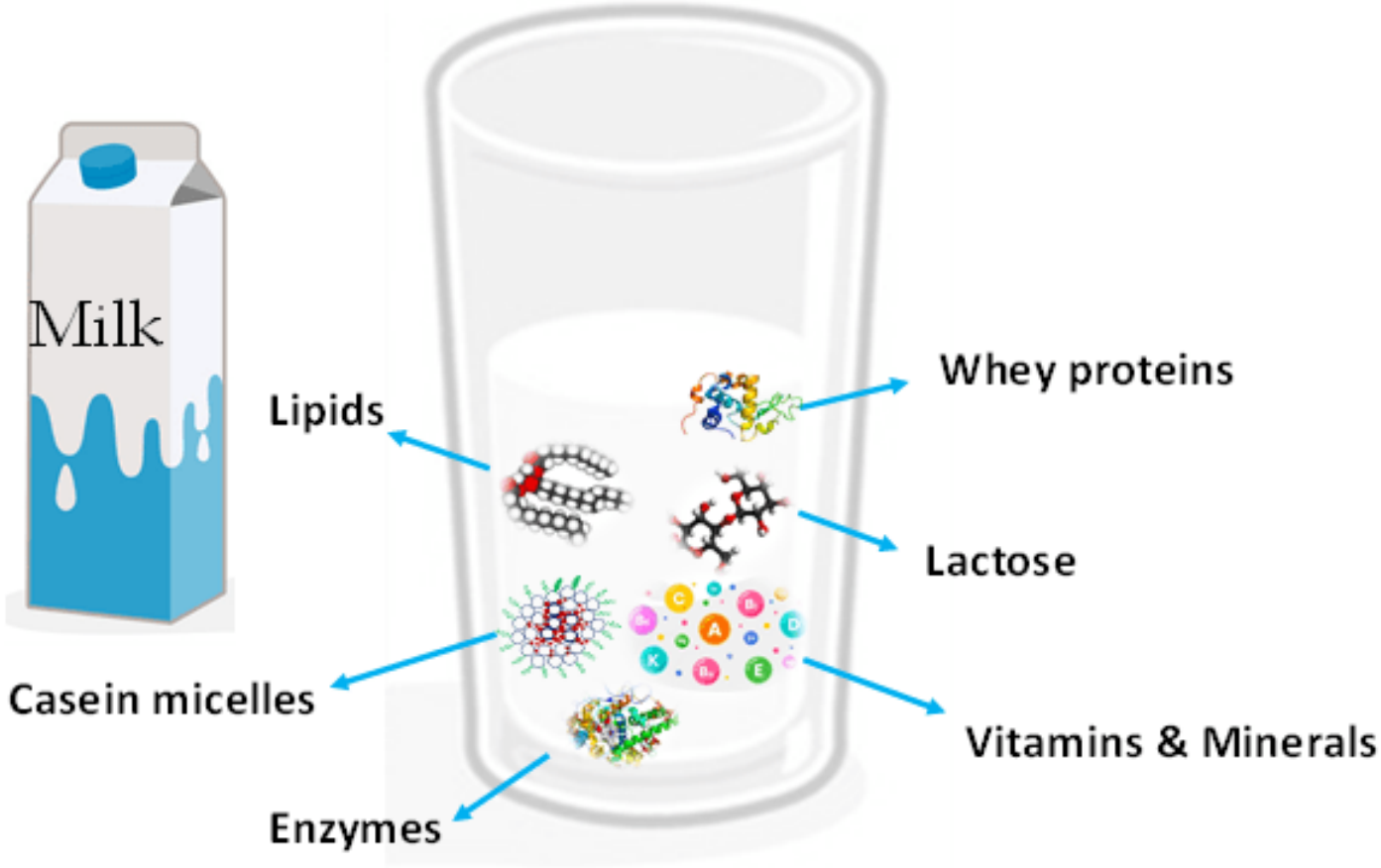
I. MILK

Milk is “The lacteal secretion, practically free from colostrum, obtained by the complete milking of one or more healthy cows”.

It is one of the most complete natural foods, providing essential nutrients such as proteins, fats, carbohydrates, vitamins, and minerals. It serves not only as a staple in human nutrition but also as the raw material for a wide variety of dairy products, including cheese, butter, yogurt, and milk powders. The processing of milk and dairy products plays a vital role in ensuring food safety, extending shelf life, improving sensory qualities, and meeting consumer demands for both traditional and innovative products.

I. MILK

Structurally, these constituents are organized as follows: lipids are present as emulsified globules surrounded by a membrane; proteins, particularly caseins, exist as colloidal micelles; while most minerals and all lactose remain in true solution.

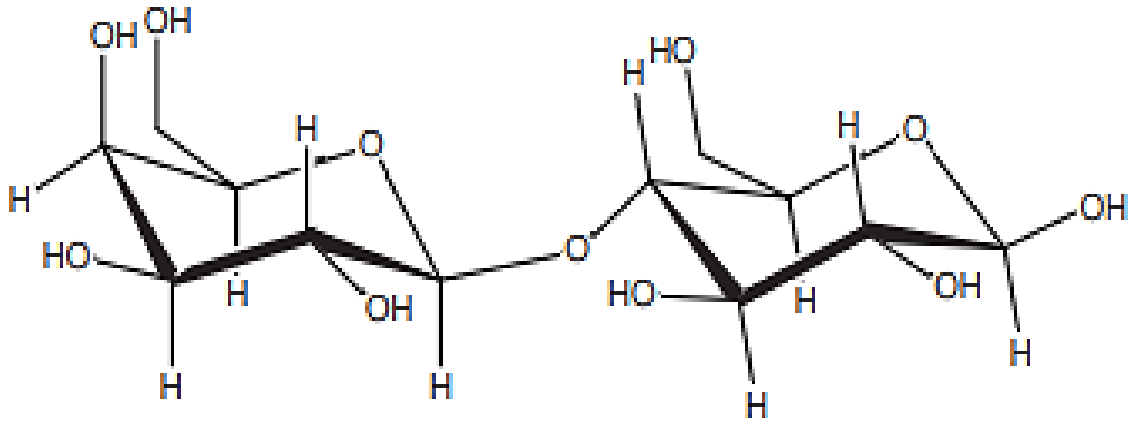


Source: https://agriwiseway.com/understanding-the-structure-of-milk-composition-and-properties

I. MILK

1. Lactose

Lactose is the main carbohydrate in milk, composed of glucose and galactose linked by a β-1,4-glycosidic bond. It is synthesized in the Golgi apparatus of mammary secretory cells. During this process, the whey protein α-lactalbumin modifies the enzyme galactosyltransferase, making it specific for glucose as the acceptor molecule. This regulation ensures efficient lactose synthesis and, since lactose is the primary osmotic regulator in milk, it also determines water secretion and thus the volume of milk produced.



Primary structure of lactose.

I. MILK

1. Lactose: Heat-Induced Changes

When milk is heated, lactose undergoes chemical transformations:

- **Isomerisation:** Leads to the formation of lactulose, which can further degrade into compounds such as galactose, tagatose, saccharinic acids, and epilactose. Lactulose is often used as an indicator of heat treatment and can promote the growth of beneficial bifidobacteria.
- **Maillard Reaction:** At higher heat intensity, lactose reacts with amino acids (especially lysine) to form brown pigments (melanoidins) and flavor compounds. This non-enzymatic browning process contributes to changes in color and taste of heated milk products.

I. MILK

2. Salts

Milk contains various salts, both organic and inorganic, including phosphates, citrates, chlorides, sulphates, carbonates, and bicarbonates of sodium, potassium, calcium, and magnesium. Highly soluble salts (e.g. chlorides, sodium, and potassium) are mostly found in the **milk serum**. Less soluble salts, particularly **calcium phosphate**, are partly dissolved and partly bound to **casein micelles** in the form of **micellar calcium phosphate (MCP)**, which is crucial for micelle structure and stability.

Heat-Induced Changes

I. MILK

2. Salts : Heat-Induced Changes

Heating affects the **salt balance** between the serum and micellar phases.

- **Calcium phosphate solubility decreases** as temperature rises (opposite to most salts).
- With heating (4–90 °C), levels of calcium and phosphate in the serum decrease, with smaller decreases in magnesium and citrate.
- Sodium and potassium remain unaffected.
- Moderate heating (≤85 °C): changes are **reversible** upon cooling.
- Severe heating (>90 °C): may cause **irreversible alterations** in the mineral balance.

Dairy Processing Stages

I. Reception and Storage

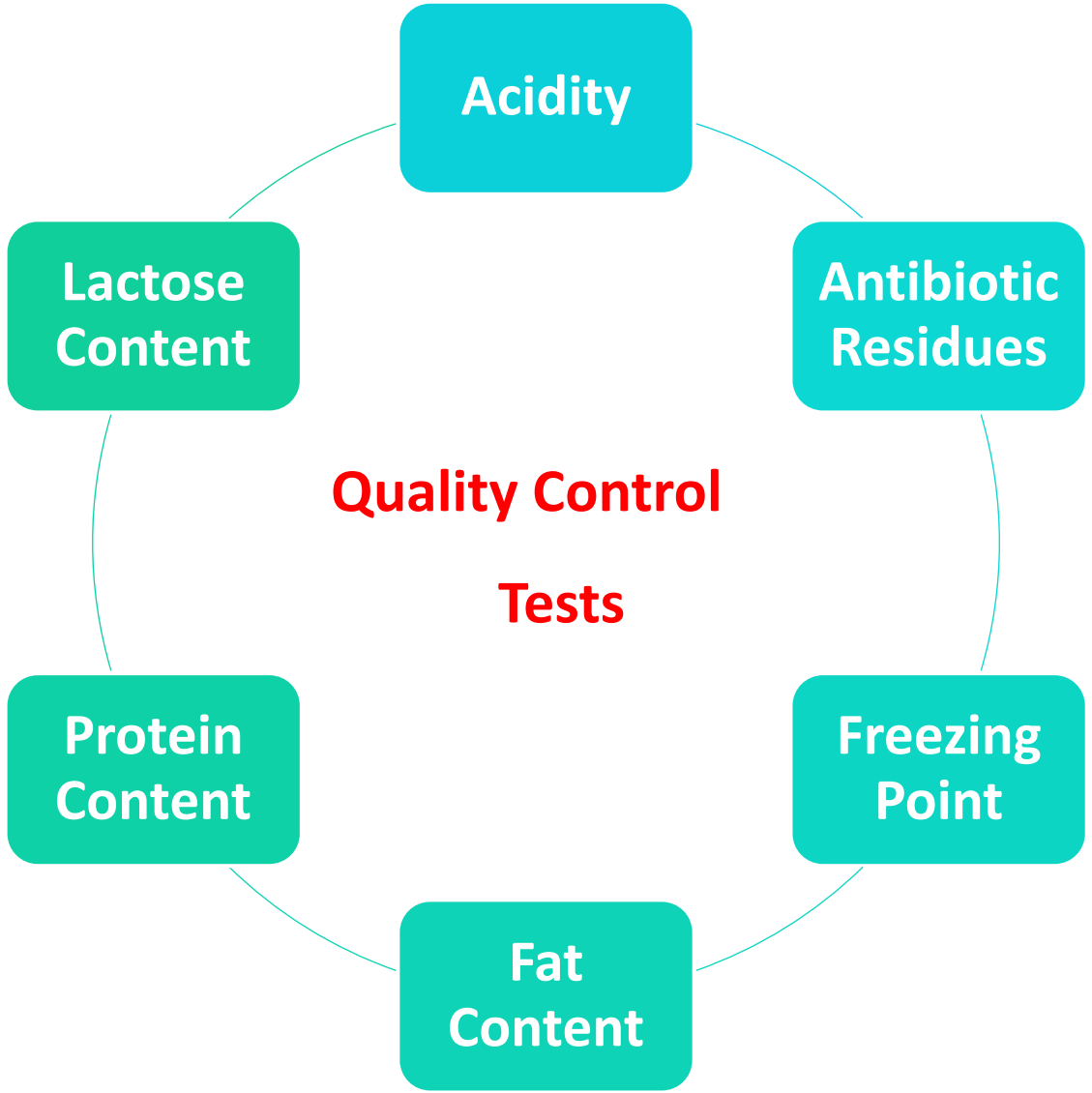
Milk is collected from farms using refrigerated trucks.

- Milk is first cooled and stored in silos . The temperature of raw milk must be kept between **4–6 °C** to slow down bacterial growth
- It is clarified and separated by centrifugation to remove dirt, bacteria, and to adjust fat content.
- Pasteurization destroys dangerous pathogens (*Salmonella*, *E. coli*, *Listeria*) using controlled heat treatments.
- The control quality tests confirm pasteurization by checking that alkaline phosphatase has been destroyed
- These steps ensure that milk is **safe, stable, and suitable** for further processing into cheese, yoghurt, butter, or powder.

MILK Processing

II. Quality Control Tests

- **Acidity** → indicates freshness and microbial activity.
- **Antibiotics** → must be absent to protect consumers and fermentation processes.
- **Freezing point** → detects adulteration with water (fraud prevention).
- **Fat** → influences taste, nutrition, butter/cream yield.
- **Protein** → key for cheese-making and milk pricing.
- **Lactose** → important for fermentation and nutritional balance.



Dairy Processing Stages

II. Quality Control Tests

Raw milk undergoes several tests that follow **international ISO standards**. These tests ensure the milk is safe, authentic, and suitable for processing into dairy products.

- **Acidity (Titratable Acidity, TA):**
  - Fresh milk normally has very low natural acidity (from citrates, phosphates, dissolved CO_2).
  - Developed acidity comes from bacteria converting lactose into lactic acid.
  - TA is measured by neutralizing acids with NaOH until a faint pink color (phenolphthalein endpoint).
  - Expressed as % lactic acid; must be **≤0.18%** (ISO 6091:2010).
  - Important for **cheese-making**, as acidity influences coagulation.
- **Antibiotic Residues:**
  - Milk must not contain antibiotics, as they can affect **human health** and lead to **antibiotic resistance**.
  - Rapid tests include:
    - *Charm test*: detects tetracycline residues.
    - *Delvo test*: detects β-lactams and other antibiotics.
  - Standards: absent/≤0.1 g (ISO 26844:2006).
- **Added Water (Freezing Point Test):**
  - Normal milk has a freezing point of about **−0.54 °C**.
  - Adding water raises this freezing point (less negative).
  - Measured using a **cryoscope** (ISO 5764:2009).
  - Also sensitive to acidification and protein denaturation.

Dairy Processing Stages

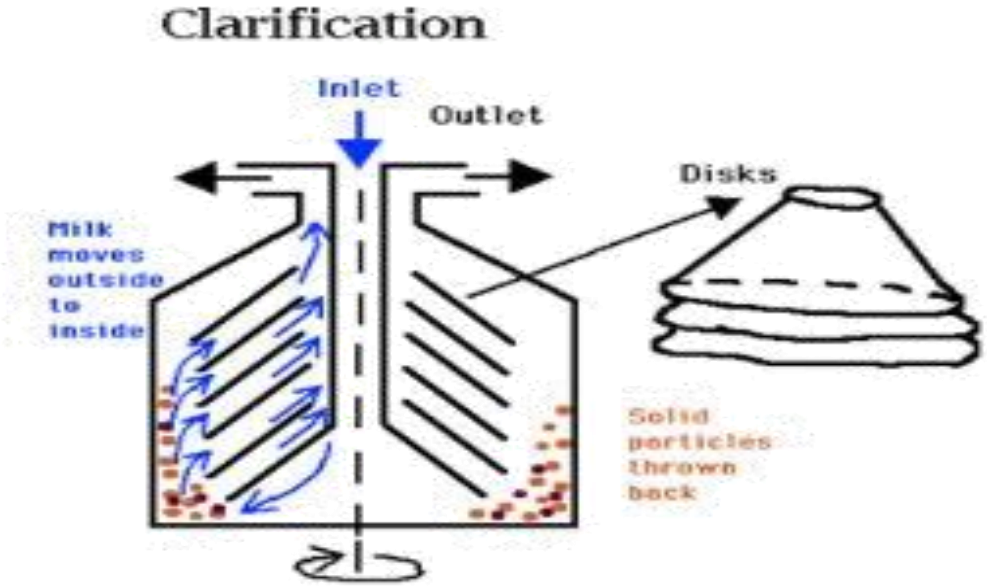
II. Quality Control Tests

- **Fat Content:**
  - Average **4.4 g/100 g**. Fat is made of more than **400 fatty acids**.
  - Main fatty acids: **palmitic (30%), myristic (11%), stearic (12%)**.
  - Composition varies with **diet, lactation stage, breed**.
  - Measured by:
    - **Gerber method** (classic, still used in dairies).
    - **Infrared (IR) analysis** (fast and modern, ISO 9622:2013).
  - Important because fat contributes to **flavor, texture, and energy value** of milk.
- **Protein Content:**
  - Average **3.4%** in milk.
  - Proteins = ~95% of milk nitrogen; rest = non-protein nitrogen (urea).
  - Measured by:
    - **Kjeldahl method** (digestion, ISO 8968:2014).
    - **Dumas method** (combustion, ISO 14891:2002).
  - Critical for **nutrition** and **cheese yield**.
- **Lactose Content:**
  - Normally **>4.2%** (ISO 22662:2007).
  - Provides energy for humans and acts as the main substrate for bacteria in fermentation (yoghurt, cheese).

Dairy Processing Stages

III. Separation, Clarification, and standardization

- **Clarification**: centrifugation removes particles and some microorganisms.
- **Bactofugation / Microfiltration**: removes up to **99.9% of spores and bacteria**, improving shelf life and cheese ripening.
- **Separation (skimming)**: hot milk (50–60 °C) is separated into **cream and skim milk**. The fat content of cream can be adjusted between **20–70%**.



Dairy Processing Stages

III. Separation, Clarification, and standardization

- **Standardization**: adjusting fat and solids-not-fat (SNF) content to achieve uniform milk composition for consumer milk or products (powder, condensed milk, ice cream, cheese).

https://milkyday.com/blog/2018/09/27/milk-separator-how-it works/?srsltid=AfmBOoo8udhRJjUUxbA5NbKyRcdyvNBRnI1DP5M44fBtSZWgOAyPGhyg

Dairy Processing Stages

IV. Pasteurization

Pasteurization is a heat treatment applied to milk in order to:

•**Destroy pathogenic microorganisms** (e.g., *Coxiella burnetii*, the most heat-resistant milk pathogen, and *Mycobacterium bovis*, which causes bovine tuberculosis).

•**Improve shelf life and quality** by inactivating undesirable enzymes and reducing spoilage bacteria.

The process relies on an optimized **temperature–time combination**, followed by rapid cooling, and must avoid recontamination.

- **Traditional methods** (vat, LTLT) are still relevant in small-scale settings.
- **Modern methods** (HTST, UHT, Uperization) dominate large-scale industry due to efficiency and reliability.
- **Innovations** such as vacreation and solar-powered systems contribute to sustainability.
- **Current research priorities**: minimizing post-pasteurization contamination and improving hygienic design of processing equipment.

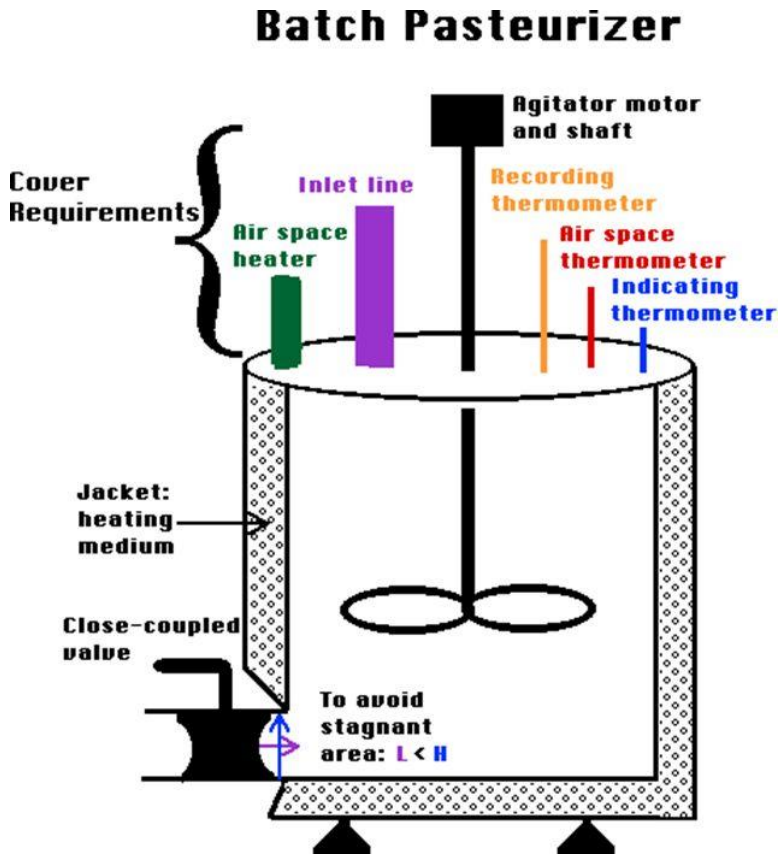
Dairy Processing Stages

IV. Pasteurization

Methods of Pasteurization

1. Long Hold / Vat Pasteurization

- Process: heating milk at 63 °C for 30 minutes in a closed vat with constant agitation.
- Vat types:
  - Spray type (hot water sprayed on the wall),
  - Flooded type (immersion in hot water),
  - High velocity flooded type (rapid fluid circulation).
- Key requirements: rapid heating, gentle agitation without foaming, immediate cooling to 4 °C.
- Advantages: simple, reliable, suitable for small volumes (artisan dairies, local cheese-making).
- Limitations: slow, energy-intensive, unsuitable for large-scale industry.



https://pmg.engineering/Article/6/vat-pasteurization-a-comprehensive-guide-for-the-food-industry

Dairy Processing Stages

IV. Pasteurization

Methods of Pasteurization

2. LTLT Pasteurization (*Low Temperature Long Time*)

- **Principle**: heating at **62.5 °C for 30 minutes**, similar to vat method.
- **Equipment designs**:
  - *Water-jacketed vat*: double wall, hot water/steam circulates for heating, cold water for cooling.
  - *Water-spray type*: continuous film of water sprayed over tank surface.
  - *Coil-vat type*: heating/cooling coils immersed in milk.
- **Advantages**: preserves certain nutritional qualities.
- **Limitations**: slow, greater risk of post-process contamination.

Dairy Processing Stages

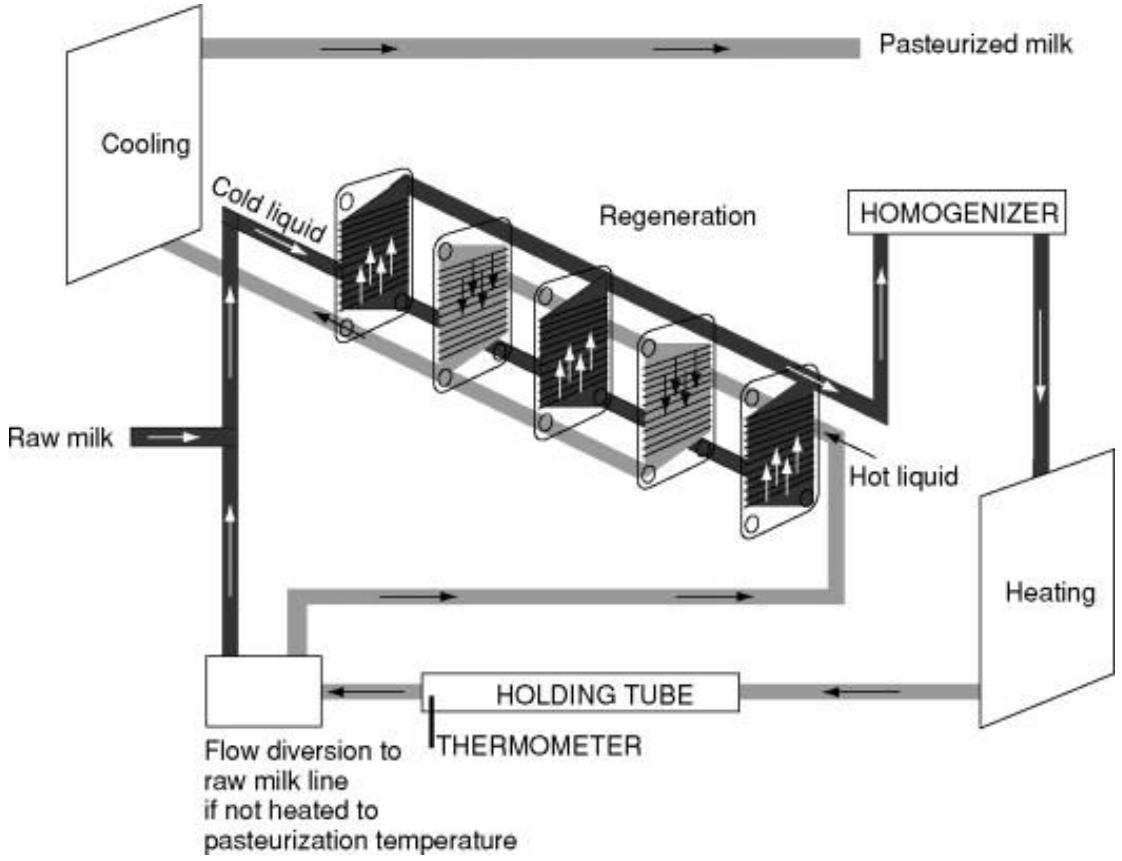
IV. Pasteurization

Methods of Pasteurization

3. HTST Pasteurization (*High Temperature Short Time*)

- **Modern industrial standard**: milk heated to **72 °C for 15 seconds**, cooled quickly to <5 °C.
- **System**: plate heat exchangers with **regeneration section** where pasteurized milk preheats raw milk (energy-saving).
- **Key stages**:
  - Preheating (~60 °C),
  - Pasteurization at target temperature,
  - Holding tube to maintain exposure time,
  - Cooling (regeneration + refrigeration).
- **Critical controls**:
  - *Flow rate*: controlled by metering pumps, must ensure minimum legal holding time.
  - *Temperature*: automatic safety diversion if below legal minimum.
  - *Pressure*: prevents raw milk from entering pasteurized lines.
- **Advantages**: rapid, energy-efficient, highly effective (used worldwide in dairies).

Limitations: requires strict hygiene and equipment maintenance



https://www.sciencedirect.com/topics/food-science/high-temperature-short-time-pasteurization

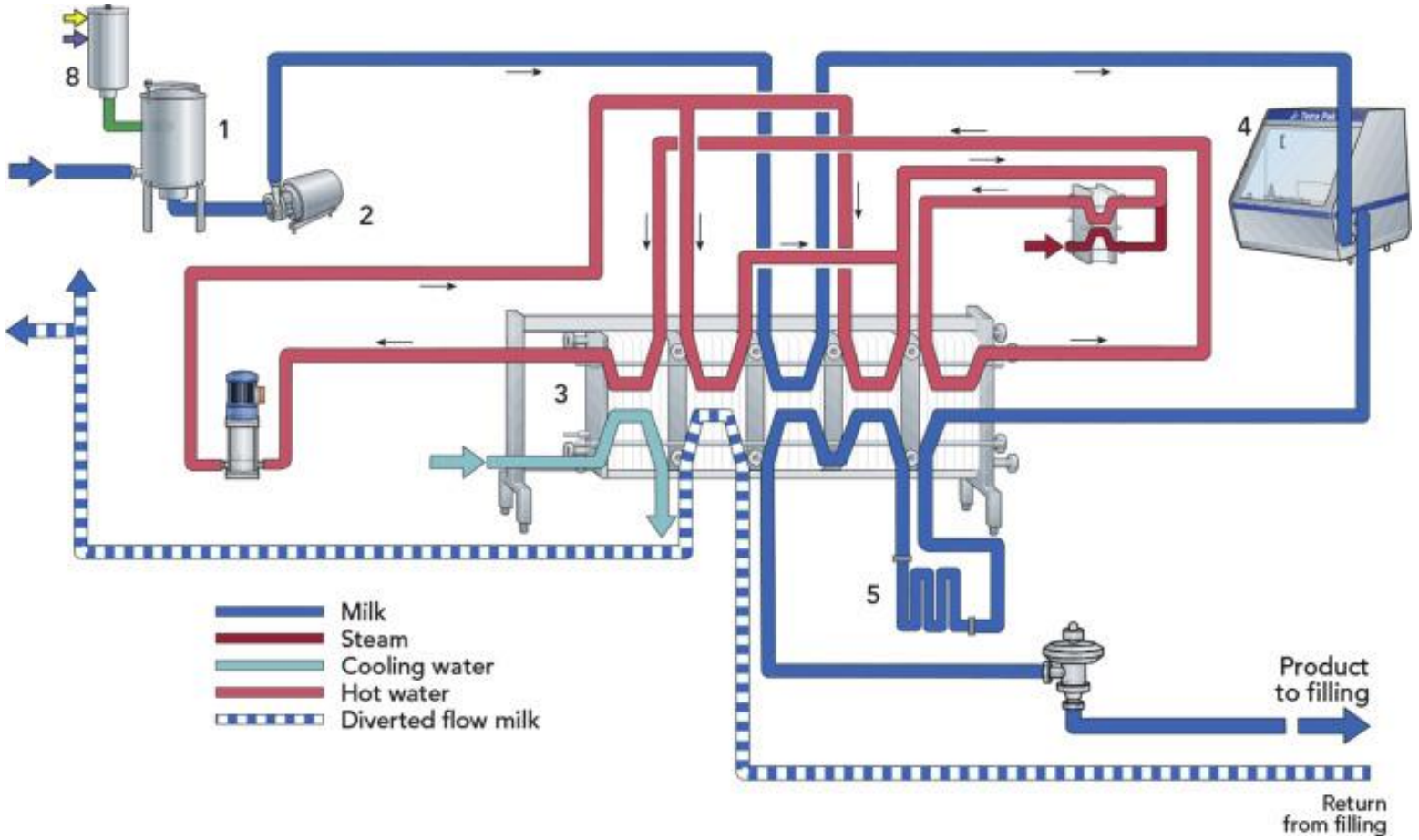
Dairy Processing Stages

IV. Pasteurization

Methods of Pasteurization

4. UHT Pasteurization (*Ultra High Temperature*)

- **Process**: heating at **88 °C for 3 seconds**.
- **Features**: very short exposure time → better preservation of texture and flavor.
- **Applications**: useful in products such as ice cream where texture is critical.
- **Advantages**: higher microbial destruction, minimal "cooked" flavor.
- **Limitations**: needs specialized equipment.



https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/ultra-high-temperature-processing

Dairy Processing Stages

IV. Pasteurization

Methods of Pasteurization

5. Ultra-pasteurization (*Uperization*)

- **Process**: direct steam injection under high pressure, heating to **150 °C for <1 second**.
- **Advantages**:
  - Very high microbial kill rate,
  - Extended refrigerated shelf life (several weeks).
- **Limitations**: costly technology, possible sensory changes.

https://wowsooru.wordpress.com/wp-content/uploads/2020/10/5-pasteurisation_of_milk_dairy_and_food_engineering.pdf

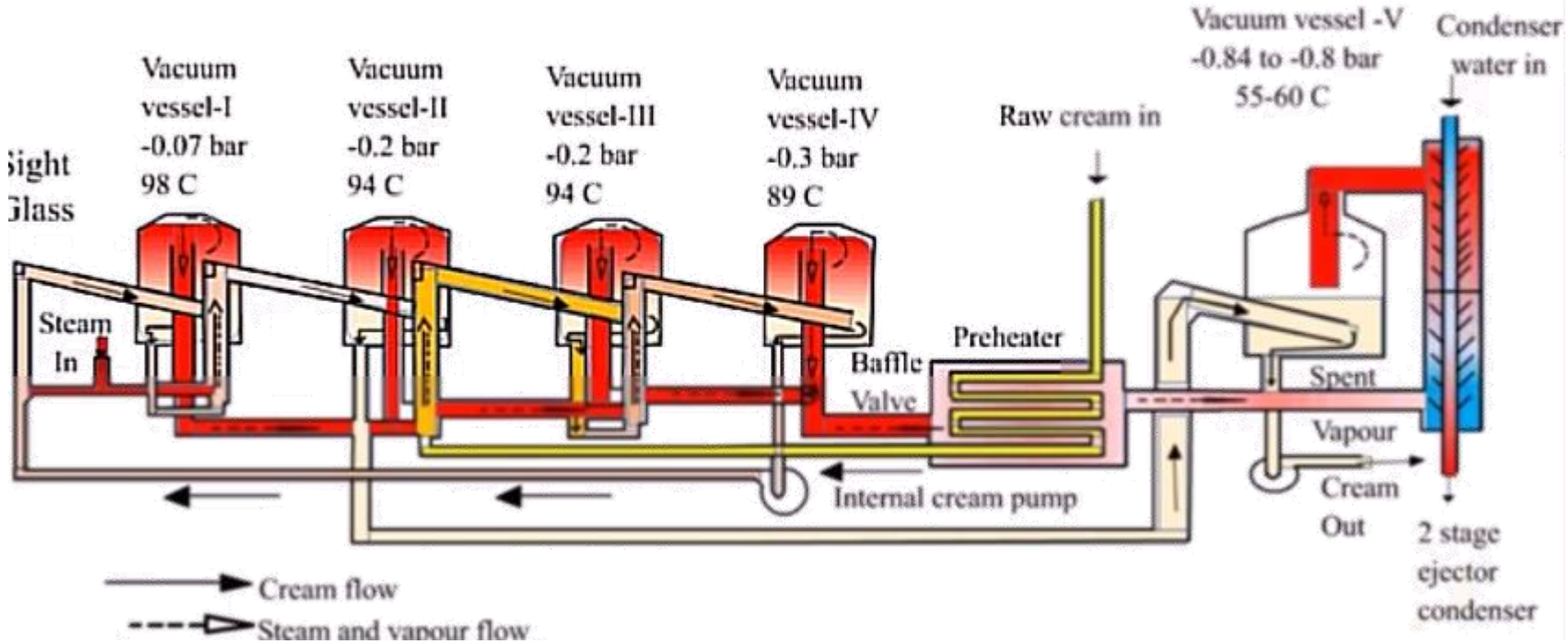
Dairy Processing Stages

IV. Pasteurization

Methods of Pasteurization

6. Vacreation

- **Principle**: heat treatment **under vacuum** in a stainless steel chamber.
- **Applications**: mainly for cream in butter manufacturing.
- **Objectives**:
  - Destroy bacteria,
  - Inactivate enzymes,
  - Remove undesirable odors/flavors,
  - Deaerate (remove dissolved gases and bubbles).
- **Equipment**: known as the *Vacreator*, with pumps, pressure/vacuum controllers, and temperature recorders.



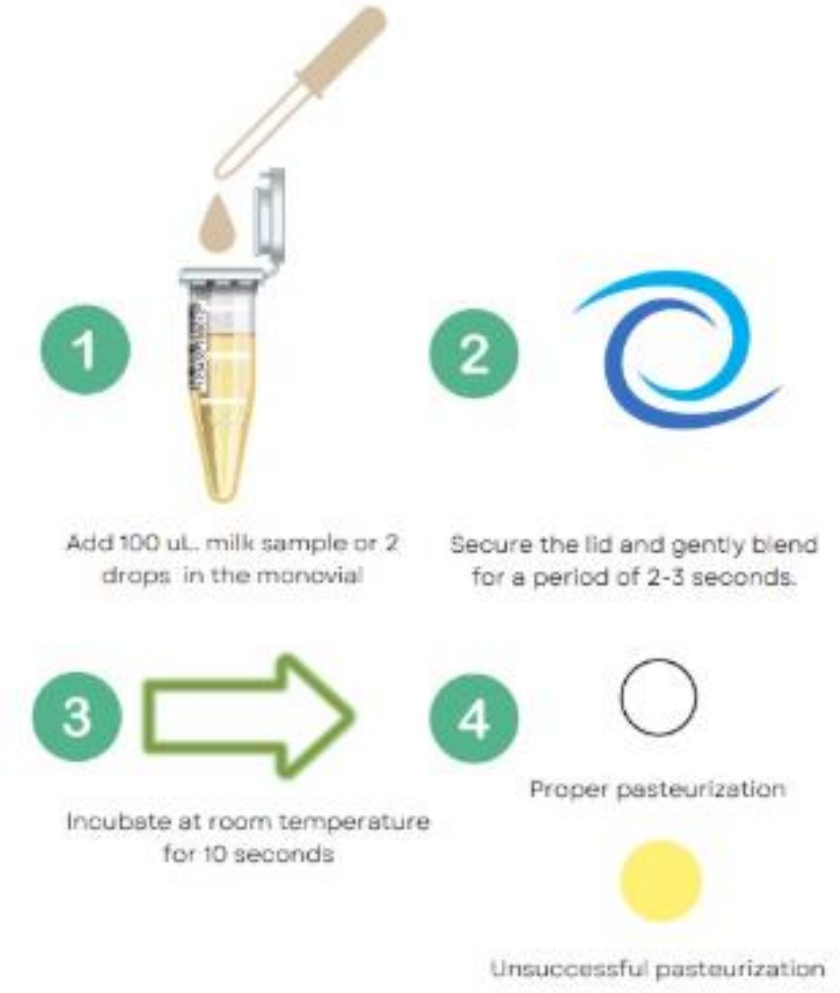
https://www.youtube.com/watch?v=SQvEilg3TOc

Dairy Processing Stages

V. Quality Control

1. Phosphatase Test

- Checks for inactivation of the natural enzyme alkaline phosphatase → indirect proof of proper pasteurization.
- Positive reaction (yellow color) = inadequate pasteurization or post-process contamination.
- Principle: detects **alkaline phosphatase**, an enzyme naturally present in raw milk that is destroyed by pasteurization.
- Procedure: sample mixed with reagents → incubation → light emission proportional to enzyme level.
- Readings:
  - Proper pasteurization → <350 mU/L phosphatase (US & EU standard).
  - PasLite sensitivity: detects as little as **20 mU/L**, ensuring accuracy.



Dairy Processing Stages

V. Quality Control

2. Post-pasteurization Contamination (PPC)

- **Key issue**: recontamination by environment or equipment surfaces.
- **Spoilage agents**: psychrotrophic spore-formers, *Listeria monocytogenes*.
- **Prevention strategies**:
  - Rapid detection and traceback systems,
  - Strict sanitation and cleaning protocols,
  - Hygienic equipment design,
  - “Seek and destroy” approaches (identify and eliminate contamination sources).

https://www.mdpi.com/2304-8158/13/18/2908

Dairy products

Milk Processing stages

- **Raw milk** → collected, quality tested, cooled, and pasteurized.
- **Separation** → divides milk into **cream (fat-rich)** and **skim milk (protein, lactose, minerals)**.
- **Cream** → **churned** into **butter** and **buttermilk**, or sold as **fresh cream**.
- **Skim milk** → **concentrated** and **dried** into **skim milk powder**.
- **Casein proteins** → obtained by **coagulation**, then **dried** into **casein powder**.
- **Whey** → the liquid left after casein removal; processed into **whey powder**, rich in proteins.
- **Yogurt** is produced from pasteurized and standardized milk by **fermentation** with specific lactic acid bacteria
- **Cheese** is made by **coagulating** milk with enzymes or starter cultures, while the liquid whey is collected for further use.

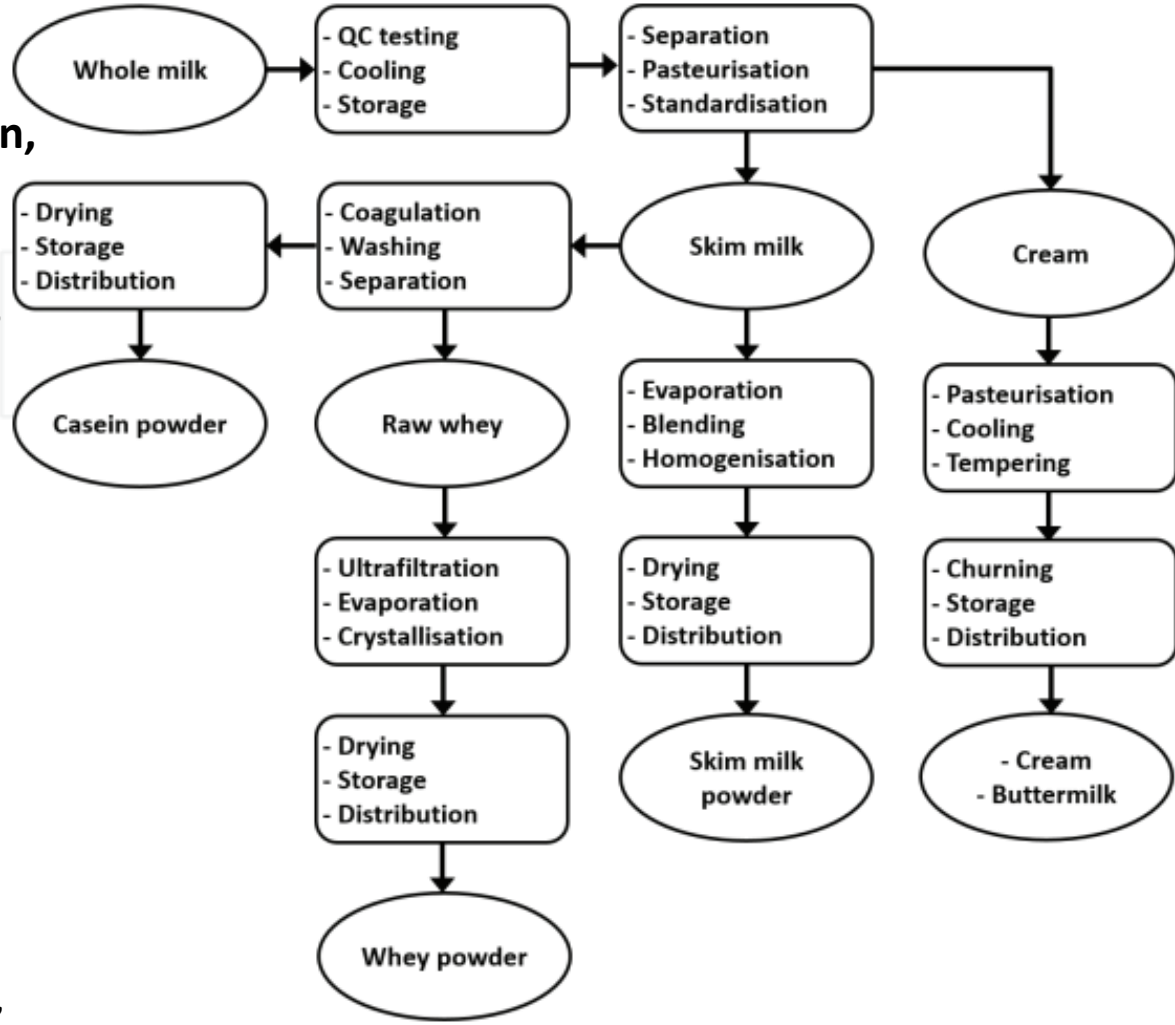


Figure 1. Milk processing stages.

Nothing is wasted : every fraction of milk is transformed into useful dairy products.

Dairy products

Milk Processing stages

•**Cream Definition**: Cream is the fatty layer that naturally rises to the top of milk when it is left to stand.

•Composition: It is rich in milk fat (typically 18–55% fat, depending on the type: light cream, whipping cream, heavy cream).

•Uses: Used in butter, ice cream, sauces, and desserts because of its fat content, which gives smooth texture and richness.

•2. **Skim Milk Definition**: Skim milk is milk from which most of the cream (fat) has been removed.

•Composition: It contains less than 0.5% fat, but still keeps proteins, lactose, vitamins, and minerals.

•Uses: Consumed as a low-fat beverage, and also used in diet products and food formulations where fat reduction is required.

•**Main Difference:**

•Cream = fat-rich fraction of milk (high energy, smooth texture).

•Skim Milk = fat-reduced fraction of milk (lighter, healthier for low-fat diets).

Keep in mind

Dairy products

Fresh Product

Pasteurized Milk (HTST ~72 °C / 15 s, shelf-life 7–10 days (0–4 °C)

1.Raw milk reception → cooling (≤6 °C) → storage (silos): QC on intake (antibiotics, acidity, freezing point, SCC, TBC).

2.Clarification / bactofugation (optional): Removes sediment, somatic cells; bactofuge reduces spores/bacteria load.

3.Standardization (fat adjustment) : Inline cream separator sets fat.

4.Pre-heating in plate/tubular heat exchanger (55–65 °C): Improves separation efficiency and prepares for homogenization.

5.Homogenization (150–250 bar, 55–70 °C): Reduces fat globules

6.HTST pasteurization (legal minimum 72 °C for 15 s): Plate heat exchanger with **regenerator** (energy recovery), holding tube (verified residence time), flow-diversion valve (FDV returns underprocessed milk).

7.Rapid cooling to ≤4 °C : Limits post-process microbial growth and proteolysis/lipolysis.

8.Packaging (non-aseptic, clean fill): HDPE bottles or gable-top cartons; cold chain required.

9.Cold storage & distribution (0–4 °C)

Dairy products

Fresh Product

Sterilized / UHT milk

Sterilized / UHT Milk (135–150 °C / 3–5 s, shelf-life 3–6 months ambient)

a heat treatment severe enough to inactivate vegetative cells + spores, then keep the product and package aseptic.

Two UHT heating methods

- **Indirect** (tubular/plate/scraped-surface): product heated through metal surfaces—good energy recovery, slightly more “cooked” flavor.
- **Direct** (steam injection or infusion): culinary steam contacts milk, then flash-vacuum to remove added water—very short exposure, fresher flavor.

Dairy products

Fresh Product

- **Direct UHT** = steam injection/infusion + flash vacuum → better taste, higher quality, but costly.
- **Indirect UHT** = tubular/plate exchangers → cheaper, more energy-efficient, but more flavor damage.
- Both achieve safe, long-life milk by combining very high temperature with very short holding time.

Dairy products

Fresh Product

Fermented milk

Fermented milk refers to dairy products obtained through the controlled action of specific microorganisms—mainly *Lactobacillus*, *Lactococcus*, *Streptococcus thermophilus*, and sometimes yeasts—that ferment lactose into lactic acid. This acidification lowers the pH of milk, causing partial coagulation of casein proteins and leading to a thicker texture, extended preservation, and development of distinctive flavors and aromas.

Dairy products

Fresh Product

Fermented milk

Microbial Action

•Lactic acid bacteria (LAB) such as *Lactobacillus delbrueckii ssp. bulgaricus* and *Streptococcus thermophilus* are the main starters.
•They hydrolyze lactose via the **Embden–Meyerhof pathway**, producing lactic acid as the primary metabolite.

Biochemical Changes

•**pH reduction**: From ~6.6 to ~4.5, inhibiting pathogenic and spoilage organisms.
•**Protein modification**: Caseins aggregate, forming a gel matrix.
•**Flavor compounds**: Acetaldehyde, diacetyl, and other volatile metabolites give characteristic aromas.

Nutritional and Functional Effects

•Enhanced digestibility (lactose is reduced).
•Increased bioavailability of vitamins (e.g., folate, riboflavin).
•Potential probiotic benefits when live cultures are present.

Dairy products

Fresh Product

Yogurt

1. Milk Preparation

•Raw or processed milk is **standardized** to adjust its fat and solid content.

•Then, it is **homogenized** to break down fat globules and ensure a smooth texture.

2. Heat Treatment

•The milk is heated (85–95 °C for a few minutes).

•Purposes: to destroy undesirable microorganisms and to denature whey proteins, which helps the gel structure form.

3. Cooling

•The heated milk is cooled to about **40–45 °C**, which is the optimal temperature for starter bacteria growth.

. Inoculation (Starter Addition)

•A **starter culture** is added (usually *Streptococcus thermophilus* and *Lactobacillus delbrueckii ssp. bulgaricus*).

•These bacteria ferment lactose into lactic acid.

5. Fermentation

•The inoculated milk is incubated at controlled temperature.

•Acidification lowers the pH to ~4.5, leading to **coagulation of casein proteins** and formation of the yogurt gel.

6. Final Cooling and Storage

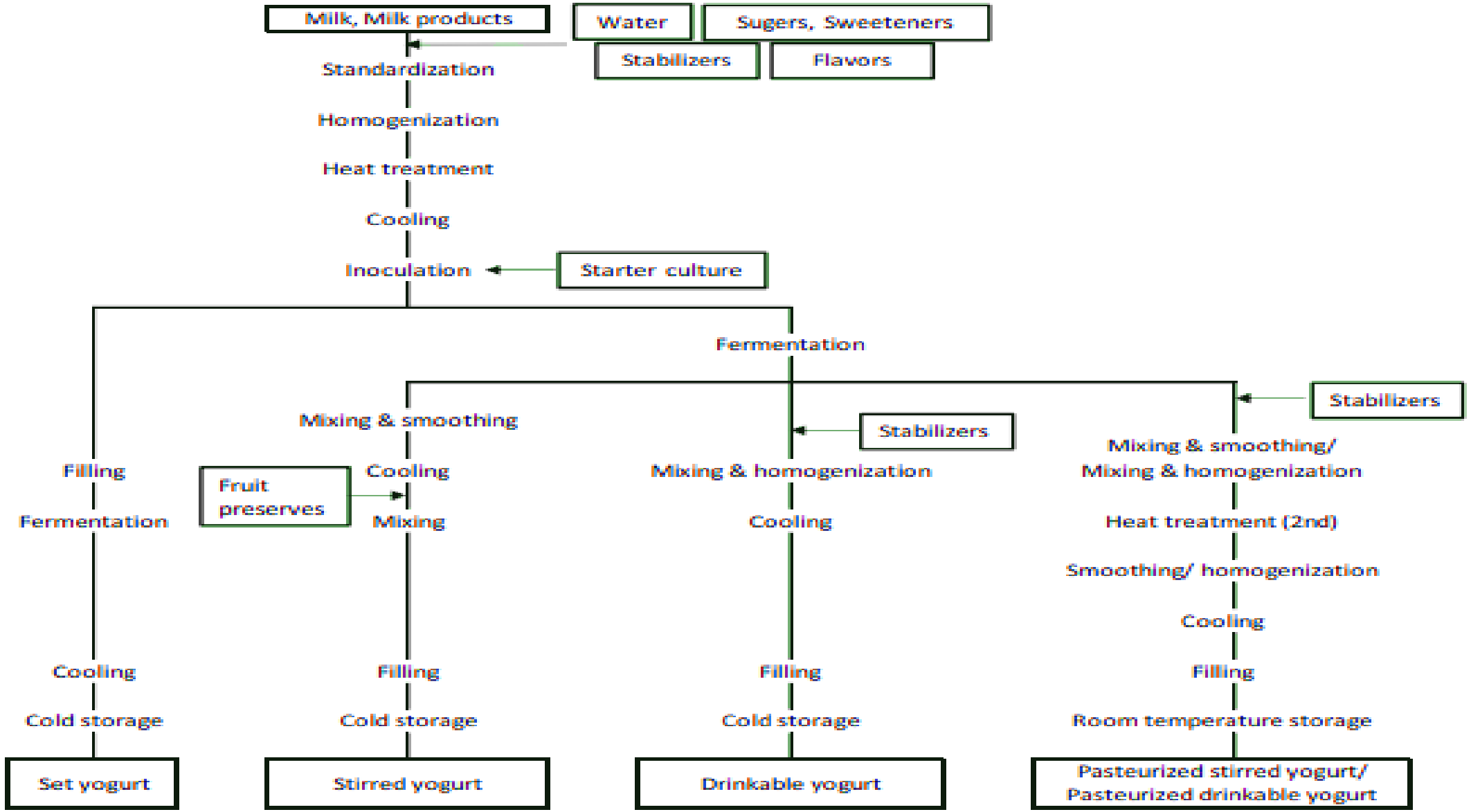
•Once the desired acidity and texture are reached, the product is rapidly cooled to stop bacterial activity.

•Yogurt is then packaged and stored under refrigeration.

Dairy products

Fresh Product

Yogurt



Dairy products

Fresh Product

Yogurt

Set Yogurt (firm texture in the cup)

- **Standardization & Homogenization**: Adjust milk composition and break fat globules.
- **Heat treatment**: 85 °C for 20–30 min (or 90–95 °C for 5 min) to kill pathogens and denature whey proteins (improves gel).
- **Cooling**: Bring mix to incubation temperature (40–43 °C).
- **Inoculation**: Add starter culture (*S. thermophilus* + *L. bulgaricus*).
- **Filling**: Milk is poured into final cups **before fermentation**.
- **Fermentation**: Keep at 40–43 °C until pH ~4.6 (acidity 0.8%).
- **Cooling & storage**: Refrigerate at 5 °C → final set yogurt.

Stirred Yogurt (softer texture, often with fruits)

- Same steps as set yogurt **until inoculation**.
- **Fermentation**: Incubated in bulk tanks (not in cups).
- **Mixing & smoothing**: The curd is broken by stirring to give a creamy texture.
- **Cooling**: Immediately cooled to 10–25 °C.
- **Additives**: Fruits, sugar, sweeteners, flavors, stabilizers may be mixed in.
- **Filling & storage**: Filled into cups, then stored at 5 °C.

Dairy products

Fresh Product

Yogurt

Drinkable Yogurt

- Same steps as stirred yogurt up to smoothing.
- **Stabilizers added** (e.g., pectin, CMC) → prevent whey separation (syneresis).
- **Homogenization**: 10–20 MPa to reduce viscosity to a liquid form.
- **Cooling & filling**: Immediately cooled, then bottled.
- **Cold storage**: Refrigerated at 5 °C.

Pasteurized Stirred Yogurt

- Follows stirred yogurt process initially.
- **Pasteurization (second heat treatment)**: 75–110 °C for 2–20 s → kills lactic acid bacteria.
- **Stabilizers & thickeners**: Added to maintain texture (pectin, gelatin, starch).
- **Homogenization/smoothing**: To avoid clumps.
- **Cooling & filling**: Packed aseptically at 10–25 °C.

Dairy products

Fresh Product

LEBEN

Leben is a fermented milk product obtained by the action of lactic acid bacteria, mainly *Lactococcus* and *Leuconostoc* species, which acidify the milk, coagulate proteins, and produce a mildly sour, refreshing dairy beverage

Key Differences from Yogurt

- Yogurt uses *Streptococcus thermophilus* + *Lactobacillus bulgaricus*; leben relies on mesophilic LAB (e.g., *Lactococcus*, *Leuconostoc*).
- Leben often has a more fluid, slightly effervescent texture and a milder flavor.
- Traditional leben may be made without heating (risk of contamination), while industrial production always includes pasteurization.

Dairy products

Fresh Product

LEBEN

Industrial Leben (controlled fermentation)

To improve safety and uniformity, dairies use controlled fermentation similar to yogurt production.

1. **Milk standardization** : Fat and solids are adjusted.
2. **Homogenization** : To improve texture and stability.
3. **Heat treatment** : Milk is pasteurized (85–90 °C for several minutes) to kill pathogens.
4. **Cooling** : Milk is cooled to fermentation temperature (~37–40 °C).
5. **Inoculation** : Specific starter cultures (usually *Lactococcus lactis*, *Leuconostoc mesenteroides*, or traditional LAB strains) are added.
6. **Fermentation** : Milk ferments until it reaches the desired acidity (pH ~4.5).
7. **Cooling** : Rapid cooling to stop fermentation.

Packaging and storage : Filled in bottles or cups and stored refrigerated.

Dairy products

Fresh Product

LEBEN

Traditional Leben (spontaneous fermentation)

This common method in Algeria and other North African countries:

1.Milk selection : Usually raw cow's milk (sometimes goat or sheep).

2.Boiling or heating (optional) : boil the milk briefly to kill unwanted microbes; or use it raw.

3.Cooling : If heated, milk is cooled to a warm temperature (~30–40 °C).

4.Spontaneous fermentation – The milk is left at room temperature for 12–24 h. Naturally present lactic acid bacteria (LAB) or a bit of leftover *leben* from a previous batch acts as the starter.

5.Coagulation : LAB convert lactose into lactic acid, lowering pH to ~4.2–4.5, which coagulates caseins.

6.Stirring / Breaking curd : The coagulum is stirred, giving *leben* its characteristic smooth, slightly viscous texture.

Dairy products

Coagulated Products

Milk coagulated products (enzymes or fermentation):

These are dairy products made by coagulating milk proteins, especially casein, through the action of enzymes (like *rennet*) or fermentation by lactic acid bacteria. The process turns liquid milk into a thicker or solid texture, often forming curds and whey. Coagulation is a crucial step in the production of many traditional and industrial dairy foods.

Coagulation Methods:

- **Enzymatic coagulation:**

Uses enzymes (e.g., **rennet**) to directly cleave casein, forming a firm gel (Common in **cheese** production).

- **Fermentation-Based Coagulation:** Involves **lactic acid bacteria** that acidify milk, reducing pH and causing casein to coagulate (Found in **yogurt**, **kefir**, **curd**, etc).

Dairy products

Coagulated Products

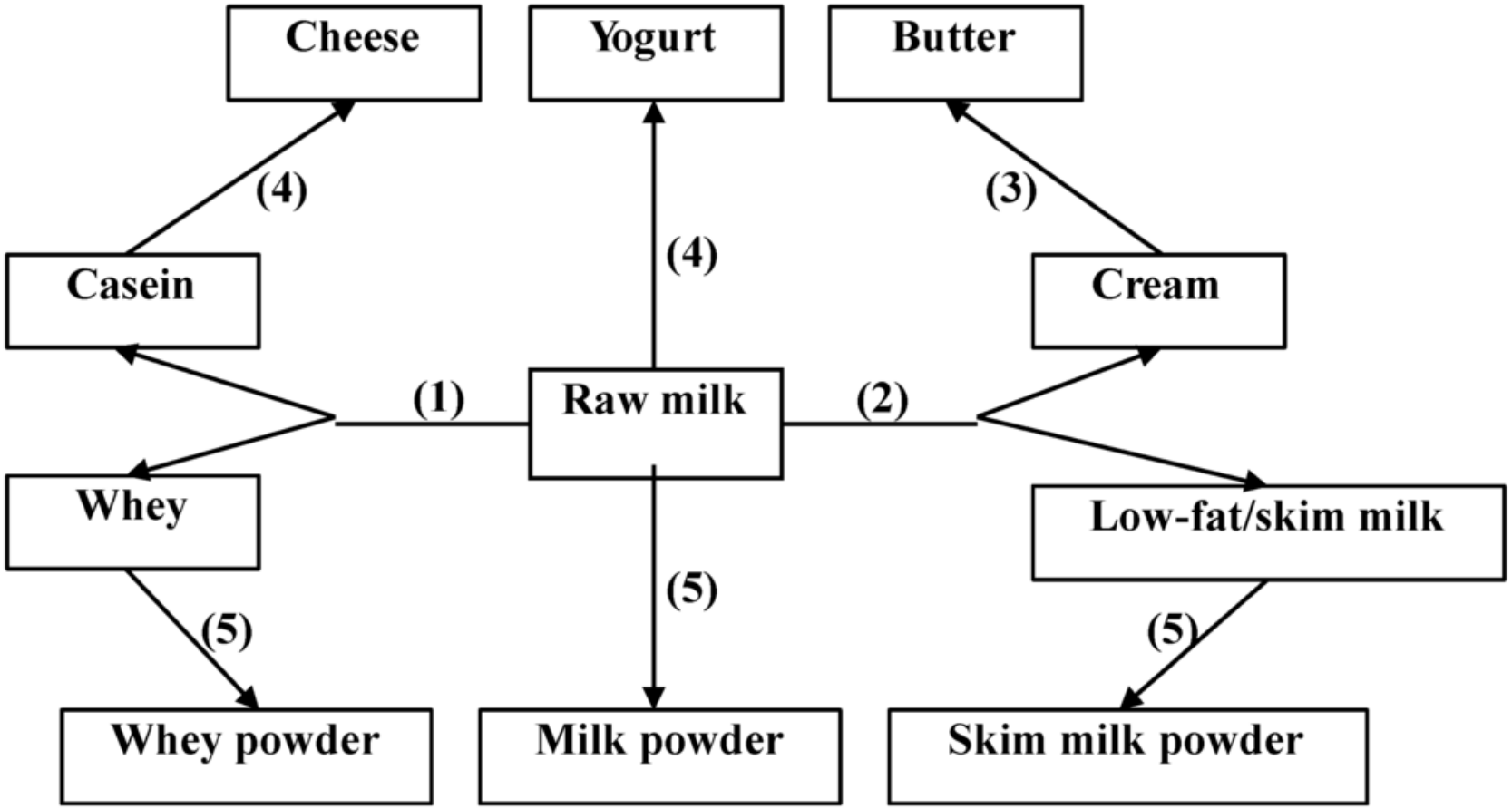


Figure 1. Overview of milk and various dairy products obtained from different processing schemes: (1) coagulation; (2) separation; (3) churning; (4) fermentation; (5) evaporation.

https://www.mdpi.com/2072-6643/7/6/4875