People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University Sétif 1Ferhat Abbas
Faculty of Natural and Life Sciences
Department of Biotechnology

TECHNOLOGY OF FOOD INDUSTRY I

Target: L3 Food Biotechnology "1st Semester"

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2025–2026

Overview

The Agro-Food Industry Technology course is an integral part of the scientific and technical training framework designed to prepare students for a dynamic career in the agri-food sector. This course aims to equip students with the essential skills, knowledge, and competencies required to master the intricate processes of transforming agricultural raw materials into safe, nutritious food products that meet the ever-evolving expectations of consumers. By the end of this course, students will be able to understand, analyze, and apply the fundamental technological principles that govern the primary processing industries, focusing specifically on critical sectors such as milk and dairy products, sugar production, fats, and beverages. One of the primary objectives of this course is to provide students with a robust theoretical foundation regarding the biochemical composition and physicochemical properties of various raw materials utilized in the agri-food industries. Key materials of focus will include milk, sugar beet, oilseeds, and fruits. Students will gain insights into how these intrinsic characteristics influence the selection of appropriate processing methods and dictate the quality attributes of the final products. Understanding these principles is vital for ensuring that the food products created not only meet safety standards but also satisfy consumer preferences for taste, texture, and nutritional value.

In addition to theoretical knowledge, this course will also emphasize the practical applications of this knowledge. Students will explore the various reaction mechanisms involved in biological, chemical, and physical transformations that are critical to food processing. This includes a detailed examination of processes such as enzymatic and acid coagulation, which are fundamental in the production of cheese and yogurt; lactic fermentation, which is crucial for producing a variety of dairy and plant-based products; sucrose crystallization, essential for sugar production; lipid extraction, important for fats and oils; and juice stabilization, which is vital for maintaining the quality of fruit juices.

Moreover, students will be encouraged to engage in hands-on laboratory experiences where they can apply their theoretical knowledge to real-world situations. This experiential learning will not only enhance their understanding of the course material but also prepare them to tackle practical challenges in the agro-food industry. By the end of the course, students will possess a well-rounded understanding of both the scientific principles and practical skills necessary to thrive in the ever-changing landscape of the food industry.

Through a combination of lectures, laboratory work, and collaborative projects, this course aims to foster critical thinking, problem-solving skills, and a deep appreciation for the complexities of food production. Ultimately, students will emerge from this course ready to contribute meaningfully to the field of agro-food technology, equipped with the tools and knowledge necessary to innovate and meet future challenges in food processing and product development.

Prerequisites

Students enrolling in this course are expected to have prior knowledge in chemistry, biochemistry, microbiology, physics, thermodynamics, and energy principles. These foundational subjects are essential for understanding the scientific basis of agro-food processing operations, including raw material composition, reaction mechanisms, heat and mass transfer, microbial control, and the technological transformations involved in the production of dairy products, sugar, fats and oils, and beverages.

Information about this course

Target: Third year (food Biotechnology)

Coefficient: 3

Semester: 1st (UE fundamentals)

Global Hourly volume: 67 h30

List of Abbreviations

Abbreviation	Signification
α-La	α-Lactalbumin
β-Lg	β-Lactoglobulin
°Brix	Degrés Brix (concentration en sucres)
av	Water Activity (activité de l'eau)
BHA	Butylated Hydroxyanisole
BHT	Butylated Hydroxytoluene
CAC	Codex Alimentarius Commission
CFU	Colony Forming Units (unités formant colonies)
CLA	Conjugated Linoleic Acid (acide linoléique conjugué)
CIP	Cleaning in Place (nettoyage en place)
COI	Conseil Oléicole International
CSD	Carbonated Soft Drink (boisson gazeuse)
DE	Diatomaceous Earth (terre de diatomée)
DGCC	Direction Générale du Commerce et de la Concurrence
DM	Dry Matter (matière sèche)
DSH	Direct Steam Heating (chauffage direct par vapeur)
E102	Tartrazine
E129	Allura Red / Red 40
E150	Caramel color
E202	Potassium sorbate
E211	Sodium benzoate
E950	Acesulfame-K
E951	Aspartame
E955	Sucralose
E960	Stevia glycosides
EDTA	Ethylene Diamine Tetraacetic Acid
EU	European Union
EVOO	Extra Virgin Olive Oil (huile d'olive extra vierge)
FA	Fatty Acid (acide gras)
FAO	Food and Agriculture Organization
FFA	Free Fatty Acid (acide gras libre)
F_0	Valeur de stérilisation (équivalent temps à 121,1°C)
GR	Ghee Residue (résidu de ghee)
HFCS	High Fructose Corn Syrup
HPP	High Pressure Processing (traitement par haute pression)
HTST	High Temperature Short Time (haute température courte durée)
IANOR	Institut Algérien de Normalisation et de la Protection du Consommateur
Ig	Immunoglobulin
IgG	Immunoglobulin G
ISH	Indirect Steam Heating (chauffage indirect par vapeur)
K_{232}	Coefficient d'absorption UV à 232 nm
K_{270}	Coefficient d'absorption UV à 270 nm
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
LTLT	Low Temperature Long Time (basse température longue durée)
LTP	Low Temperature Powder (poudre basse température)
MF	Microfiltration
MFGM	Milk Fat Globule Membrane (membrane du globule gras du lait)
MPC	Milk Protein Concentrate (concentré de protéines du lait)
MPI	Milk Protein Isolate (isolat de protéines du lait)
MSNF	Milk Solids Not Fat (matières solides du lait non grasses)

MWCO	Molecular Weight Cut-Off (seuil de coupure moléculaire)
MXD6	Poly(m-xylene adipamide) - barrière au CO_2
NA	Norme Algérienne
NF	Nanofiltration
NFC	Not From Concentrate (non concentré)
NS	Non-Sugars (non-sucres)
OMWW	Olive Mill Wastewater (eaux usées de moulin à huile)
ONSSA	Office National de la Sécurité Sanitaire des Produits Alimentaires
PAH	Polycyclic Aromatic Hydrocarbons (hydrocarbures aromatiques polycycliques)
PEF	Pulsed Electric Fields (champs électriques pulsés)
PET	Polyethylene Terephthalate
PLC	Programmable Logic Controller
PME	Pectin Methyl Esterase
POD	Peroxidase
PPO	Polyphenol Oxidase
PP	Polypropylene
Q_{10}	Facteur de température (accélération réaction par 10°C)
RDA	Recommended Daily Allowance (apport journalier recommandé)
RO	Reverse Osmosis (osmose inverse)
ROPP	Roll-On Pilfer-Proof (capsule inviolable)
RT	Room Temperature (température ambiante)
SCADA	Supervisory Control and Data Acquisition
SCP	Single Cell Protein (protéine unicellulaire)
SI	Saponification Index (indice de saponification)
SMP	Skim Milk Powder (poudre de lait écrémé)
SNF	Solids Not Fat (matières solides non grasses)
SSHE	Scraped-Surface Heat Exchanger (échangeur à surface raclée)
TMP	Transmembrane Pressure (pression transmembranaire)
UE	Unité d'Enseignement
UF	Ultrafiltration
UHT	Ultra High Temperature
UV	Ultraviolet
VFD	Variable Frequency Driver
VOO	Virgin Olive Oil (huile d'olive vierge)
W/O	Water-in-Oil (eau dans huile)
WPC	Whey Protein Concentrate (concentré de protéines de lactosérum)
WPI	Whey Protein Isolate (isolat de protéines de lactosérum)
WHO	World Health Organization

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Part 2: Sugar

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Part 4: Beverages

Part 1: Milk and dairy products

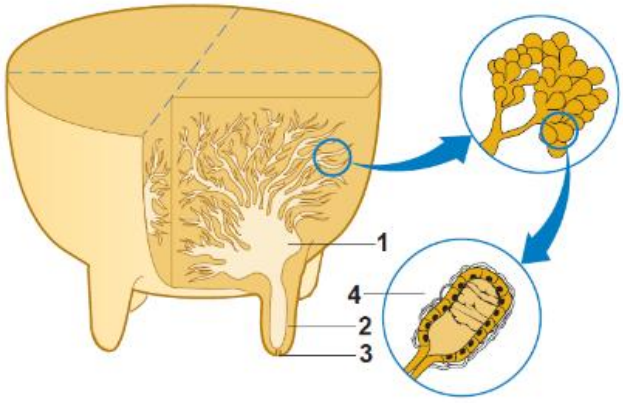
1. Milk

1.1. Definition

The milk is a fluid secreted by the mammary glands of female mammals after birth. It is an opaque, white to yellowish aqueous fluid with a slightly acidic pH (6.6 to 6.8). Milk was defined in 1908 during the International Congress for the Suppression of Fraud in Geneva as: "The integral product of the total and uninterrupted milking of a healthy, well-fed and not overworked dairy female. Milk must be collected cleanly and must not contain colostrum. »

The Colostrum is the initial secretion after parturition. It is a yellowish liquid, exceptionally rich in proteins (especially immunoglobulins/antibodies) and minerals, designed to provide passive immunity to the newborn.

Cow's milk production begins after the young is born, which triggers hormonal changes, including the release of prolactin (triggers milk synthesis) and oxytocin (causes milk to be ejected).
Milk forms in the breast sockets and then accumulates in the cistern of each udder (figure 1).

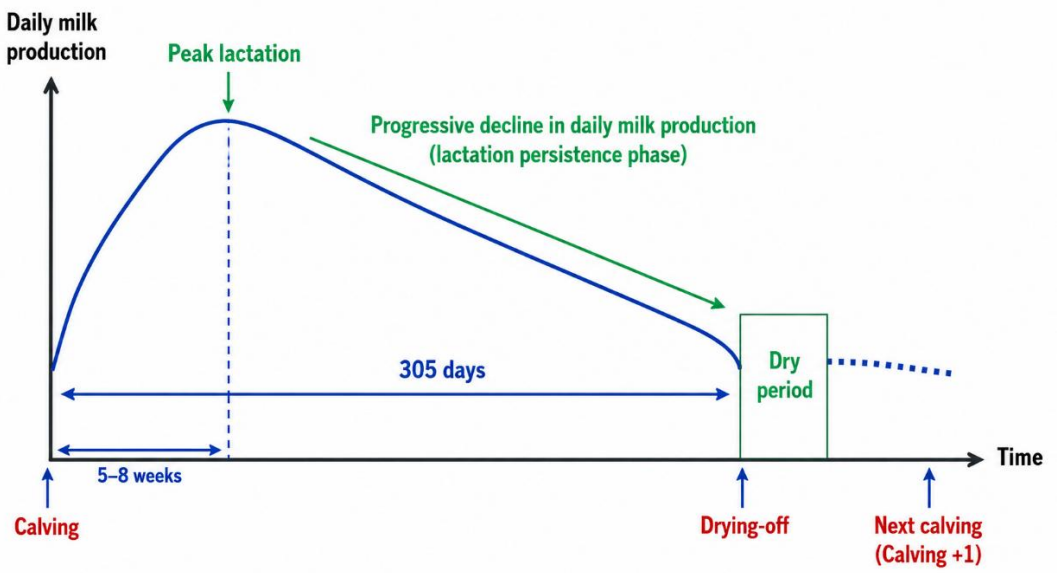


1. **Udder cistern**
2.**Teat cistern**
3.**Teat canal**
4.**Alveolus**

Figure 1: Cross-section of the mammary gland (udder)

The cow's udder, which is the large organ with four independent breast quarters, serves as the main reservoir for storing milk before it is released during milking.

After calving, milk production gradually increases until the peak of lactation (3 to 8 weeks), is maintained for a time, and then decreases until the calf is dried off about 300 days after the calf is born (figure 2).



Figures 2: Typical Lactation Curve of a Dairy Cow

1.2. Milk Structure

Milk is a complex liquid, not uniform. It contains very small droplets of fat suspended in a liquid called plasma.
In this plasma, there are also protein particles called casein micelles. The rest of the fluid, called serum, contains other small particles and is also a bit cloudy.
The fat droplets are surrounded by a thin membrane that is different from the casein proteins.

Looking at milk under a microscope, at low magnification (5X) a uniform but turbid liquid is observed. At 500X magnification, spherical droplets of fat, known as fat globules, can be seen. At even higher magnification (50,000X), the casein micelles can be observed. The main structural components of milk, fat globules and casein micelles, will be examined in more detail later (figure 3).

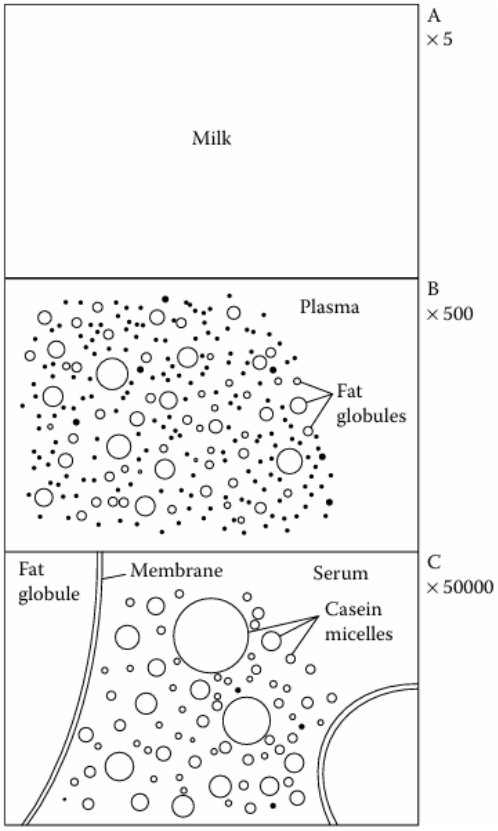


Figure 3: Milk viewed at different magnifications, showing the relative size of structural elements (A) Uniform liquid. However, the liquid is turbid and thus cannot be homogeneous. (B) Spherical droplets, consisting of fat. These globules float in a liquid (plasma), which is still turbid. (C) The plasma contains proteinaceous particles, which are casein micelles. The remaining liquid (serum) is still opalescent, so it must contain other particles. The fat globules have a thin outer layer (membrane) of different constitution.

1.3. Biochemical Composition

From a physicochemical point of view, milk is a very complex product. A thorough understanding of its structure is essential for comprehending the transformations that occur within it and its products during various industrial treatments. Milk is a colloidal system consisting of an aqueous solution of lactose (5%), saline substances (0.7%), and several other elements in a dissolved state, in which proteins (3.2%) are found in suspension and fats in emulsion. The total dry extract of milk is on average 13.1% and the defatted dry extract is 9.2%.

The general composition of milk is as follows:

1. Major constituents

- Water (86.9%); - Fat (3.9%); - Proteins and non-protein nitrogenous compounds (3.2%); - Carbohydrates (5.1%); - Mineral salts (0.9%).

2. Minor constituents

- Enzymes; - Vitamins; - Pigments (carotenes, xanthophylls, riboflavin); - Various cells (epithelial cells, leukocytes, bacteria, yeasts, moulds); - Various elements (carbon dioxide, oxygen, nitrogen, and other gases); - Foreign materials.

These data are quantitative approximations that vary depending on a multitude of factors. The exact composition of a milk sample can only be obtained through analysis.

1.3.1. Milk Proteins

Proteins are essential building blocks of every living cell and occupy a predominant place in milk and dairy products. Milk contains an average of 3.2% protein, of which 80% is made up of casein (Table 1). Casein is usually distinguished by its precipitation at pH 4.6, from the others, which are referred to as whey proteins. These do not precipitate with casein, unless they have been previously denatured by heat or otherwise. Coagulation with trichloroacetic acid includes all proteins plus proteoses and peptones. The whey proteins include lactalbumins and lactoglobulins.

These two groups can be separated using a saturated magnesium sulphate solution, which precipitates the lactoglobulins and retains the lactalbumins in solution.

From a practical standpoint, it is useful to remember that caseins precipitate upon acidification at pH 4.6, whereas albumins and globulins must be destabilized by heat before being coagulated with acid. Albumins are distinguished from globulins in that they are soluble in water, in a saturated MgSO4 solution, or in a half-saturated (NH4)2SO4 solution.

A. Caseins

Caseins are the main proteins in milk and account for about 80% of the total protein content. They are ampholytes and present in milk as calcium phosphocaseinate micelles, whose stability depends mainly on electrical charges and hydration. They can be precipitated by acidification at their isoelectric point, around pH 4.6. They are heterogeneous proteins and are divided into five main families: αs1-casein, αs2-casein, β-casein, κ-casein, and γ-casein

(Figure 4).

These fractions are not completely uniform because they may vary by one or more amino acids, which explains their genetic polymorphism.

Table 1: Milk proteins and their concentration

Type	Nomenclature	Concentration (g/L)	% Total Protein (W/W)
Caseins		26	79.5
	αs1-casein	10.0 (12-15)	30.5
	αs2-casein	2.6 (3-4)	8
	β-casein	9.3 (9-11)	28
	κ-casein	3.3 (2-4)	10
	γ-casein	1	3
Milk Serum Proteins		6.3	19.3
	β-lactoglobulin	3.2	10
	α-lactalbumin	1.2	3.6
	Bovine Serum Albumin	0.4	1.2
	Immunoglobulins	0.7	2.1
	Proteoses-peptones	0.8	2.4
Membrane Proteins		0.4	1.2
Total Proteins		32.7	100

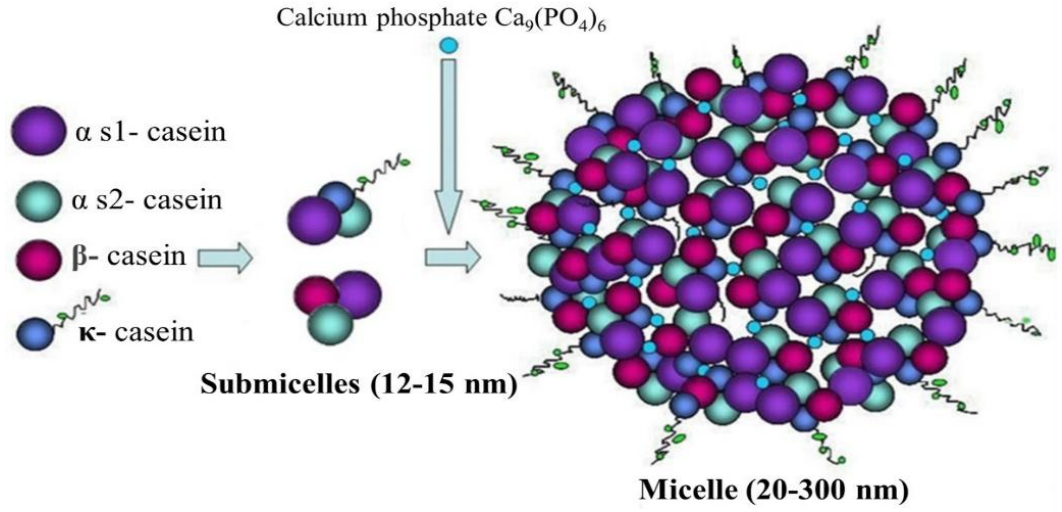


Figure 4: Schematic representation of the casein micelle

Caseins are important in dairy processing because they coagulate during acidification or enzymatic treatment. In cheese making, enzymatic coagulation breaks the micelle structure and forms calcium phosphoparacaseinate, which is essential for curd formation. Their ability to form stable micelles also makes them important for the structure and texture of milk and dairy products.

B. Whey Proteins

Whey proteins are the soluble proteins of milk and differ strongly from caseins. They are true emulsoids, meaning they have a high affinity for water and remain soluble under conditions where caseins precipitate. Unlike caseins, whey proteins do not coagulate at pH 4.6 by simple acidification; they usually require heat or alcohol to denature. They are also more sensitive to heat and can be denatured above pasteurization temperatures.

The main whey proteins include α-lactalbumin, β-lactoglobulin, and serum albumin (Table 1). α-Lactalbumin is highly soluble in water and has a molecular weight of about 16,000. β-Lactoglobulin is the major whey protein and is characterized by its high abundance, its genetic variants, and its tendency to form dimers or polymers. Serum albumin is also present in smaller amounts and has nutritional importance because of its amino acid composition.

Whey proteins are nutritionally valuable because they are richer than caseins in certain essential amino acids, especially lysine, methionine, and tryptophan.

C. Minor Milk Proteins

Milk also contains minor proteins in small quantities. These include proteins attached to fat globule surfaces, such as euglobulin, alkaline phosphatase, and xanthine oxidase, as well as mucoproteins, lipoproteins, and iron-containing proteins such as lactoferrin and transferrin. Although they are present in low amounts, they are important in milk chemistry and can influence milk stability and biological activity.

1.3. 2. Structure and chemical composition of fat globule (fat/cream)

The substances that can be extracted from milk using non-polar organic solvents such as ether, benzene, or chloroform are the fats in the milk. It represents 3.6% to 4.4% of the total composition of milk. It occurs in globular form and dispersed in the aqueous phase represented by skimmed milk.

It consists of 65% saturated fatty acids and 35% unsaturated fatty acids. These are composed mainly of glycerides (99%), but also include complex lipids that are very important in dairies, such as phospholipids and cerebrosides. The fat fraction of milk also includes sterols, such as cholesterol and its precursors, and free fatty acids. Extraction with non-polar solvents results in substances soluble in ether but which are not lipids. This is the case for carotenoids and vitamins E and K.

The lipid composition of milk is as follows (Figure 5):

1. Glycerides (3.85%);
2. Phospholipids (0.035%):

- Lecithins (0.021%), - Cephalins (0.011%), - Sphingomyelins (0.003%);

3. Cerebrosides (0.002%);
4. Cholesterols (0.015%);
5. Carotenoids.

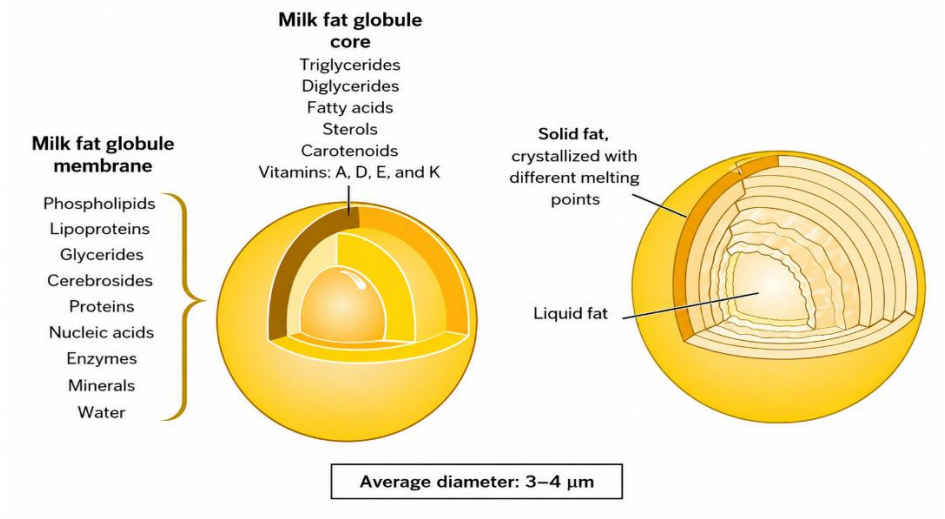


Figure 5: Structure and chemical composition of the fat globule (cross-section view)

1.3. 4.Factors Affecting Milk Composition

Milk composition is influenced by many factors, including genetics, nutrition, level of milk production, stage of lactation, disease, season, and age of the cow. The main components of milk are water, fat, protein, lactose, and minerals. Among these, milk fat is the most sensitive to dietary change, while milk protein also changes with feeding management, although to a lesser extent. Lactose and minerals, however, are less predictable in their response to diet.

a) Genetics and Breed

Genetics has an important role in determining the natural composition of milk, but changes through traditional breeding are slow. Different breeds show different average levels of fat, protein, and total solids. For example, Jersey cows generally produce milk with higher fat and protein percentages than Holstein cows. However, milk yield and component yield have relatively low heritability, so environmental and nutritional factors often have a greater practical impact than genetics alone.

b) Level of Milk Production

Milk composition is closely related to production level. When milk yield increases, the percentages of fat and protein often decrease, even if the total yields of these components increase. Otherwise, a cow producing more milk may make more total fat and protein per day, but these components become diluted in the larger volume of milk.

c) Stage of Lactation

The concentration of milk fat and protein is highest in early and late lactation and lowest during peak milk production in mid-lactation. As milk yield rises during peak production, the percentages of fat and protein usually decline. Even so, the absolute yields of these components may remain stable or increase. This shows that stage of lactation strongly influences the nutritional profile of milk.

d) Disease and Mastitis

Disease, especially mastitis, has a major effect on milk composition. Mastitis reduces fat and casein content while increasing whey protein content. It also alters lactose, mineral balance, and pH, which negatively affect cheese yield and curd quality. Milk from cows with high somatic cell counts has longer coagulation time and forms weaker curds, making it less suitable for dairy processing.

e) Season and Environmental Conditions

Season also affects milk composition. Fat and protein percentages are usually higher in fall and winter and lower in spring and summer. This variation is linked to feed quality and climate. Lush spring pasture can reduce milk fat, while hot and humid weather lowers feed intake and reduces forage consumption, which can decrease both fat and protein percentages.

f) Age of the Cow

As cows age, milk protein content tends to decrease gradually, while fat remains relatively stable. The protein content may decline slightly over several lactations.

g) Feeding and Rumen Function

Feeding management is one of the most important practical tools for improving milk composition. Adequate feed intake supports milk production and helps maintain normal levels of fat and protein. A balanced forage-to-concentrate ratio, sufficient fiber, and proper grain feeding are essential for healthy rumen fermentation. If the diet contains too much grain or too little fiber, milk fat depression may occur because rumen pH falls and fermentation patterns change.

h) Protein and Energy Nutrition

Milk protein concentration is influenced by dietary protein, especially when the diet is deficient. Increasing crude protein or balancing undegradable intake protein can improve milk protein content. However, excess protein alone does not always improve milk quality unless energy and fiber are also properly balanced. The optimization of rumen function is key to maximize both milk yield and milk component percentages.

2. Dairy processing techniques

Dairy techniques refer to the methods and processes used to collect, treat, process, and preserve milk so it can be turned into safe and marketable dairy products such as pasteurized milk, yogurt, cheese, butter, and milk powder. It includes both the handling of raw milk and the industrial operations that improve its safety, shelf life, texture, and nutritional quality (Figure 6).

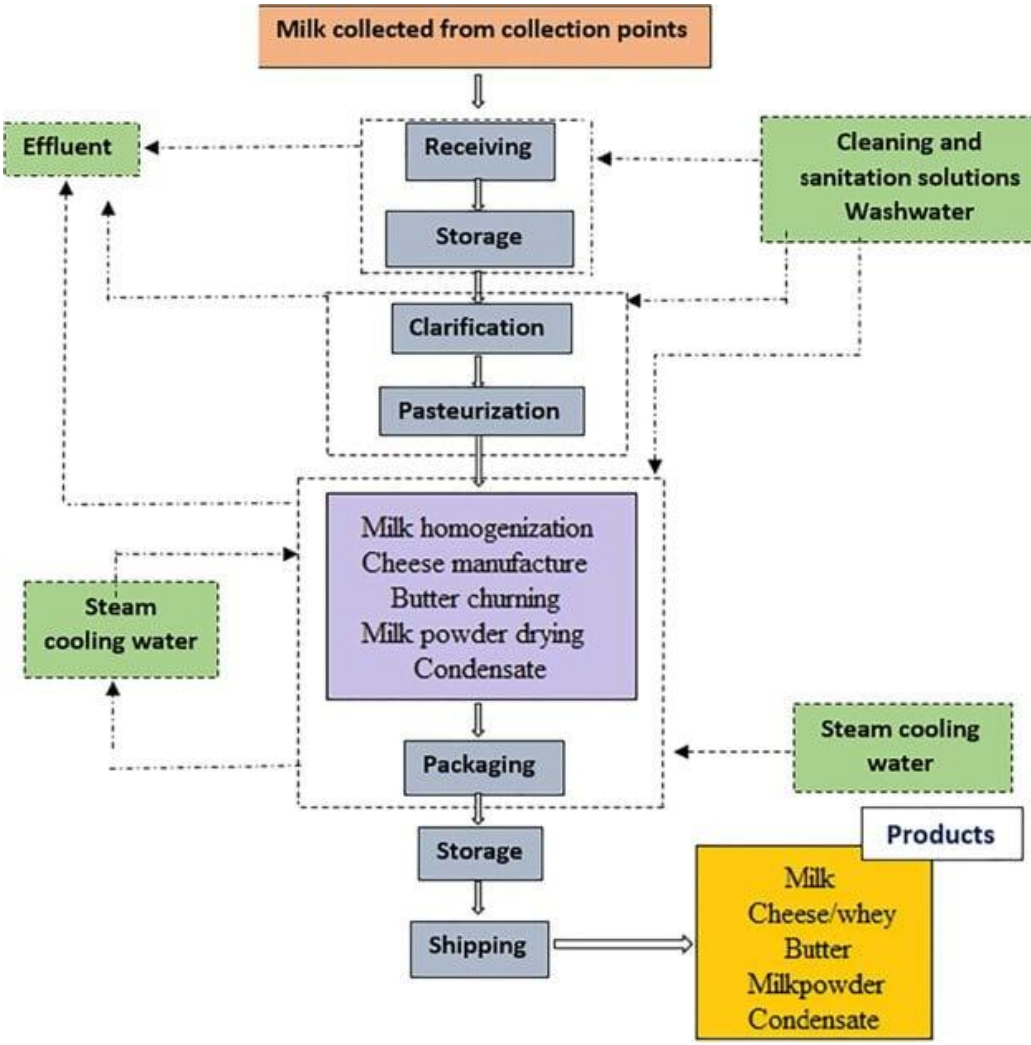


Figure 6: Flowchart showing milk processing steps in a dairy

2.1. Receiving milk

The milk is delivered to the dairy, usually by insulated tanker truck to avoid any alteration due to temperature.

Upon arrival, the milk is measured (volume or weight), checked for quality (appearance, odor, acidity), filtered to remove impurities and debris, and then quickly transferred to refrigerated tanks.

The goal is to process the milk within 2 hours of milking, in order to limit microbial growth.

Specific equipment ensures pumping, hygienic transfer, and cleaning in place of the systems to avoid cross-contamination.

2.2. Milk Storage

The milk is stored in metal tanks or refrigerated tanks, at a stable temperature, ideally around 4°C, in order to slow down the development of bacteria.

These tanks are hygienically designed for easy and effective cleaning (alkaline (proteins and fats)/acidic (mineral deposits).

The storage time is limited, often less than 24 hours, the time it takes to check and prepare the milk for the next phase, such as pasteurization or skimming.

Maintaining a low temperature throughout storage is essential to preserve the organoleptic, functional and nutritional qualities of milk.

2.3. The clarification

Separation and clarification can be done at the same time in one centrifuge (Figure 7). Particles, which are denser than the continuous milk phase, are thrown back to the perimeter. The solids that collect in the centrifuge consist of dirt, epithelial cells, leukocytes, corpuscles, bacteria sediment and sludge. The amount of solids that collect will vary, however, it must be removed from the centrifuge.

More modern centrifuges are self-cleaning allowing a continuous separation/clarification process. This type of centrifuge consists of a specially constructed bowl with peripheral discharge slots. These slots are kept closed under pressure. With a momentary release of pressure, for about 0.15 s, the contents of sediment space are evacuated. This can mean anywhere from 8 to 25 L are ejected at intervals of 60 min. For one dairy, self-cleaning translated to a loss of 50 L/hr of milk.

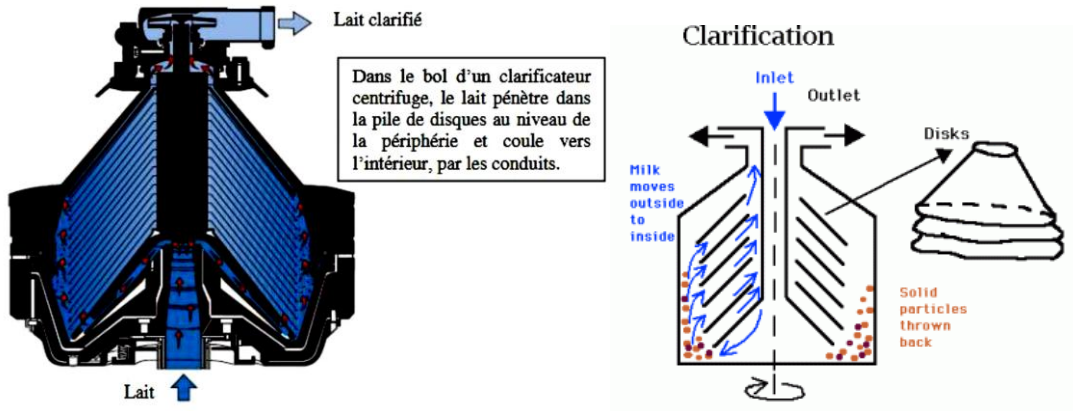


Figure 7: Diagram of Clarification and Separation

2.4. Thermisation

In some large dairies, milk cannot be pasteurized and processed upon receipt. Some of the milk must be stored in vats for several hours or days. Under these conditions, intense refrigeration does not prevent serious deterioration in quality. Many dairies preheat milk to a lower temperature than pasteurization to stop the growth of pathogenic bacteria. This process is called thermization. The milk is heated to 63-65°C for 15 seconds.

2.5. Skimming

The main purpose of milk skimming is to separate the cream (fat) from the whole milk in order to adjust or reduce the fat content in the milk according to production needs (skimmed milk, partly skimmed milk, cream, etc.).
A centrifugal separator is used to accelerate the separation of the two lipid and aqueous phases, by continuously discharging the cream on the one hand and the skimmed milk on the other (Figure 8).

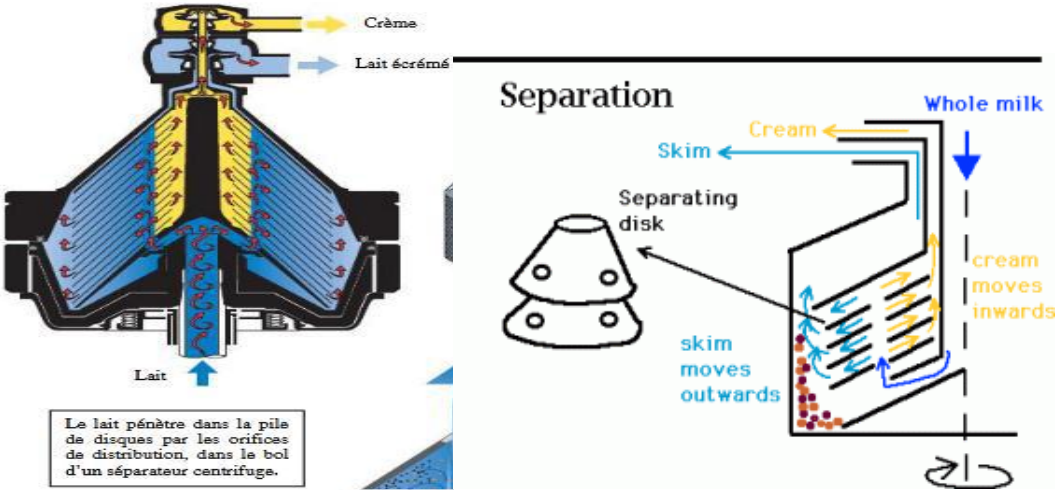


Figure 8: Diagram of skimming and separation

2.6. Standardization

Milk standardization is a physical process that involves adjusting the fat content of milk to achieve a precise and consistent composition that meets the specifications of the finished product (Figure 9). This step compensates for natural variations in milk composition related to factors such as the breed of cows, their diet, and the seasons.

It is carried out industrially using automated standardization units:

- Cream separator, to separate skimmed milk and cream
- Mass flow meters to accurately measure the flow of skim milk and cream
- Automated mixing and dosing units, which reinject a certain quantity of cream into the

skim milk to reach the desired fat content

- Inline regulation and control systems

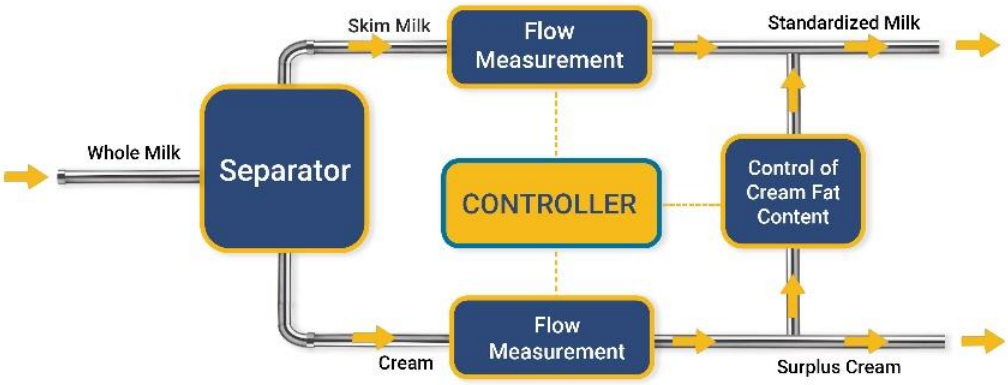


Figure 9: diagram of milk Standardization

Example of standardization (Figure 10)

The processing of 100 kg of whole milk at 4% fat: The objective is the production of an optimal quantity of milk standardized at 3% and cream containing 40% fat. The separation of 100 kg of whole milk fat. The amount of 40% cream that must be added to skimmed milk is 7.2 kg. This gives a total of 97.3 kg of 3% commercial milk, leaving 9.9 - 7.2 = 2.7 kg of surplus cream at 40%produces 90.1 kg of skimmed milk with 0.05% fat and 9.9 kg of cream with 40%.

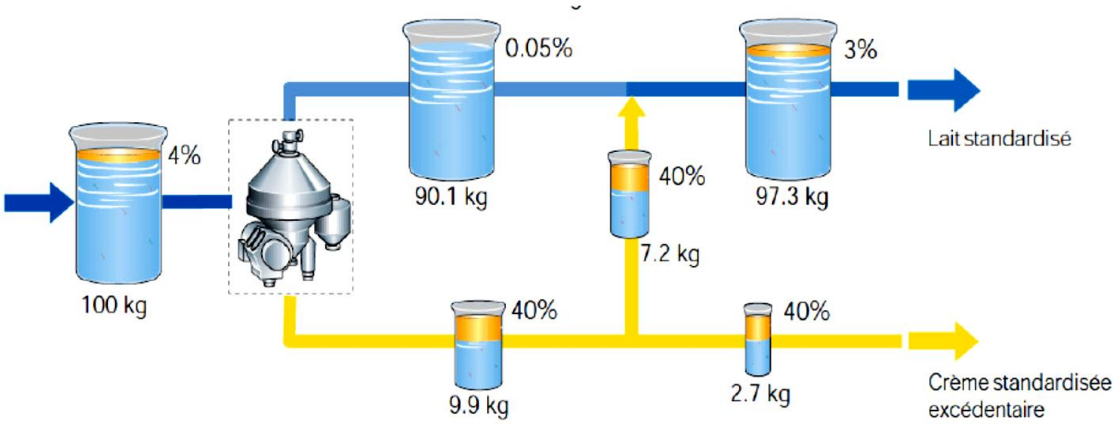


Figure 10: example of milk Standardization

2.7. Homogenization

Homogenization limits the rise of fat globules to the surface of milk by reducing their size to

about 0.5 to 1 µm using a two-stage homogenizer.

During the first stage, the high pressure causes the fat globules to break up. In the second stage, the lower pressure allows the lipid droplets to be finely dispersed in the protein phase.

This treatment makes the emulsion more stable in the milk. It also improves the texture and softens the flavor of the product for the same fat content.

Homogenization improves the texture of the milk, which becomes smoother, creamier, and softens its flavor. The color also becomes whiter due to the uniform diffusion of light by the small droplets.

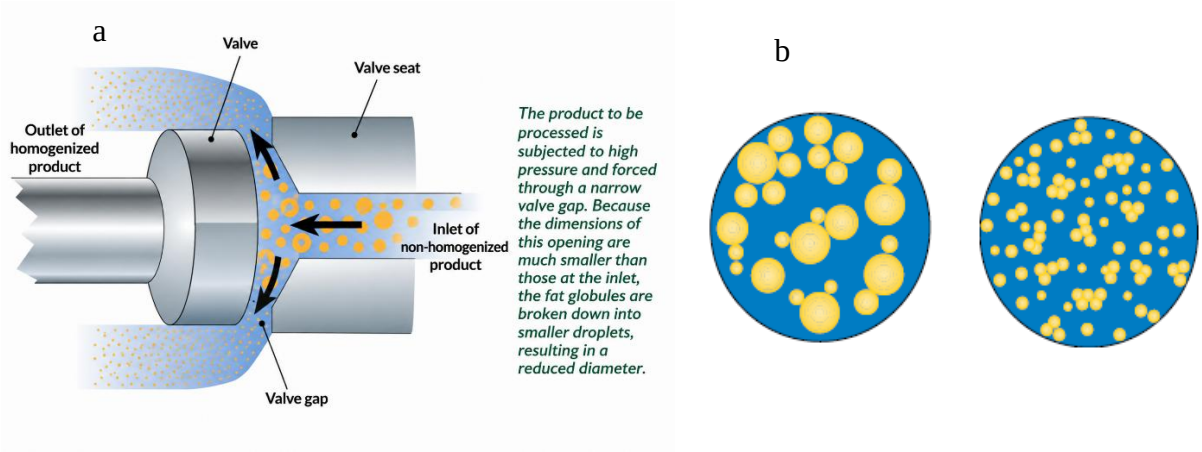


Figure 11: a. principle of homogenizer, b. Fat globules before and after homogenization

2.8. Heat treatment

Heat treatment of milk is an essential step in milk production. It involves heating milk to specific temperatures for a set amount of time to destroy pathogenic microorganisms, reduce the total bacterial load, and increase the shelf life of the product. This method aims to ensure safety while limiting the loss of the nutritional and organoleptic qualities of milk.

2.8.1. Pasteurization

Pasteurization is a moderate heat treatment that, while preserving the quality of the milk, aims to destroy bacteria in their vegetative form. The spores that are thermoresistant are not affected, and this is particularly the case for *Bacillus subtilis* and others. Pasteurization destroys 98 to 99.99% of the germs present, including pathogenic bacteria, the most feared of which are *Bacillus* of Koch (tuberculosis), *Bacillus abortus* (brucellosis), *Salmonella*, etc.

Unlike sterilization, which aims at the complete elimination of microorganisms and requires much more severe thermal treatment conditions (temperature x duration), pasteurization practically does not affect the quality of the milk. Pasteurized milk under normal (standard) conditions retains its taste quality and appearance, its nutritional value, digestibility, and the technological properties it had initially. In other words, pasteurization refrains from destroying the spores in order to preserve the essential organoleptic qualities of raw milk, avoid the "cooked" taste, and prevent the loss of cream separation ability. The serum proteins of pasteurized milk are not denatured.

Pasteurized milks keep better than raw milks; they can be stored for 2 to 3 days depending on the ambient temperature. The preservation of sterilized milk lasts several weeks, especially at low temperatures (4 - 5°C). One can observe that the same pasteurization effect can be achieved at different temperatures: the higher the treatment temperature, the shorter the duration of exposure (holding time) at that temperature. Thus, the effect obtained at 71°C and 0.25 minutes (or 15 seconds) is the same as at 62°C and 20 minutes (Figure 12).

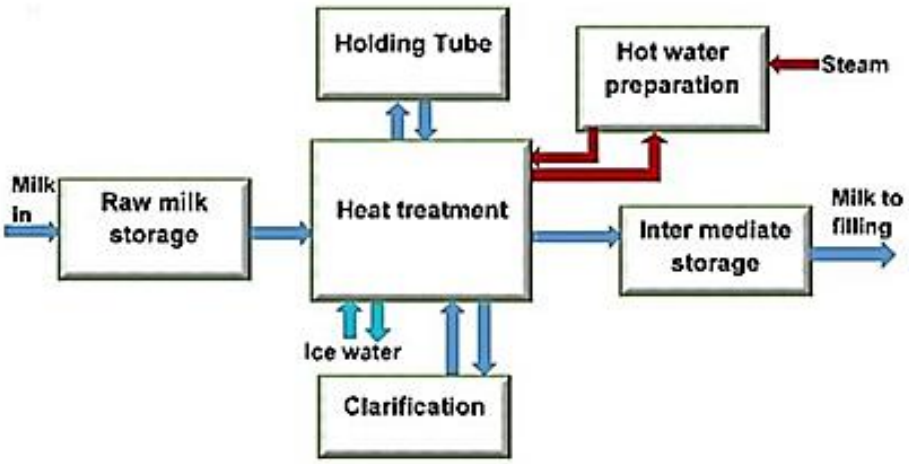


Figure 12: generalized flow chart of milk pasteurization

2.8.1.1.Methods of pasteurization

There are four different methods of pasteurization as given below, the first and second being more common in literature than the third and fourth, which sometimes are not even referred

as pasteurization

1) Low Temperature Long Time (LTLT) Pasteurization

LTLT pasteurization, also called batch pasteurization or vat pasteurization, involves heating milk to at least 62.8°C for 30 minutes. It was the first time-temperature treatment developed to destroy pathogenic microorganisms. Today, it is mainly used by small-scale processors and sometimes in cheese making because it is simple and inexpensive.

2) Continuous (HTST) Pasteurization

HTST pasteurization, or continuous pasteurization, is carried out in a plate heat exchanger. The milk is heated to at least 71.7°C for 15 seconds. It is the most widely used method in the dairy industry because it is fast, efficient, and economical in energy use thanks to regenerative heating and cooling.

3) Flash Pasteurization

Flash pasteurization heats milk to 85–90°C for 1 to 4 seconds. It is a more severe treatment than HTST and is usually done by direct steam injection or infusion. This method is mainly used for cream, especially in butter making, rather than for liquid milk.

4) Ultra-High Temperature (UHT) Pasteurization

UHT pasteurization heats milk to at least 135°C for 1 second, followed by aseptic packaging. It destroys almost all microorganisms, including spore-forming organisms, allowing the product to be stored for 3 to 6 months without refrigeration. Although it is a very severe heat treatment, it is different from sterilization and causes less nutritional damage than sterilized milk.

2.8.1.2. Equipment Types for Pasteurization

1) Batch method

The batch method uses a vat pasteurizer which consists of a jacketed vat surrounded by either circulating water with added steam or heating coils of hot water or direct steam (Figure 13). In the vat the milk is heated and held throughout the holding period while being agitated. The milk may be cooled in the vat or removed hot after the holding time is completed for every particle. As a modification, the milk may be partially heated in tubular or plate heater before entering the vat. This method has very little use for milk but some use for milk by-products and special batches. The vat pasteurizer is used extensively in the ice cream industry as it

allows for dissolution and blending of ingredients during the heating stage.

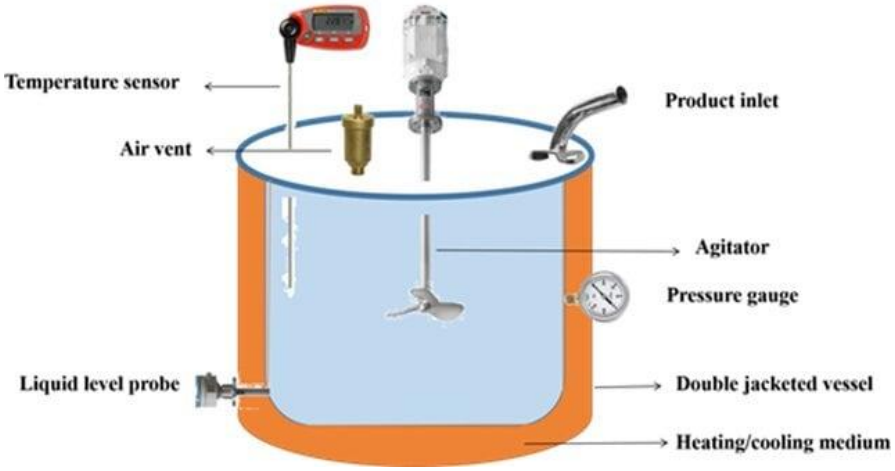


Figure 13: Batch pasteurizer used for liquid food products such milk.

2) Continuous Method

Continuous process method has several advantages over the vat method, the most important being time and energy saving. For most continuous processing, a high temperature short time (HTST) pasteurizer is used. The heat treatment is accomplished using a plate heat exchanger (Figure 14). This piece of equipment consists of a stack of corrugated stainless-steel plates clamped together in a frame. There are several flow patterns that can be used. Gaskets are used to define the boundaries of the channels and to prevent leakage. The heating medium can be vacuum steam or hot water.

2.8.2. Sterilization

Sterilization is a thermal treatment aimed at achieving commercial sterility: the destruction of all viable microorganisms, including the most heat-resistant bacterial spores such as *Bacillus cereus, Clostridium perfringens, and Bacillus stearothermophilus*. Unlike pasteurization, sterilization gives milk a shelf life of several months at room temperature, without the need for a cold chain. This commercial sterility is characterized by the sterilization value F_0, which represents the equivalent time (in minutes) at 121.1 °C necessary to achieve the desired destruction of the most heat-resistant spores. Two sterilization processes are distinguished: container sterilization (classic sterilized milk) and UHT treatment with aseptic packaging (UHT milk).

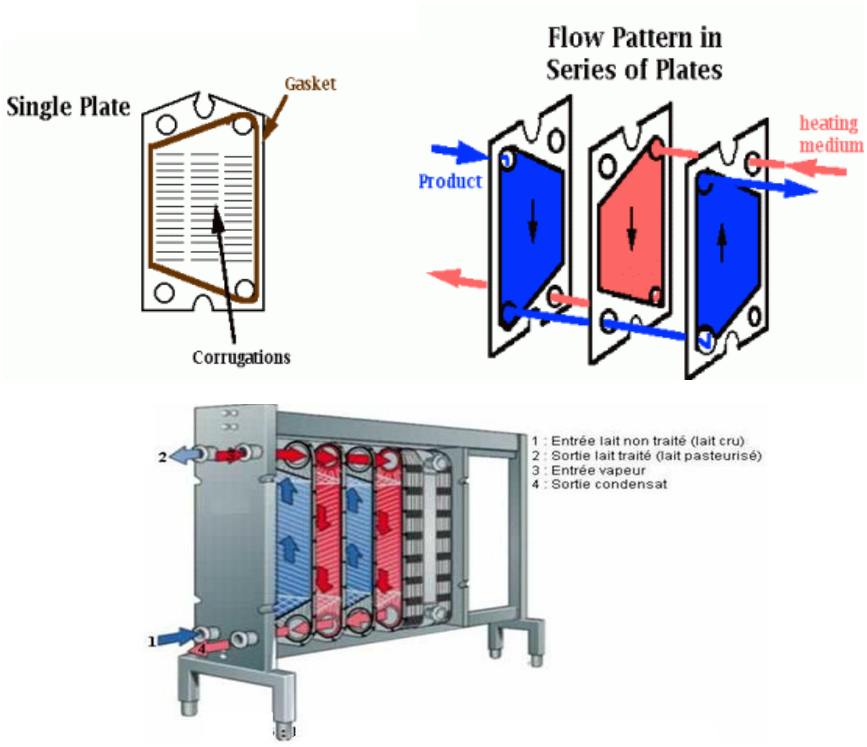


Figure 14: principle of operation of a plate heat exchanger pasteurizer

A. Sterilized milk

Container sterilization, sometimes called bottle sterilization or retort sterilization, is the historical method of long-term preservation of milk at room temperature. It involves filling and hermetically sealing the containers (glass bottles, metal cans, Tetra Pak pouches filled before sterilization), and then subjecting them to a thermal treatment in an autoclave at temperatures of 110 to 121 °C for 15 to 40 minutes. This sequence heating, holding, cooling is carried out on the already packaged product, which guaranties the sterility of the packaging-product system, but imposes very severe thermal conditions.

Sterilized milk in containers can be stored for 6 months to over 2 years at room temperature, depending on the quality of the treatment and the type of packaging. The containers used are mainly sterilizable glass bottles, metal cans, and, more recently, pouches or cartons filled with hot liquid before treatment. The slightly caramelized color of the product, its characteristic cooked taste, and its more viscous texture generally allow for distinguishing sterilized milk from UHT milk.

B. UHT (Ultra High Temperature) Milk

The UHT (Ultra High Temperature) treatment is a continuous flow sterilization process that involves heating the milk to temperatures between 135 and 150 °C for 1 to 10 seconds, and then immediately packaging it in pre-sterilized containers under strict aseptic conditions. This process combines two key principles that fundamentally distinguish it from container sterilization. First, it relies on the difference in Q_{10} values between bacterial destruction and chemical degradation reactions: spore destruction has a $Q_{10} \approx 10$, while chemical reactions (browning, vitamin degradation) have a $Q_{10} \approx 3$. Thus, by increasing the temperature and reducing the time, the same bactericidal effect can be achieved with considerably lesser chemical damage. Secondly, the need to inactivate thermophilic spores (notably *Bacillus cereus*) determines the minimum treatment conditions, while the minimization of chemical changes (undesirable flavors, color, vitamin losses) determines the maximum conditions. There are two main types of UHT systems: direct and indirect (Figure 15).

- **Indirect heating (Indirect Steam Heating**)

Milk is heated through a plate or tubular heat exchanger without direct contact with the product. This approach is cheaper and improves thermal regeneration energy recovery. A slower heating time-temperature profile (gradual temperature rise) causes more thermal damage, including serum protein denaturation, lactulose and furosine synthesis, and cooked flavor development. Indirect steam heating (ISH) results in 79-100% β-lactoglobulin denaturation and 168 mg/100 g furosine levels in UHT milk, compared to 44 mg/100 g in direct processing.

- **Direct Steam Heating (DSH)**

Milk is directly injected or infused with steam. This process raises the temperature in a few tenths of a second, then cools with vacuum flash evaporation to remove condensed steam and rectify product dilution. Rapid heating-cooling reduces thermal damage, resulting in decreased serum protein denaturation (35-80% for β-Lg in DSH vs. 79-100% in ISH), reduced lactulose and furosine production, and reduced cooked flavor. Steam injection can achieve high temperatures (151-156 °C) in <0.2 s, producing milk with thermal damage indicators similar to pasteurized milk. However, the direct process is more expensive and requires a composition change due to flash evaporation.

2.9. Cooling.

Cooling milk after heat treatment is a crucial step in dairy processing because it rapidly lowers the product temperature and therefore inhibits microbial growth, preserves quality, and extends shelf life. In practice, cooling should begin immediately after pasteurization or any other heat treatment, since delayed cooling can allow surviving microorganisms to multiply and may lead to physicochemical and microbiological deterioration of the milk.

The goal is to bring milk as quickly as possible to about 4°C or below, because microbial growth is strongly reduced at this temperature. According to FAO sources, bacterial proliferation slows markedly as the temperature drops below 10°C and is practically stopped around 4°C for many organisms, although the final result still depends on the initial microbial load and the types of bacteria present. For this reason, rapid cooling is effective only when the milk is already hygienically collected and handled properly.

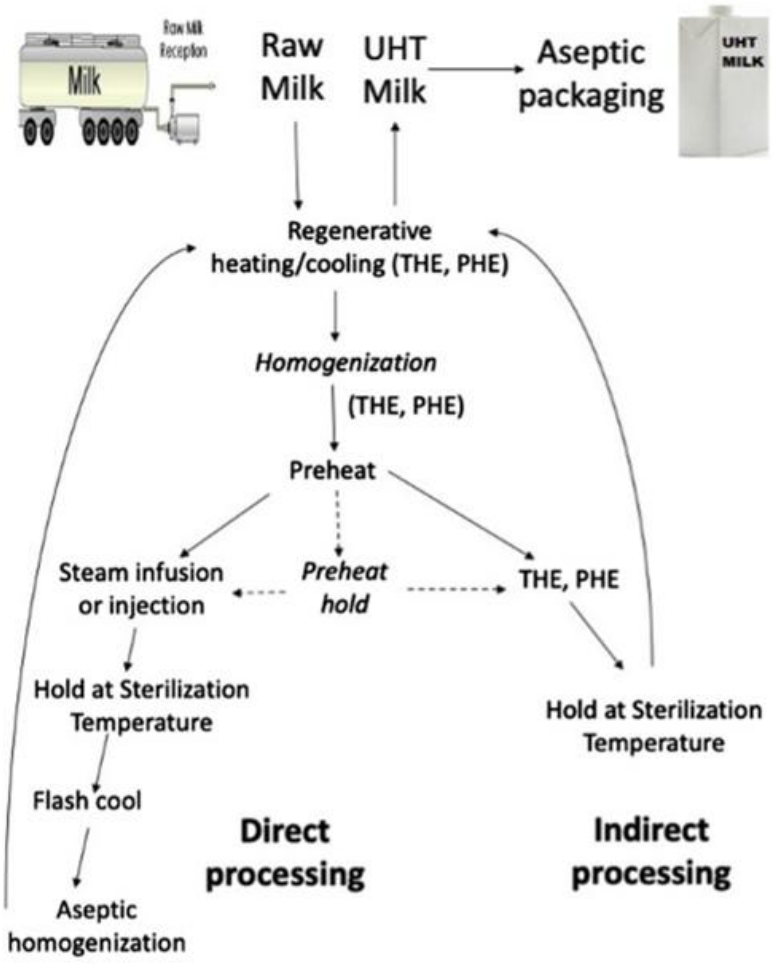


Figure 15: Direct and indirect UHT processing of milk

2.10. Packaging.

There are two main types of packaging systems for fluid milk: the traditional bottling system, in which the container is returned, and the one-way delivery system, in which the container is disposable and does not return to the dairy. In non-returnable distribution systems, several alternative packaging materials, shapes, sizes, and machines are used. The choice of a suitable packaging material depends on the characteristics of milk and milk products, which are highly perishable and sensitive.

Milk packaging materials must help preserve the initial quality of pasteurized milk for as long as possible. Suitable packages should:

- Be free from off-flavors.
- Not impart any taste or flavor to the product.
- Act as a barrier against bacterial contamination.
- Be resistant to UV light.
- Have no physiological effects on the product.
- Possess good mechanical properties such as sealing strength, tensile strength, and structural strength.
- Be tamper-proof.
- Provide good oxygen barrier properties.
- Be economical.
- Be suitable for in-line processing.

The main materials used for milk packaging are:

- Glass.
- Plastics, especially LDPE and LLDPE.
- Other materials such as coated paperboard, wax-coated paperboard, and ESL pouches.

The table 2 groups the different packaging used for milk.

Table 2: milk packaging type

Type of packaging	Main characteristics	Advantages	Disadvantages / limitations
Glass bottles	Transparent, rigid, hygienic, non-toxic, compatible with milk storage	Good product visibility, good hygienic quality	Heavy, fragile, requires much storage space, high cost for washing, sterilization, return, and transport
Returnable plastic bottles	Similar to glass bottles, but lighter and less breakable	Lighter than glass, less fragile	Need collection, cleaning, and reuse; similar logistics to glass bottles
Non-returnable plastic bottles	Lightweight, one-way use; often HDPE bottles with PP lids	Practical, reduces transport costs, simplifies distribution	Disposable system, less reusable
Plastic films	LDPE or co-extruded LDPE-LLDPE pouches, formed and filled by form-fill-seal machines	Hygienic, safe, economical, no need for washing before use, recyclable	Can have pinhole problems if not well designed
Aseptic packaging of milk	UHT milk packed under sterile conditions; includes aluminium foil in the laminate	Long shelf life, protects against light and gases, can be stored 3–6 months without refrigeration	More complex technology, higher processing requirements
Paperboard cartons	Multilayer structure: printed paper, polyethylene, aluminium foil, inner sealing layers	Strong, good barrier properties, suitable for milk and other liquid foods	More complex structure than simple plastic packs

3. Butter Making techniques

3.1. Definition

A butter is a water-in-oil emulsion, comprised of >80% milkfat, but also containing water in the form of tiny droplets, perhaps some milk solids-not-fat, with or without salt (sweet butter); texture is a result of working/kneading during processing at appropriate temperatures, to establish fat crystalline network that results in desired smoothness (compare butter with melted and recrystallized butter); used as a spread, a cooking fat, or a baking ingredient.

The principal constituents of a normal salted butter are fat (80 – 82%), water (15.6 – 17.6%), salt (about 1.2%) as well as protein, calcium and phosphorous (about 1.2%). Butter also contains fat-soluble vitamins A, D and E.

Butter should have a uniform color, be dense and taste clean. The water content should be dispersed in fine droplets so that the butter looks dry. The consistency should be smooth so that the butter is easy to spread and melts readily on the tongue.

Milk, which is initially a complex emulsion, is industrially fractionated to produce cream and butter via physical separation (centrifugation) and structural transformation of the fat (churning) (figure 16).

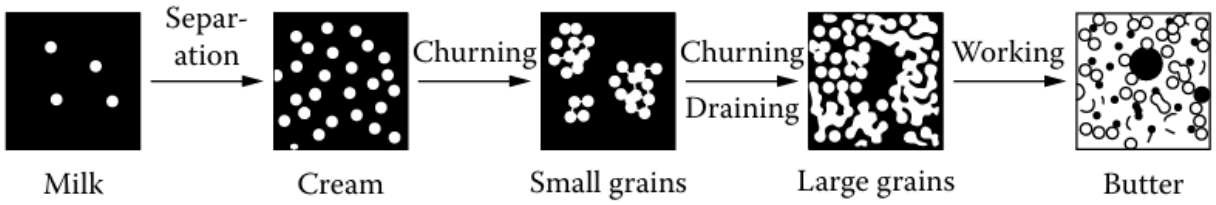


Figure 16: Stages in the formation of butter.

3.2. Structure of butter

Butter is a complex dairy fat system in which the fat appears in two main forms: globular fat and free fat (Figure 17). A part of the fat is present as small fat globules, while another part is dispersed as free fat within the continuous phase. In addition, butter contains both crystallized fat and a smaller proportion of liquid fat, which gives it its characteristic semi-solid consistency.

The average diameter of the fat globules in butter is about 3.5 to 4.0 µm. These small globules contribute to the fine structure of butter and influence its smoothness, spread ability, and overall mouthfeel. Their distribution, together with the state of fat crystallization, plays an important role in the physical properties of the product.

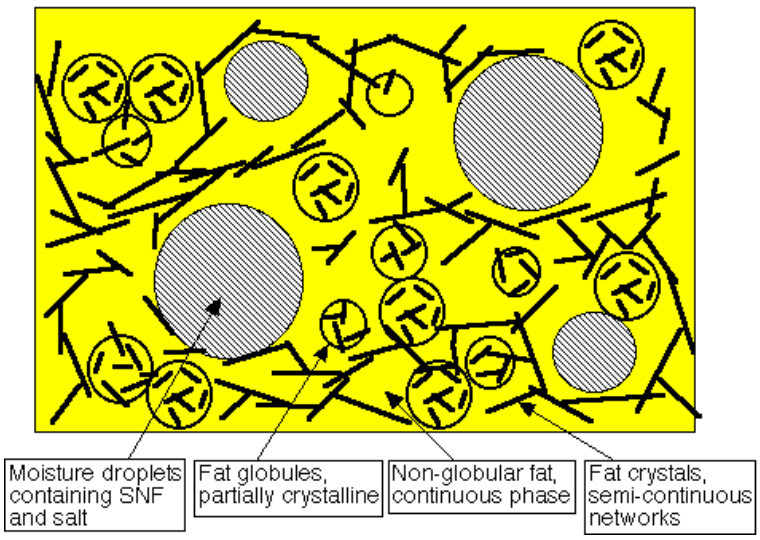


Figure 17: Butter structure

3.3. Classification

Butter can be classified on the basis of type of cream, manufacturing process and ripening process etc. as listed below:

Table 3: The different type of butter

Title	Definition	Key point
Sweet cream butter	Made from non-acidified cream with a pH of 6.4 or acidity lower than 0.20% L.A.	Mild flavour
Sour cream butter	Made from cream acidified by bacterial fermentation with a pH below 5.1 or acidity above 0.20% L.A.	Acid flavour
Mildly acidified butter	Made from partially acidified cream with a pH between 5.2 and 6.3.	Intermediate acidity
Pasteurized cream butter	Made usually from pasteurized sweet cream.	Milder flavour
Ripened cream butter	Made from cream ripened with butter culture before churning.	Develops “real butter flavour”
Un-ripened cream butter	Made from fresh cream without ripening.	Mild flavour
Salted butter	Contains up to 3% salt after buttermilk drainage.	Better taste and preservation
Unsalted butter	Contains no added salt.	Also called sweet butter or cooking butter
Fresh butter	Butter that has not been stored in cold storage.	Usually kept less than 3 weeks
Cold storage butter	Butter stored at about –18°C for some time.	Usually 1 to 6 months old
Dairy butter (USA)	Usually made from unpasteurized sour cream.	Sour flavour
Creamery butter	Made in a creamery or dairy factory.	More uniform quality

3.4. Butter Making

There are two completely different methods for manufacturing butter: the churning method and the emulsification method.

3.4.1. Batch Churning Method

The batch churning method is the traditional approach for butter manufacture. The basic principle is that air is mixed into cream where it forms foam, disrupting fat globule membranes and causing liquid fat to be squeezed out and spread at the foam interface.

a) Churn Preparation and Cleaning

After cleaning and disinfecting the churn, it must be specially prepared to prevent butter from sticking to the surface. With wooden churns, this is achieved by scalding with boiling water and immediately cooling with chilled water, which leaves a film of water on the wood surface. All wooden equipment must be kept wet until used. Batch butter churns may be barrel or cone shaped with fixed or rotating internal "workers," with capacities ranging from a few liters to

a maximum of about 45,000 liters, originally made of wood but later replaced with stainless steel.

b) Pretreatment of Cream Prior to Churning

The cream must be concentrated in a centrifugal separator to a fat content of about 35–42 g/100 g or higher. The cream is heated to 85–110°C for 10–30 seconds in a plate heat exchanger to kill pathogens and reduce spoilage-type microorganisms. It may be possible to combine HTST treatment with vacuum deodorization (vacreation). The cream is cooled immediately after heat treatment to 4–5°C, kept overnight, and then churned to permit adequate crystallization (at least 50% of milk fat should be crystalline).

c) Churning Process

The churn is rotated, and the combined actions of rotating and beating cause the cream to break, forming butter grains (fatty phase) and buttermilk (aqueous phase). During the first few turns, gases (e.g., carbon dioxide from heterofermentative fermentation) are liberated from the cream and must be released by depressing a small valve in the lid. Each churn has an indicator glass to observe the process inside. Churning takes about 15–20 minutes from the beginning. The cream breaks and forms small grains of butter clearly visible on the indicator glass. For hand churning, grains should be kept small, approximately 3 mm in diameter (size of wheat grains).

d) Washing and Grain Control

Chilled water at approximately 5°C is used to harden and control the size of butter grains, as well as to remove traces of buttermilk. Washing reduces yield and is not necessary if cream is of good quality and hygienic precautions have been observed. Well-washed butter traditionally has a longer shelf life than unwashed and overworked butter. Salt may be added dry or in the form of brine (10% solution) as a final wash to reduce the need for chilled water and prevent streakiness due to uneven salt mixing.

e) Working the Butter

The butter grains are "worked" to expel excess moisture, create an even, fine distribution of water droplets, and produce a close-textured, evenly colored product. During working, drainage, and addition of dry salt, samples are tested to determine salt and moisture contents. The operator determines the "end-point" of working when moisture content is between 15.5% and 16% and by visual assessment. The moisture content of butter must not exceed the legal

maximum limit of 16%. Manufacturers attempt to be as near that limit as possible to ensure maximum yield. At this stage, butter is removed from the churn in readiness for packing.

3.4.2. Continuous Butter-Making Method

Continuous butter making was commercialized by the mid-20th century and has largely replaced batch churning in industrial production due to its superior throughput, improved hygiene (closed systems), more precise composition control (moisture deviation $\leq \pm 0.1\%$), and reduced labor and floor space requirements. Three distinct engineering principles are employed, differing in the fat content of the cream feed and the mechanism by which phase inversion is achieved.

3.4.2.1. Principle "by flotation or agglomeration"

The principle "by flotation or agglomeration" is that of batch butter production, but applied in an accelerated manner. Under the effect of the agitation of the cream and the formation of fine foam by paddles rotating at high speed (2000 revolutions per minute), an agglomeration of fat globules into butter grains forms very quickly, in less than three seconds, which are then transported to a kneading section, with buttermilk being continuously expelled. The treated cream has a normal concentration of 40 to 50% fat.

3.4.2.2. Principle "by concentration"

The "by concentration" principle involves a prior concentration of the cream, obtained through centrifugal skimming, to a fat content close to that of butter. The concentrated cream being unstable due to the proximity of fat globules and their deformation, the phase inversion occurs through cooling at the entrance of the butter churn and through the mechanical friction of the propulsion screws or agitators. The production is completed by continuous churning and kneading.

The Swedish-origin Alfa processes and the Australian-origin New-Way process operate according to this principle.

3.4.2.3. Method "by emulsion or combination"

The "emulsion or combination" method includes three main operations: destabilization of a cream very rich in fats (85 to 99%), standardization of the composition by incorporating water or an aqueous salt solution into the fats in oil state, and cooling to solidify the butter. This is the principle underlying the Cherry-Burrell, Creamery Package, and Kraft processes.

3.5. Packaging

Butter is packed to protect it from chemical, microbiological, and mechanical damage. Large packs are used for wholesale and long-term storage, while small packs are used for retail sale. The best packaging materials are those that protect butter from light, oxidation, foreign odors, moisture loss, and color changes. Automatic machines are used for wrapping and shaping butter, and packaging should be done quickly after production under hygienic conditions.

3.6. Storage

Butter must be cooled immediately after packaging because cooling improves its texture and stability. Slow cooling keeps butter too soft, while rapid refrigeration helps it crystallize properly. Butter for short-term use is usually stored at 4°C for about 48 hours, whereas butter for long-term storage is frozen at between -18°C and -25°C. A cold chain is necessary during transport and distribution.

4. Cheese Techniques

4.1. Definition

According to the Food Safety and Standard Regulations (2011), cheese is a ripened or unripened product that may be soft, semi-hard, hard, or extra-hard, and it is obtained by coagulating milk or milk-derived products using suitable coagulating agents, followed by partial removal of whey. The final product may also contain starter cultures, harmless microorganisms, enzymes, and sodium chloride. Cheese may be presented in different forms, such as blocks, slices, shredded, or grated.

During the transformation of milk into cheese, the main components are not equally retained. Casein and fat are concentrated in the curd, whereas most of the water and other soluble components are removed with the whey. As a result, cheese becomes a more concentrated product than milk, and salt may also be added during processing to improve flavor and preservation. Figure 18 clearly shows this redistribution of milk constituents from milk to cheese.

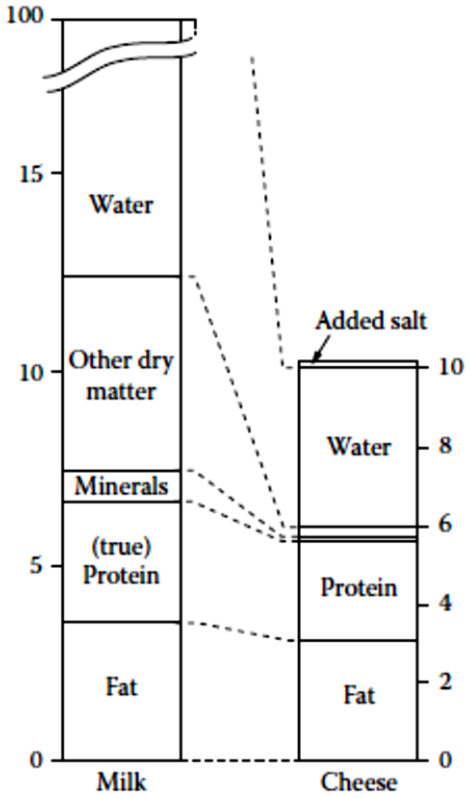


Figure 18: Example of the gross composition of milk and cheese and of the transfer of components from milk to cheese.

4.2. Cheese production

4.2.1. Selection of Milk

Milk selection is a critical step in cheesemaking, as its composition has a direct impact on cheese yield, texture, and overall quality. In particular, the levels of fat, protein, calcium, and pH play a decisive role in determining the final characteristics of the product. Milk quality may vary according to the animal species, breed, nutritional status, health condition, and stage of lactation; therefore, milk obtained from cows in early or late lactation, as well as from animals affected by mastitis, should be excluded. The somatic cell count is also an important quality parameter, since it reflects the sanitary condition of the milk. Moreover, certain genetic polymorphisms of milk proteins may influence cheese yield and technological performance, which has increased interest in genetic selection for cheesemaking purposes. Milk must also be free from chemical contaminants, such as antibiotic residues and free fatty acids, which may negatively affect flavor. Moreover, microbiological quality is essential, because undesirable microorganisms may become concentrated in the curd during processing, resulting in defects in quality and potential health hazards.

4.2.2. Pre-treatment of milk for cheese production

The pre-treatment of milk is a crucial step in cheese production, as it aims to ensure sanitary safety, standardize milk composition, and optimize coagulation and cheese quality. Depending on the type of cheese and the desired technological outcome, several treatment methods may be applied before manufacture. These include pasteurization, standardization, maturation, and, in some cases, more advanced processes such as homogenization, membrane separation, ultrafiltration, microfiltration (figure 19), high-pressure treatment, carbon dioxide treatment, or the addition of specific enzymes and protein concentrates. Reception and filtration are the first steps, during which raw milk is quality-controlled and solid impurities are removed. Pasteurization by the HTST method, typically at 72°C for 15 seconds, is used to eliminate pathogens and is mandatory for fresh cheeses, while it may be optional for aged cheeses ripened for more than 60 days. Standardization follows, involving adjustment of fat and protein content according to the cheese variety, such as whole milk for soft cheeses or partially skimmed milk for Gruyère. Maturation is then carried out by adding lactic ferments, usually for about 45 minutes at 30°C, to acidify the milk and prepare it for coagulation.

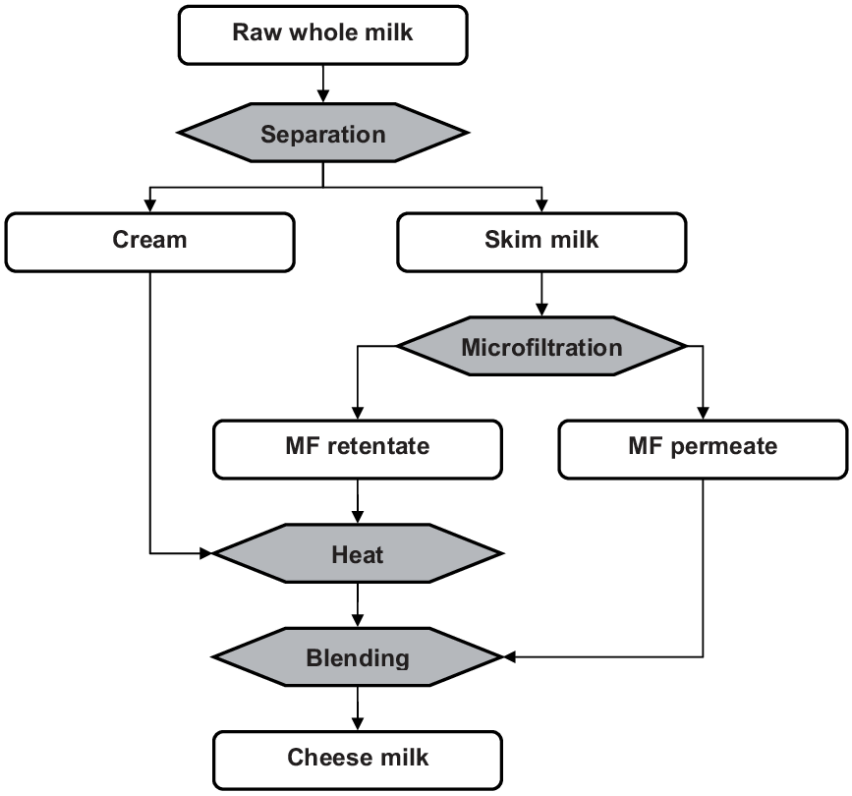


Figure 19: Pre-treatment of milk using microfiltration for cheese production

4.2.3 Curdling or coagulation

Two methods are used to curdle milk in cheesemaking: acidification and the addition of rennet, resulting in two types of curd, namely acid curd and rennet curd (figure 20). The properties and behavior of each of them differ significantly, so much so that their differences are the basis of the technology and characteristics of the various types of cheese.

4.2.3.1. Coagulation by Acidification

Coagulation by acidification occurs when the milk proteins, especially casein, lose their electrical charge as the pH decreases until the isoelectric point is reached, around pH 4.6. As the acidity increases, the casein micelles become unstable, begin to aggregate, and finally form a gel. At the same time, minerals such as calcium and phosphorus become more soluble and move into the aqueous phase, which produces a curd that is partially demineralized and allows whey to drain easily. This type of curd is porous, friable, and not very suitable for mechanical handling, which is why it is mainly used for fresh cheeses such as cottage cheese. In some cases, acid is added directly to milk and then heated, but this produces a more flocculent precipitate rather than a homogeneous curd.

4.2.3.2. Rennet Coagulation

Rennet coagulation is the most widely used method in cheesemaking. It consists of adding an enzyme, called rennet, that destabilizes the casein complex and transforms soluble calcium phosphocaseinate into insoluble calcium paracaseinate. Unlike acid curd, rennet curd is not demineralized; calcium and phosphorus remain part of the gel structure. As a result, the curd is compact, elastic, cohesive, and able to withstand mechanical treatment during drainage and processing. Original rennet was obtained from the stomach of young calves and contains mainly chymosin, with pepsin as a secondary enzyme. Today, animal, microbial, and fermentation-produced rennets are also used. Rennet has both a primary role, by causing milk coagulation through specific cleavage of κ-casein, and a secondary role, by slowly contributing to cheese ripening and flavor development.

4.2.3.3. Mixed Coagulation

In most cheeses, coagulation results from the combined action of rennet and acidification. The relative importance of each factor can vary depending on the cheese type. This mixed coagulation produces curds with intermediate properties, less distinctive than pure acid curds or pure rennet curds, but very useful for a wide variety of cheeses. It is one of the main reasons for the great diversity found in cheesemaking.

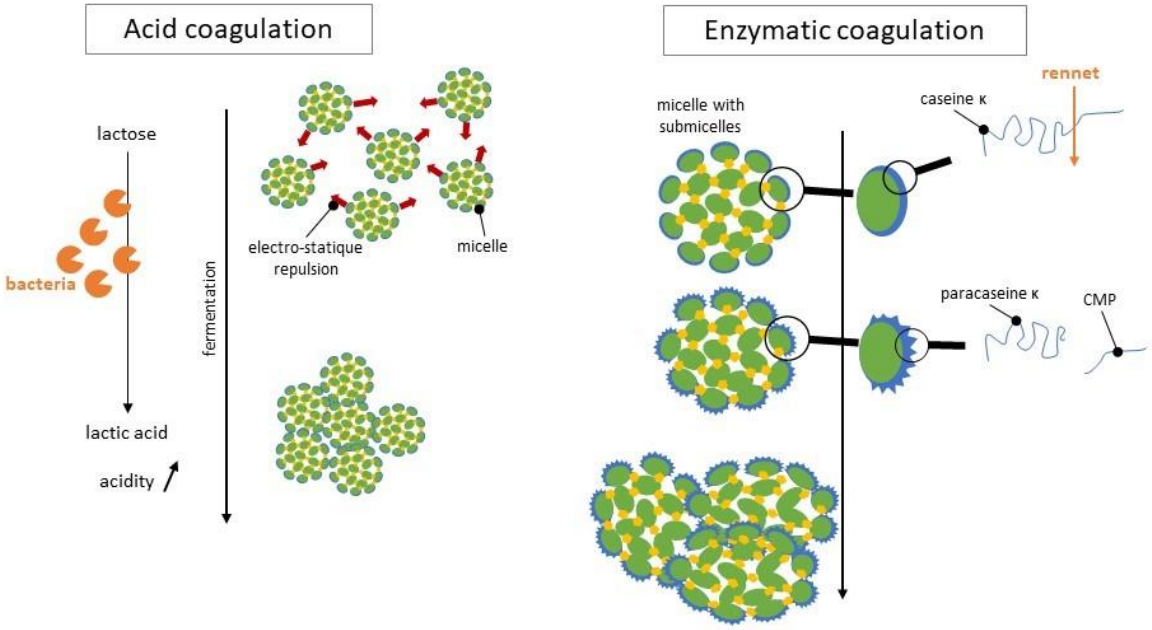


Figure 20: Acidic and rennet coagulation

Depending on the coagulation mode, coagulums are usually classified into 3 types leading to 3 main categories of cheeses:

- Coagulum with dominant lactic character: Fresh paste type: white sheese, P. Swiss….
- Coagulum with predominant rennet: Pressed paste type: Saint-Paulin, Edam, Cantal, Cheddar, Gruyére), …..
- Coagulum with mixed character: Soft type: Camembert, Brie, Blue, ...

4.2.4. Draining

Draining is a physical separation between solid and liquid. Depending on the nature of the coagulum, the dispersing phase spontaneously separates from the whey.

Draining is the result of 2 different physical phenomena:

- **Active Phenomenon**: Contraction of the gel that actively expels whey, characteristic of rennet coagulums. (During enzymatic coagulation (rennet), the milk proteins (caseins) clump together tightly, which reduces the space between them and expels much of the water (whey) trapped in the gel.

- **Passive Phenomenon**: Natural flow of whey through a more porous gel, typical of lactic coagulums (the gel formed is more fragile and porous, allowing the whey to flow spontaneously without much contraction).

4.2.5. Salting

Salting is the last manufacturing operation. Salting promotes syneresis but it is not a satisfactory method for controlling the moisture content of cheese curd which is best achieved by ensuring that the degree of acidification, heating and stirring in the cheese vat are appropriate to the particular variety. Although salting should be a very simple operation, quite frequently it is not performed properly, with consequent adverse effects on cheese quality. A low level of Na is essential in the diet (the RDA in the USA and UK is 2.4 g) but an excessive intake is undesirable. Although cheese contributes relatively little NaCl, even with a high consumption of cheese (consumption of 20 kg of cheese, containing 2 % NaCl, per annum, which is at the upper level of consumption, contributes 400 g NaCl per annum, i.e., about 1.1 g NaCl or 0.7 g of sodium daily), there is a commercial incentive to reduce the level of salt in cheese

Salting cheese plays an essential role in several aspects of cheese making and ripening:

a. Completes the draining (Salting-out)

b. Contributes to the formation of the crust (protection during refining and contribute to organoleptic development)

c. Regulates the water activity of the cheese (inhibits the growth of microorganisms)

d. Enhances the flavor and influences the taste

4.2.5.1. Types of salting

1) Dry Salting

Dry salting, also called direct salting, is a method where salt crystals are applied directly to the cheese surface or curds. This technique involves sprinkling measured amounts of dry salt onto the cheese. For soft rind-type cheeses like Saint-Marcellin and Camembert, the salt is sprinkled directly onto the surface of the cheese, covering the whole rind including both sides, using fine salt. For hard rind-type cheeses, dry salt is rubbed onto the rind and can be scrubbed into the surface, using coarse granular salt rather than very fine salt to slow down the dissolving speed. For milling or direct curd salting used in Cheddar, Colby, and Monterey Jack cheeses, after the coagulated milk has been cut, cooked, and drained, salt is applied

directly to the cut-up curds at approximately 1.5-3% of the curd weight, then mixed uniformly with agitation before pressing. This method takes advantage of the large surface area exposed and allows for quick salt absorption and rapid whey/moisture expulsion.

2) Brine Salting

Brine salting is a salting technique where whole wheels or blocks of cheese are submerged in a salty brine solution, and this is the most common method used worldwide for the large majority of cheese varieties. The firm curd is removed from the mould and immersed in a salt solution strong enough to float the cheese, typically an 18% NaCl solution (fully saturated brine). The immersion time varies depending on the size of the cheese and its moisture content, as salt is taken up by the cheese from the brine while the cheese releases water into the brine, which results in a reduction in salt concentration in the brine. After brining, cheeses are removed from the brine bath and allowed to dry out, and once dried, sufficient salt has spread through the cheese. This method allows gradual penetration of salt throughout the cheese, aids in rind formation since the outermost layer dehydrates to some degree, and forms a dehydrated protein layer on the outer surface. Typical cheese varieties using brine salting include Mozzarella, Blue cheese, Feta, Parmesan wheels, Gouda wheels, Swiss, and Gruyere.

4.2.6. Curing

Cheese ripening is the term used to describe the process whereby changes occur in the cheese, resulting in the development of flavor, texture, and aroma in the matured product. Cheese ripening is initiated by the addition of a starter culture and coagulant to milk. The starter lactic acid bacteria convert lactose into lactic acid, reducing the pH at which biochemical reactions occur during cheese ripening. Enzymes released from the bacteria are also involved in the degradation of proteins into peptides and amino acids, and the breakdown of fatty acids released by lipolysis into keto acids, ketones, and esters. These breakdown products are important in the development of flavor, aroma, and texture. Special characteristics can also develop in cheese during ripening, for example, the blue veins in Roquefort, the holes (eyes) in Emmental, the red smear on Limburger, and the white mold on Brie. Temperature and humidity are carefully controlled to promote the development of the desirable microbial flora and the secretion of the enzymes responsible for the biochemical changes taking place during ripening. The ripening time varies from 4 weeks to 28 months depending upon the variety of cheese.

5. Ice cream manufacturing technique

5.1. Definition

Ice cream is a frozen dairy product obtained by blending and processing cream and other milk ingredients with sugar, flavorings, and, in some cases, stabilizers and colorants, while incorporating air during freezing. Its creamy texture results from the interaction of four main structural elements: a partially frozen foam, partially coalesced fat globules, ice crystals, and a continuous aqueous phase. The partially frozen foam contributes to the lightness and smoothness of the product, while the partially coalesced fat globules provide a rich and creamy mouthfeel. Ice crystals influence the texture and perceived sweetness, and the continuous aqueous phase, which contains sugars, proteins, and stabilizers, maintains moisture and binds the different components together.

Ice cream is therefore a partially frozen foam containing about 50% air by volume, although this value may vary depending on the product type. The air bubbles are stabilized by partially coalesced fat globules and the ice crystal network, all dispersed within the continuous aqueous phase (figure 21).

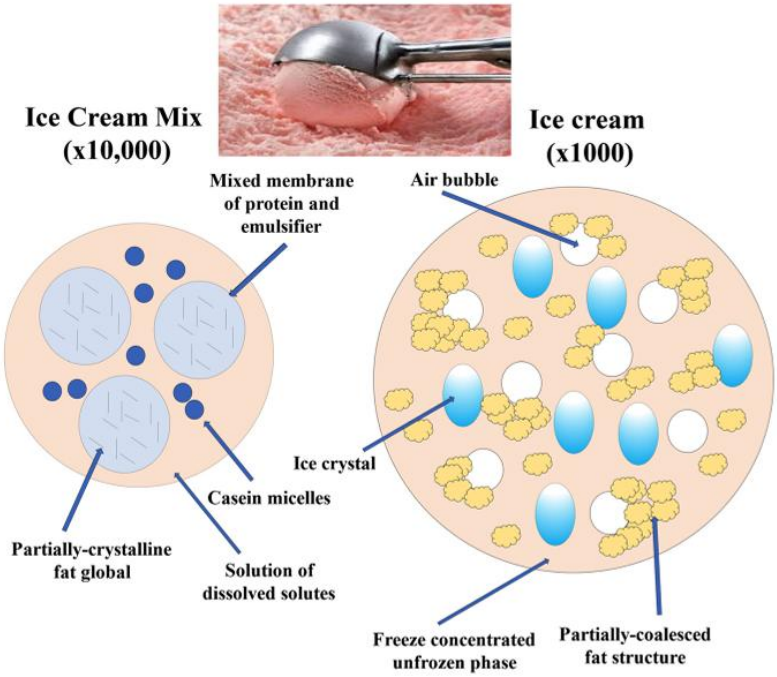


Figure 21: Highly schematic illustration of the structure of ice cream mix and ice cream

5.2. Composition

Composition of ice cream is decided after giving considerations to legal requirements, mix handling properties, quality of product desired, raw material available, plant procedures, trade demand, composition and cost. Ice cream varies rather widely in composition, making it difficult to provide a formula that will produce best ice cream. However, an approximate composition for economy, good average and deluxe ice cream is given in table.

Table 4: Approximate Composition of Commercial Ice Cream

Category	Milk fat (%)	MSNF (%)	Sugar (%)	Stabilizers & emulsifiers (%)	Total solids (%)
Economy ice cream	10	10–11	13–15	0.30–0.50	35–37
Good average ice cream	12–14	8–11	13–16	0.20–0.40	37–39
Deluxe ice cream	16–20	5–8	13–17	0.20–0.25	40–41

MSNF: Milk solids not fat

5.3. Ice cream manufacturing processes

The production of frozen dairy products is divided into two main essential phases: Preparation of the mixture and the processing of the mixture. The basic steps in the manufacturing of ice cream are generally, blending of the mix ingredients, pasteurization, homogenization, aging the mix, freezing, packaging and hardening (Figure22).

5.3.1. Preparation of ice cream mix

Ice cream mix is the unfrozen blend of dairy and non-dairy ingredients used to make ice cream. It usually contains milk products, sweeteners, stabilizers, emulsifiers, flavors, and coloring materials. A balanced mix is one in which all ingredients are proportioned correctly to give the finished ice cream good flavor, body, and texture.

5.3.2. Calculation of mix ingredients

The ingredients must be carefully calculated to produce a uniform product that meets legal standards. Correct weighing and blending are important because the composition of the mix directly affects the quality of the final ice cream.

5.3.3. Pasteurization of ice cream mix

All liquid ingredients are first placed in a stainless-steel tank and mixed with stirring. Dry ingredients such as sugar, skim-milk powder, and stabilizers are then added gradually. The mix is pasteurized to destroy pathogenic microorganisms, improve flavor, and help dissolve the ingredients completely. Common pasteurization conditions are 68.5°C for at least 30 minutes in batch processing or 80°C for at least 20 seconds in the HTST method.

5.3.4. Homogenization of mix

Homogenization is essential for making the fat evenly dispersed throughout the mix. It reduces fat globule size to about 2 microns or less, preventing cream separation and producing a smoother texture. It is usually done at temperatures above 60°C, and two-stage homogenization is generally preferred for better results.

5.3.5. Cooling and ageing of mix

After pasteurization and homogenization, the mix is cooled rapidly to 4°C or below. Cooling slows bacterial growth and prepares the mix for ageing. Ageing means holding the mix at low temperature for about 4 hours or longer, often overnight, so that fat crystals form, stabilizers hydrate, and viscosity increases. This step improves whipping ability, body, texture, and melting resistance.

5.3.6. Freezing of Mix

Freezing is one of the most important steps in ice cream manufacture because it determines the texture, palatability, and yield of the final product. During freezing, the mix is agitated while air is incorporated and small ice crystals are formed. Fast freezing is necessary to obtain a smooth texture, because small ice crystals give better quality than large ones. After partial freezing, the product is packaged and then hardened in cold storage.

5.3.7. Packaging

Packaging is an important final step in ice cream production because it protects the product from contamination, moisture loss, odors, light, and temperature fluctuations. It also helps maintain the texture and appearance of the ice cream during storage and distribution. Common packaging materials include plastic cups, cartons, pouches, and insulated containers, depending on the product type and market. Good packaging should be sealed tightly, food-safe, and suitable for low-temperature storage.

5.3.7. Hardening of Ice Cream

Hardening is the stage that follows freezing and is used to complete the freezing process and stabilize the product structure. When ice cream leaves the freezer, it is only partially frozen, with a large part of the water still unfrozen, so hardening is needed to reduce the temperature further and form smaller, more stable ice crystals. This step improves smoothness, firmness, and storage stability.

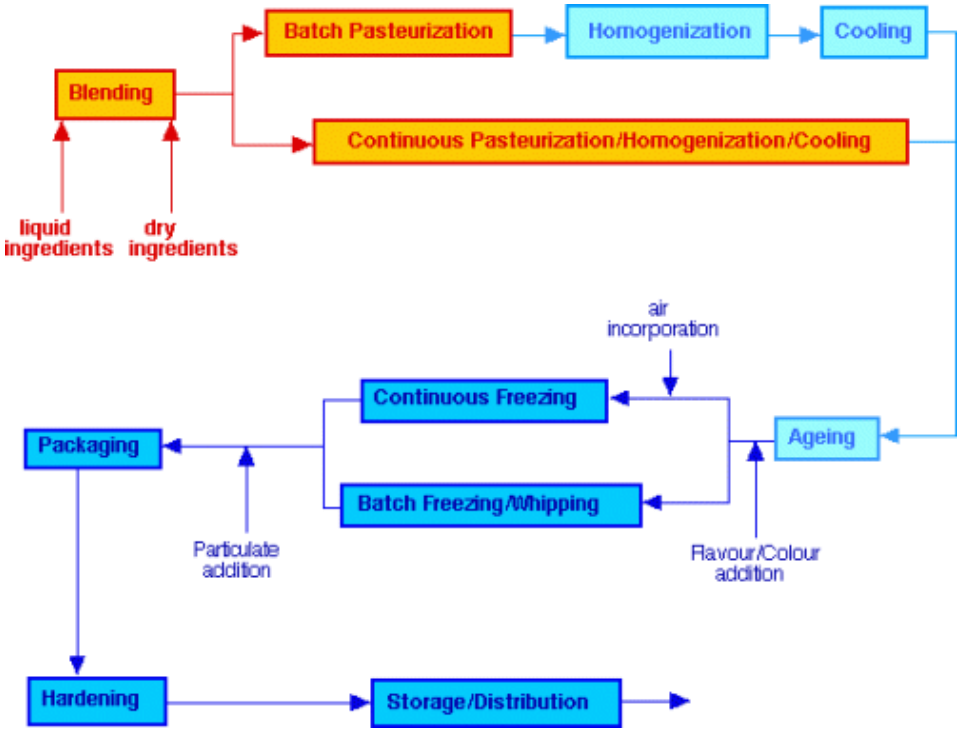


Figure 22: A process flow diagram for ice cream manufacture. The red section represents the operations involving raw, unpasteurized mix, the pale blue section represents the operations involving pasteurized mix, and the dark blue section represents the operations involving frozen ice cream.

6. Processing and use of milk processing by-products

Dairy by-products , skim milk, buttermilk, whey, and ghee residue were historically treated as waste streams of negligible commercial value. Today, they are recognized as nutrient-dense, biologically active matrices containing proteins, lipids, lactose, minerals, and vitamins of exceptional nutritional and functional interest. Their valorization has become central to the economic viability and environmental sustainability of the dairy industry: whey valorization

alone has been shown to increase dairy plant profit by over 24%. The transformation of these by-products from disposal problems to high-value ingredient streams described as the transition from "gutter to gold" has been driven by advances in membrane filtration, fermentation technology, spray drying, and enzymatic processing. Important by-products available from the dairy industry and their utilization are given in the Table 5

Table 5: Main by-products available in the dairy industry and their use

Main Product	By-product	Processing Method	Manufactured Products
Cream	Skimmed milk	Pasteurization	Flavored milk
		Sterilization	Sterilized flavored milk
		Fermentation	Cultured buttermilk
		Fermentation and Concentration	Concentrated sour skimmed milk
		Concentration	Concentrated skimmed milk (plain and sweetened)
		Drying	Skimmed milk powder or LTP skimmed milk powder
		Coagulation	Cottage cheese, Quark, food-grade casein
Butter	Buttermilk	Fermentation and Concentration	Concentrated buttermilk
		Concentration and drying	Dried buttermilk
		Coagulation	Soft cheese
Cheese, Casein, Channa, Panir	Whey	Fermentation	Whey-based beverage, yeast-based whey beverage
		Concentration	Concentrated whey (plain and sweetened), whey proteins concentrate, whey paste, lactose
		Drying	Dried whey
		Coagulation	Ricotta cheese
Ghee	Ghee residue	Processing	Confectionery, caramel, sweet paste

6.1. Skim milk and its by-products

Skim milk is obtained as the aqueous phase during the centrifugal separation of cream from whole milk. It retains virtually all the non-fat solids of milk: caseins (~2.7%), whey proteins (~0.6%), lactose (~4.8%), and minerals (calcium, phosphorus, potassium), making it exceptionally rich in milk solids-not-fat (SNF) and of high nutritional value. When used for standardization of dairy products or for spray-drying into skim milk powder (SMP) for direct commercial sale, it is not considered a by-product in the strict sense. It becomes a by-product only when it is utilized as a feedstock for further derivation of specialty proteins (casein, coprecipitates, protein hydrolysates) or when it is under-utilized economically.

Table 6 summarizes the different processing methods for skim milk.

Table 6: Processing methods for skim milk

Processing method	Main principle	Main products / uses	Key effect
Pasteurization and heat treatment	HTST or UHT heating to destroy pathogenic microorganisms and extend shelf life	Pasteurized skim milk, UHT skim milk	Improves safety and shelf stability while preserving soluble proteins
Concentration and evaporation	Vacuum evaporation removes water and increases total solids	Condensed skim milk, sweetened condensed skim milk	Produces concentrated products for beverages, confectionery, and recombined dairy foods
Spray drying	Concentrated skim milk is atomized into hot air to form powder	Skim milk powder (SMP), low-temperature powder (LTP)	Converts skim milk into a stable, free-flowing powder with long shelf life
Fermentation	Lactic starter cultures ferment lactose to produce acid and texture	Cultured buttermilk, fermented skim milk, yogurt-type skim milk	Produces fermented beverages and functional food ingredients
Acid coagulation	Milk is acidified to the isoelectric point of casein	Acid casein, cottage cheese, quark	Separates casein from whey and produces high-protein products
Rennet coagulation	Chymosin coagulates casein at near-neutral pH	Rennet casein, cheese analogues, processed cheese spreads	Produces casein for food formulations and processed cheese
Membrane filtration	MF, UF, NF, and RO separate milk components without intense heating	Standardized milk, MPC, MPI, concentrated skim milk	Improves protein concentration, microbial reduction, and process efficiency

6.2. Buttermilk

Buttermilk is the aqueous phase separated during churning of cream into butter. Its distinguishing characteristic compared with skim milk is its high content of milk fat globule membrane (MFGM) material, rich in phospholipids (phosphatidylcholine, phosphatidylethanolamine, sphingomyelin), glycoproteins, and bioactive lipids (conjugated linoleic acid, CLA; gangliosides). Phospholipids in MFGM provide exceptional emulsifying capacity and documented health benefits including anti-tumor, cholesterol-lowering, anti-*Helicobacter pylori*, and gastrointestinal protective properties.

Three types of buttermilk are distinguished by the origin of the cream:

A. Sweet cream buttermilk: By-product of churning pasteurized sweet cream. Composition similar to skim milk (protein ~3.3%, lactose ~4.6%, fat ~0.3–0.5%) but enriched in phospholipids.

B. Cultured / sour cream buttermilk: By-product of churning ripened/fermented cream. Higher acidity (pH 4.5–4.9), lactic flavor; lower keeping quality due to residual lactic acid bacteria activity.

Lot of processing methods are used for the treatment of buttermilk, table 7 summarizes some of theme.

Table 7: Processing Methods for Buttermilk

Processing method	Main principle	Main products / uses	Key effect
Fermentation	Sweet cream buttermilk is inoculated with mesophilic lactic acid bacteria and fermented at 20–22°C until pH 4.4–4.6.	Fermented buttermilk beverages such as chaas and lben; functional ingredients in bakery and beverages.	Produces a refreshing acidic drink with buttery aroma and probiotic potential.
Concentration and drying	Buttermilk is concentrated by vacuum evaporation and then spray-dried into powder.	Condensed buttermilk, dried buttermilk powder.	Produces a stable ingredient used in chocolate, ice cream, biscuits, bread, and pastry.
Coagulation for soft cheese production	Buttermilk is acidified or heat-acid coagulated to form a curd.	Soft fresh cheeses, quark-like products, chhana.	Gives a creamy texture and pleasant flavor; can improve yield in soft cheese products.
Membrane filtration for MFGM isolation	Microfiltration and ultrafiltration separate the milk fat globule membrane fraction and whey proteins.	MFGM-rich powder, whey protein concentrates from buttermilk.	Produces high-value phospholipid-rich ingredients for nutraceutical, infant formula, and functional food applications.

6.3. Ghee residue

Ghee residue (GR) also known as *bagri*, *kittu*, *samna residue*, or *ghee mava* is the brownish-black solid by-product remaining after straining molten ghee. It consists predominantly of denatured proteins (Maillard-reacted casein and whey proteins), residual fat, carbohydrates (lactose, glucose, galactose degradation products), minerals, and phospholipids. The yield of GR depends strongly on the method of ghee preparation: direct cream method yields the highest GR (~12%), while creamery butter and desi butter methods yield ~3.7% GR. Ripening of cream before clarification reduces GR yield, as acidification promotes protein loss in the liquid phase before clarification.

GR is an exceptionally concentrated source of flavor compounds formed during the Maillard reaction and lipid oxidation/hydrolysis during heating:

C. Free fatty acids (FFAs): present at levels 11× higher than in ghee itself; major contributors to the characteristic rancid-buttery background note.

D. Carbonyl compounds (aldehydes, ketones, diacetyl): 10× more concentrated than in ghee; responsible for cooked and nutty notes.

E. Lactones (δ-C_{12}, δ-C_{14}, δ-C_{18}): 132× more concentrated than in ghee; key drivers of the caramelized, creamy, and coconut-like aroma characteristic of GR and which contributes the distinctive "ghee-like" flavor when GR is incorporated into food products.

Ghee residue is pre-treated before use to improve its quality and stability. Common methods include neutralization with sodium bicarbonate, fat recovery by solvent extraction, and drying to produce a shelf-stable powder rich in protein and minerals.

GR is used in confectionery, bakery products, ice cream, fat flavoring, and animal feed. It also has non-food applications such as biodiesel production and microbial lipase production.

6.4. Whey

Whey is the largest by-product stream of the dairy industry by volume, generated at approximately 9 L per kg of cheese produced, and representing approximately 90% of the milk volume entering the cheese vat. It contains 6.5–7% total solids, of which lactose accounts for 70–72%, mineral salts for 12–15%, and whey proteins for 8–10% (Table 8). Globally, over 145 million tons of whey are produced annually. Two types are distinguished:

F. Sweet whey (pH 6.0–6.5): generated from rennet-coagulated cheese (Cheddar, Gouda, mozzarella); contains glycomacropeptide, derived from the chymosin cleavage of κ-casein; higher mineral concentration dominated by calcium phosphate.

G. Acid whey (pH < 5.0): generated from acid-coagulated products (cottage cheese, quark, Greek yogurt); contains no glycomacropeptide; higher soluble calcium; more challenging to process due to lower pH and higher mineral content

Table 8: Composition of different whey system

Constituents	Cheddar cheese	Acid casein	Rennet casein	Chhana and paneer	Co-precipitates
Total solids (%)	7.0	7.0	6.8	6.5	6.2
Fat (%)	0.3	0.1	0.1	0.5	0.1
Protein (%)	0.9	1.0	1.0	0.4	0.3
Lactose (%)	4.9	5.1	5.1	5.0	5.1
Ash (%)	0.6	0.7	0.5	0.5	0.6
T.A. (%)	0.2	0.4	0.2	0.4	0.3

6.4.1. Separation Methods

Fractionating the components of whey into byproducts adds even more value to the process, allowing the development and adoption of technologies in the dairy sector, in addition to allowing the obtaining of target proteins with different levels of purity. Whey protein fractionation is based on different physicochemical properties, such as charge, size, and solubility. The primary separation methods include filtration, chromatographic techniques and thermal coagulation. Table 9 summarises the methods used for the separation of these differentes compounds.

Table 9: Main Separation Methods in Whey Processing and Comparative Aspects

Method	Principle	Applications	Advantages	Limitations
Microfiltration	Membrane separation with different pore sizes	Removal of bacteria and fat before whey concentration	High separation efficiency; simple operation; easy scale-up	Membrane fouling
Ultrafiltration	Membrane separation with different pore sizes; MWCO of 10–20 kDa for lactose and minerals, 10–300 kDa for whey proteins	Separation of lactose, minerals, and whey proteins	High separation efficiency; simple operation; easy scale-up	Membrane fouling
Diafiltration	Membrane separation with different pore sizes	Increases protein purity in the retentate and produces IgG-enriched solution	Protein content can be enhanced to 80%; high separation efficiency; simple operation; easy scale-up	Membrane fouling
Nanofiltration	Membrane separation with different pore sizes	Removal of bacteria; fractionation and recovery of whey proteins	Up to 40% mineral removal; high separation efficiency; simple operation; easy scale-up	Membrane fouling
Reverse osmosis	Membrane separation with different pore sizes	Protein concentration	High separation efficiency; simple operation; easy scale-up	Membrane fouling
Electrodialysis	Separation of ionic species using charged polymer membranes	Protein concentration, demineralization, salt removal	Up to 70% mineral removal; can be coupled to UF	No selectivity for different charged ions; membrane fouling
Size exclusion chromatography / gel filtration	Separation based on molecular size	Separation of milk protein allergens	Simple and rapid	Difficult to separate proteins with similar molecular weight, so it needs to be coupled with another method
Ion exchange chromatography	Proteins are separated based on their isoelectric points and interaction with the membrane	Separation of milk protein allergens; β-LG separation	Up to 90% mineral removal	More expensive; requires frequent replacement
Affinity chromatography	Separation of molecules according to their affinity for a ligand bonded to the support matrix	β-LG isolation	1000-fold purification; high specificity	More expensive
Thermal denaturation	Use of high temperatures to denature proteins	Protein fractionation	Can reduce membrane fouling; increases permeate flux when used as pretreatment	α-LA is heat resistant and its denaturation is reversible; may cause unfavorable aggregation
Precipitation	Different pH values are used to precipitate proteins	Whey flocculation, coagulation, and protein fractionation	Easy to perform; low cost; can precipitate specific proteins such as α-LA and Ig while β-LG remains soluble	Difficult to separate proteins with similar isoelectric points; often needs combination with other methods

6.4.2. Bioconversion of whey for the production of value-added products

Whey as a biotechnological resource refers to the use of whey, a by-product of cheese production, as a raw material for producing value-added products rather than treating it as waste. Because whey contains lactose, proteins, minerals, and other nutrients, it can support many microbial and industrial processes (Figure 23).

- **Single-cell protein**: Whey can be used as a substrate for yeast, fungi, algae, and bacteria to produce protein-rich microbial biomass for food and animal feed.
- **Biofuels**: Whey can be converted into bioethanol, biobutanol, biodiesel, and biogas through fermentation or anaerobic digestion.
- **Lactic acid**: Whey is an excellent substrate for lactic acid bacteria, producing lactic acid for food, pharmaceutical, and bioplastic applications.
- **Prebiotics**: Whey lactose can be converted into galactooligosaccharides and lactulose, which are used as prebiotic ingredients.
- **Enzymes**: Whey is used for producing industrial enzymes such as β-galactosidase, protease, and amylase.
- **Biopigments**, polysaccharides, and bacteriocins: Whey can also be used to produce natural pigments, microbial polysaccharides, and antimicrobial compounds.
- **Bioactive peptides**: Whey proteins can be hydrolyzed to produce bioactive peptides with nutritional and health-promoting properties.

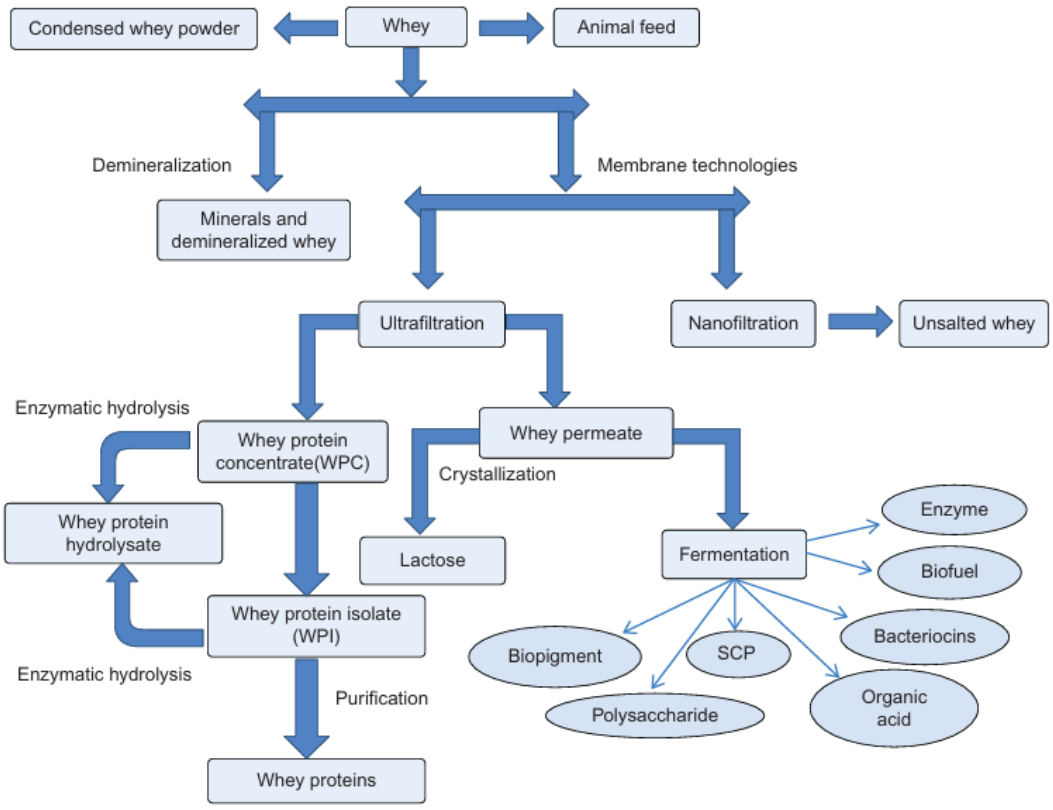


Figure 23: overview of whey valorization process

Part 2. Sugar

1. Introduction

The term "sugar" originates from the Sanskrit word "sarkara", which originally referred exclusively to sucrose, a disaccharide formed by the association of a fructose and a glucose molecule, linked by a glycosidic bond of the (1→2) type. The chemical formula of sucrose is C12H22O11, and its systematic name is α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside.

Although the term "sugar" is now used to describe a wide range of sugary substances, sucrose remains one of the most common. It can be extracted from a wide range of plants grown around the world. Only two main crops are grown on a large scale for commercial production:

- Sugar cane (*Saccharum officinarum* L.)
- Sugar beet (*Beta vulgaris*).

These two plants have the particularity of storing sucrose, produced during photosynthesis, in the form of an aqueous solution in their cells without altering its chemical composition. This sucrose is mainly accumulated in the stem of sugar cane and in the root of sugar beet.

2. Beet sugar industry

Sugar beet originated in Europe, and its cultivation intensified in the 19th century, especially after advances in sugar extraction. It has a fleshy, white-colored root, rich in sucrose (sugar), and its green leaves grow in a rosette above the ground. The underground part of the beet is the most important for sugar production. It contains about 15-20% sucrose.
Sugar beet is the source of nearly 20% of the world's sugar, the other major source being sugar cane.

Sugar beet is made up of many cells including a cell wall, a cytoplasm, a nucleus, and a vacuole filled with cell juice (Figure 24). This juice contains 12% to 20% sucrose, 6% to 8% impurities, and 72% to 80% water. Impurities are mineral matter, mixed salts, nitrogenous and non-nitrogenous organic matter.

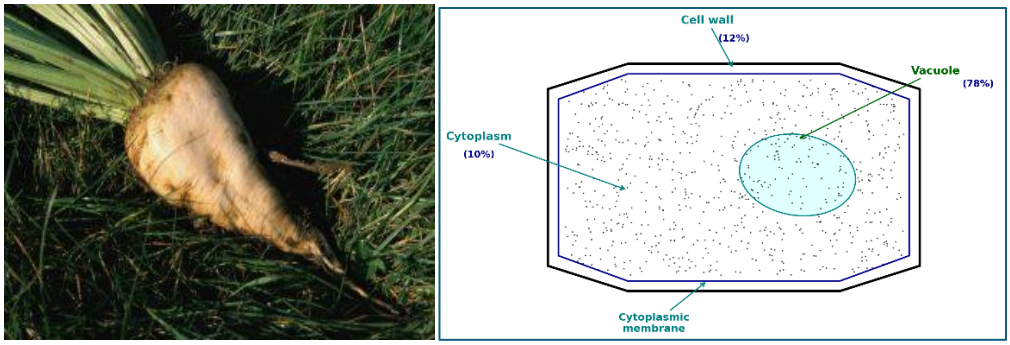


Figure 24: Sugar beet and a cell of sugar beet containing sugar juice

A sugar factory is a factory that transforms sugar-rich raw materials, mainly sugar cane or sugar beet, into refined sugar ready for consumption or use in food products. It implements a series of industrial processes to extract, purify, concentrate and crystallize the sugar contained in these plants. The main steps and functions of a sugar factory are (Figure 25):

- Receiving and preparing raw materials
- Sweet Juice Extraction
- Juice Clarification
- Juice concentration by evaporation
- Crystallization

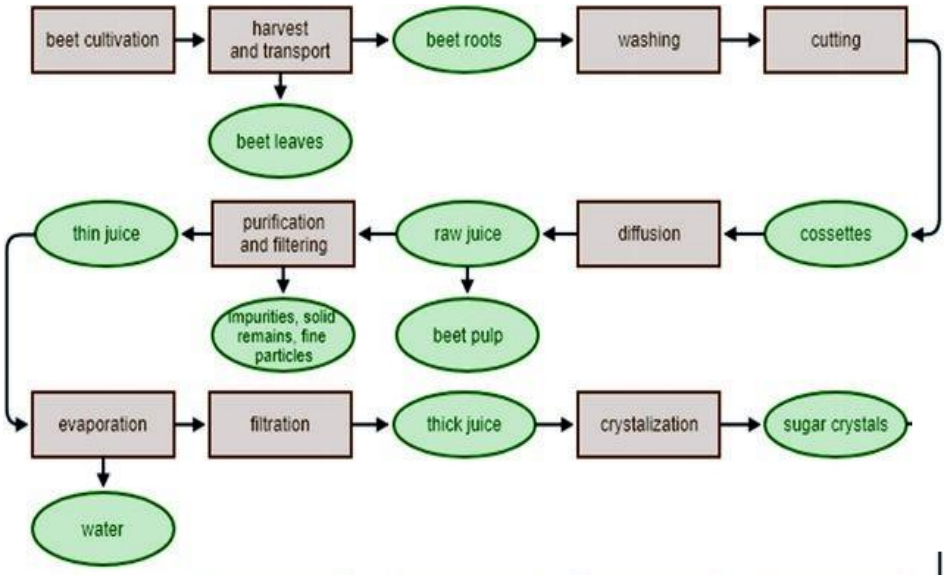


Figure 25: scheme for the production of sugar from sugar beet

2.1 Beetroot preparation

Sugar beet is planted in spring and harvested in autumn, about eight months later, when sugar content is highest. It is harvested mechanically and sent quickly to the factory to avoid deterioration. Delayed storage can reduce sugar quality and yield because of physical, chemical, and microbiological changes.

1) Reception and weighing

Beet trucks are weighed when entering the factory and again after unloading to determine the net weight. A representative sample is taken before full unloading to assess impurities and quality.

2) Sample cleaning and tare calculation

The sampled beet is first weighed in its raw state, then washed to remove soil, stones, and plant residues. After cleaning, it is weighed again, and the difference is used to calculate the tare-ground percentage, which shows the amount of impurities.

3) Sugar analysis

Several tests are carried out to evaluate beet quality for sugar production, including sugar content, juice purity, dry matter, impurity levels, beet health, and cut quality. These analyses help estimate sugar yield and processing efficiency.

4) Washing, de-stoning, and defoliation

The beets are washed to remove soil and foreign materials that could interfere with processing. The washing water is treated and its pH controlled to limit sugar losses and maintain good operating conditions.

5) Cutting into cossettes

The beets are cut into long strips called cossettes to prepare them for diffusion. Cossette quality is checked by size, permeability, and mush content to ensure efficient sugar extraction.

2.2. Sugar extraction from beet

The extraction of sugar from beet cells occurs through the transfer of soluble chemicals from the raw material to a solvent, water; this process is known as diffusion.
The objective is to maximize the extraction of sugar "sweet juice" while minimizing the

extraction of non-sugars, especially nitrogenous compounds and pectins.

- The cossettes flow in the opposite direction to hot water at 70-80°C to denature the ectoplasmic membrane of the cells. The cossettes circulate counter-currently with hot water at 70-80°C to denature the ectoplasmic membrane of the cells.

The root's dry matter content is roughly 25%. The dry materials comprise 17% insoluble cell wall, 73% sugar, and 10% soluble materials.

Following denaturation, the soluble components in beet juice migrate into solution through the porous cellulose membrane in accordance with the principles of diffusion.

There are four categories of diffusers:

- Horizontal with a revolving tube,
- Conveyor belt,
- Screw,
- Tower.

The horizontal diffuser receives the cossettes at one end and the hot water required for sugar extraction at the other. It rotates at a constant speed. Inside, several helical compartments ensure the transport of both the chips and the liquid.

The liquid flows through a helical channel made of rigid plates. With each rotation of the cylinder, the water in the channel is distributed over the cossettes placed on a perforated plate.

As it moves along the helical channel, the juice gradually becomes richer in sugar. The sweet juice is discharged at the front of the diffuser, while the exhausted pulp is collected at the rear in the form of spent pulp.

The pulp is then pressed to remove part of its moisture, which increases the dry matter content from 7% to 25%. The diffusion process produces a diluted juice with a dark gray, opalescent appearance. It contains about 15% dry matter, 15° Brix, and has a pH of 6. This juice contains 13 to 14% sugar and 1 to 2% impurities, including organic compounds (proteins, pectins, other sugars, organic acids, and colloids) as well as mineral substances (salts of Na, K, Ca, and Mg). The remaining portion is water.

Table 10: composition of beetroot juice after extraction

Jus content	Expressed %
Dry matter (DM)	15.48
Non-sugars (NS)	1.62
Sugar	13.86
Water	84.52
Total	100.00

2.3. Purification of diffusion juices

The purification of diffusion juices involves, first, a lime treatment that precipitates a number of impurities, and second, two successive carbonatation steps that remove the excess lime by introducing carbon dioxide.

In sugar factories, both purification agents, lime and carbon dioxide, are produced on site in a lime kiln from limestone and coke according to the following reaction:

$$CaCO3 \rightarrow CaO + CO2$$

This decomposition depends on temperature and is complete at about 898°C. The quicklime obtained is then slaked with water to produce lime milk:

$$CaO + H2O \rightarrow Ca(OH)2 + energy$$

Lime addition is carried out in two stages, pre-liming and liming, in order to reduce lime consumption while maintaining high purification efficiency.

a. Pre-liming

Pre-liming is a gradual alkalinization of the diffusion juice designed to achieve:

- Selective precipitation of impurities such as citric, oxalic, and malic acids, invert sugar, and nitrogenous compounds;
- Precipitation of certain cations such as Ca^{2+} and Mg^{2+}, as well as sulfate and phosphate anions;
- Coagulation and flocculation of proteins, saponins, and polyphenolic pigments.

This process takes place under controlled conditions in a compartmentalized preheater that ensures progressive alkalinity.
The main pre-liming parameters are:

- final alkalinity: 2.5 g CaO/L,

- temperature: 70–75°C,
- final pH: 11.5,
- residence time: 10–15 min minimum.

Pre-liming accounts for about one-fifth of the total lime addition.

b. Main liming

After pre-liming, the juice passes through a heater and is sent to the liming tanks at about 85°C, where the remaining lime milk is added in bulk.

Main liming increases total alkalinity to 10–15 g CaO/L and promotes the degradation of:

- nitrogenous substances,
- reducing sugars.

c. Carbonatation steps

1) First carbonatation

The first carbonatation aims to precipitate the excess lime still present in the juice, corresponding to about 0.08–0.10% free CaO, in the form of calcium carbonate.

The limed juice is heated and then bubbled with carbon dioxide, produced by the lime kiln, according to the following reaction:

$$Ca(OH)2+CO2 \rightarrow CaCO3+H2O+energy$$

The heat released helps evaporate part of the water contained in the juice. The pH after first carbonatation should not fall below the preheating level.

2) Filtration or sedimentation

The purpose of filtration is:

- to obtain a clear juice from the first carbonatation (JC1) by retaining the precipitated impurities and calcium carbonate;
- to wash the filter cake and recover the sugar-rich liquid retained in it, known as sweet juice or thin juice;
- to recover sludges, which are generally used as fertilizers.

The separation of precipitates and calcium carbonate can also be carried out in settling tanks, often with the addition of flocculants to improve clarification.

3) Second carbonatation and filtration

After reheating the juice to about 95°C, a second carbonatation is performed, similar to the first, in order to remove the remaining lime in the clarified juice.

At the end of this step, the final pH is approximately 9.2, and the alkalinity is about 0.15 g CaO/L.

After the first carbonatation, about 50% of the carbonic acid is present in carbonate form, whereas after the second carbonatation this proportion drops to about 2%.

Before being sent to the evaporation stage, the purified juice is often further treated to prevent scaling in the evaporator tubes.

Decalcification consists of passing the juice through ion-exchange resins that replace calcium ions with sodium ions. It is carried out on the clear juice before evaporation by adding sulfur dioxide, which acts as a color inhibitor by binding to carbonyl groups of reducing sugars and limiting color formation.

This process may cause slight dilution of the diffusion juice.

4) Purity index

The purity of the juice is calculated as:

$$\textbf{Purity} = 100 \times \text{sugar/total solids}$$

2.4. Evaporation

Before evaporation, the purified juice is clear, stable, and has a pH of about 9.2, so heating should not significantly alter its acidity. The juice is straw-yellow in color and contains approximately 1% dissolved impurities. Evaporation is carried out in a multiple-effect evaporator, generally made up of four to six stages, with the first units operating under pressure and the last one under vacuum.

The purpose of this step is to concentrate the purified juice from about 13–14% dry matter to a syrup approaching saturation, with a dry matter content of approximately 68.5 g per 100 g. During this process, water is removed and converted into condensate, while different grades of

steam are reused within the factory to improve energy efficiency. The evaporation stage is considered the heart of the sugar factory because it prepares the juice for crystallization.

2.5. Crystallization

The final phase of sugar purification is crystallization, which separates sucrose from remaining impurities. Sugar crystallizes while impurities remain in the liquid phase, forming molasses as the residual solution. After evaporation, the syrup reaches 65% Brix, 60.5% sugar, and 93% purity, but requires a supersaturated state for crystal nuclei to form.

Industrial crystallization is usually carried out in three stages, called jets. Each jet includes:

1. **Cooking**: Syrup is concentrated under partial vacuum in large boilers until reaching the metastable zone. Graining is performed by seeding fine sugar crystals into supersaturated syrup. As crystals grow, more syrup is added to maintain supersaturation, and boiling is tightened at the end to improve crystal yield.

2. **Mixing**: The cooked mass is transferred to a mixing trough and gently stirred and cooled for 30 minutes to 1 hour. During this time, crystals continue to grow, and small amounts of water may be added to dissolve fine crystals formed during rapid cooling.

3. **Centrifugation**: The cooked mass is separated in centrifuges where crystals are retained and mother liquor is removed. The sugar is then washed, dried with hot air, and cooled to reduce moisture content to a very low level.

3. Refining of Sugar

3.1. Definition of raw sugar

Raw sugar is a partially refined crystalline sugar obtained from sugar cane or sugar beet juice after the initial stages of extraction, clarification, evaporation, and crystallization. It consists mainly of sucrose crystals that are still coated with a thin layer of molasses, which gives it a light brown to golden color and a slightly sticky texture. Unlike fully refined white sugar, raw sugar has not undergone complete purification, so it retains small amounts of non-sugar substances such as color compounds, minerals, and organic impurities.

In industrial processing, raw sugar is usually the intermediate product obtained before final refining. It is not typically intended as the final consumer sugar in many production systems,

because it still contains residual molasses and may require further purification to produce white sugar. Its crystal size is often larger and its color darker than refined sugar.

3.2. Refining

Refining is the process that makes it possible to obtain a high-purity refined sugar from a raw sugar (a mixture of sucrose and non-sugar). In the refining process, there are a number of operations that allow:

1) To remove the impurities outside the crystal, this is the refining.
2) Removing the organic impurities of raw sugar after melting the refined crystals, this is carbonation.
3) Removing the dyes by an adsorbent, this is discoloration.
4) To recrystallize sucrose to obtain a pure crystal, this is crystallization.

Sucrose is purified from raw sugar (97.5% sucrose) in a four-step process as follows (Figure 26):

3.2. 1. Affination

Affination is the first step in sugar refining. It consists of mixing raw sugar with a saturated syrup to soften the molasses film adhering to the crystals. The mixture is then centrifuged and washed to remove as much impurity-laden syrup as possible.

Centrifugal machines operate at high speed, generating strong gravitational forces that minimize the contact time between water and sugar, thereby reducing sugar loss. The removed impure syrup is recycled, while excess syrup is treated separately in the boil-out process to recover remaining sugar.

The washed (affined) sugar is then dissolved using “sweet water” from the refinery. The resulting liquor is controlled for temperature and density and screened to remove fibrous materials.

3.2. 2. Carbonatation (Clarification Process)

Carbonatation involves adding milk of lime (calcium hydroxide) to the heated sugar liquor, followed by bubbling carbon dioxide through the mixture. This leads to the reaction:

$$Ca(OH)2+CO2 \rightarrow CaCO3+H2O$$

The calcium carbonate precipitate traps impurities such as gums, amino acids, and colorants.
This process occurs in two stages:

- First stage: 80–90% precipitation, monitored by electrical resistance.
- Second stage: Controlled by pH to ensure complete lime removal.

pH control is critical:

- Below pH 7: sucrose hydrolyzes into glucose and fructose.
- Above pH 9: sugar degradation and color formation occur.

3.2. 3. Filtration

The precipitated calcium carbonate, containing impurities, is removed by pressure filtration using polypropylene filter cloth. The calcium carbonate also acts as a filter aid.

The resulting filter mud is washed to recover residual sucrose, and the recovered sugar is recycled. The remaining mud is discarded as waste.

3.2. 4. Decolorization (Char Filtration)

The clarified "raw liquor" undergoes final decolorization to achieve the desired whiteness by removing soluble colorants.

Two main techniques are used:

- **Granular Activated Carbon**: Adsorbs color molecules due to its large surface area.
- **Ion Exchange Resins**: Exchange negatively charged color ions with non-colored ions, offering high selectivity and easier regeneration.

3.2. 5. Crystallization

Crystallization converts sucrose into solid crystals while leaving impurities in the syrup. It is performed under reduced pressure (75–90 kPa) and lower temperatures (60–70°C) to prevent color formation.

The process involves:

- Concentrating the liquor to a supersaturated state.
- Seeding with fine sugar crystals to initiate nucleation.
- Controlled crystal growth to reach the desired size.

The resulting mixture (massecuite) is centrifuged to separate crystals from syrup. The sugar is then dried, graded, and packaged. Remaining syrup is recycled for further recovery or used in by-products such as brown sugar, golden syrup, and molasses.

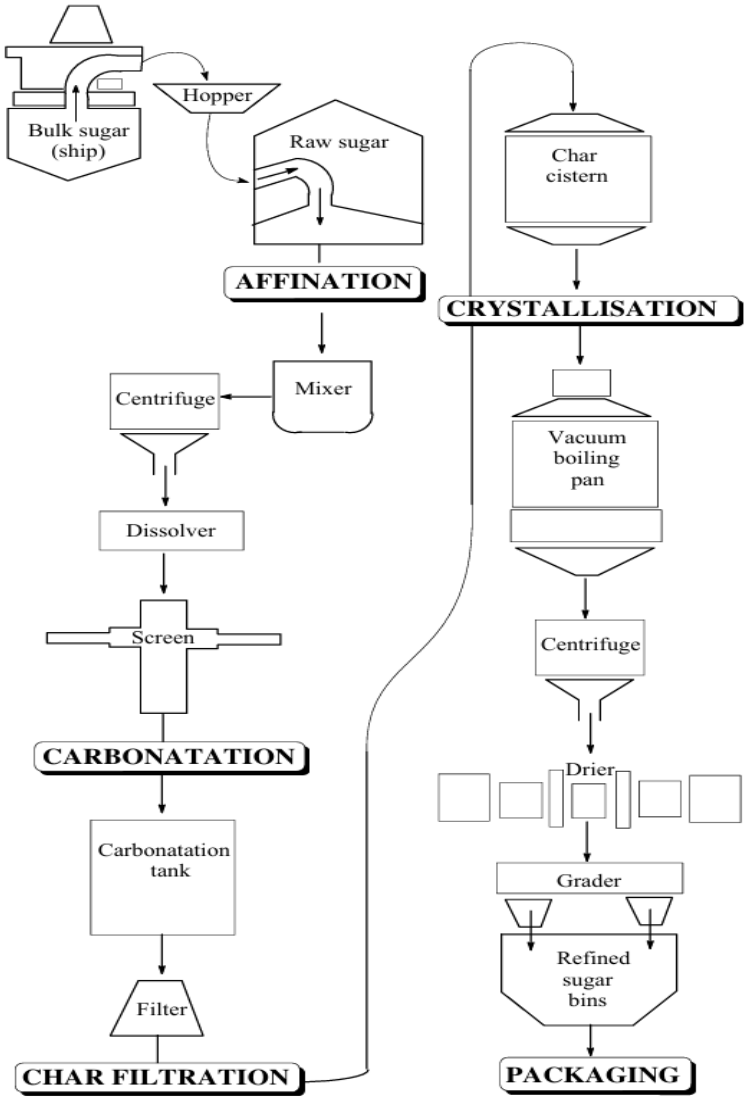


Figure 26: Flow chart of the sugar refining process

3.3. Melting and Clarification

This stage involves transforming affined sugar crystals into a purified liquid form and removing remaining impurities.

Melting consists of dissolving the washed sugar in hot water or “sweet water” (recycled process water containing dissolved sugar). The resulting solution, called liquor, is carefully controlled in terms of temperature and concentration to ensure efficient processing.

Clarification follows melting and aims to remove suspended and dissolved impurities such as organic matter, colorants, and fine particles. This is typically achieved through chemical

treatment (e.g., lime addition and carbonatation or phosphatation), which causes impurities to coagulate and form precipitates.

These precipitates are then removed by filtration, producing a clear, light-colored liquor suitable for further purification and processing.

3.4. Concentration and Crystallization

In this stage, purified sugar liquor is concentrated and converted into solid sugar crystals.

Concentration is achieved by evaporating water under reduced pressure (vacuum), which lowers the boiling point and prevents thermal degradation and color formation. The liquor becomes supersaturated, a necessary condition for crystal formation.

Crystallization is initiated by seeding the supersaturated solution with fine sugar crystals. This promotes controlled nucleation and uniform crystal growth. Process parameters such as temperature, supersaturation level, and agitation are carefully regulated to obtain crystals of desired size and quality.

The resulting mixture, called massecuite (crystals + mother liquor), is then centrifuged to separate sugar crystals from the remaining syrup. The crystals are further dried and cooled.

3.5. Packaging

Packaging is the final stage of the sugar refining process, ensuring product stability, safety, and market readiness.

After crystallization, sugar is dried to remove residual moisture and prevent microbial growth or caking. It is then screened and graded according to crystal size and quality.

The sugar is packaged in various formats depending on its intended use (e.g., bulk bags, retail packs, sachets). Packaging materials must protect the product from moisture, contamination, and mechanical damage.

Proper labeling, storage, and transportation conditions are also essential to maintain product quality and comply with food safety regulations.

Part 3. Oils and fats industry

Introduction

Fats and oils, rich in lipids, include oils, fats, butters, and margarines of vegetable and animal origin. Oils and fats are composed of triglycerides with a few minor constituents, while butters and margarines are emulsions. The distinction between oils and fats depends on the melting point: oils are liquid at room temperature, fats are solid. In food, a distinction is made between:

- Visible fats: fats extracted from animal adipose tissue, oilseeds (sunflower, peanut), grain germ (corn), oleaginous fruits (olive), or milk (butter)
- Invisible fats: Fats embedded in foods such as meat, fish, and cheese.

Fats and oil may be of vegetable, animal and marine origin. Vegetable fats include the solid fat cocoa batter and the oils such as corn oil, sun flower oil, soybean oil, cotton soil, peanut oil, olive oil, canola oil, pumpkin seed oil, safflower oil, grape seed oil, sesame oil bran oil, argan oil, palm oil, linseed oil, coconut oil. Typically, common vegetable oils including soybean. Sunflower, safflower, mustard, olive, rice bran, sesame are low in saturated fats. While palm oil, palm kernel oil, coconut oil, tallow and butter fat are high in saturated fats. Animal fats include lard tallow and butterfat while fish oils include cod liver oil, whale oil and salmon oil

1. Raw materials: lipid reminders

Lipids are complex organic molecules, defined by their insolubility in water and their solubility in nonpolar organic solvents such as benzene, ether, and chloroform. They are generally less dense than water and are characterized by the presence of fatty acids, their derivatives, or their esters.

III.1. Fatty Acids

Fatty acids form the building blocks of most lipids, consisting of a long hydrocarbon chain (typically 4–36 carbons) capped by a carboxylic acid group (-COOH). They are classified by saturation level:

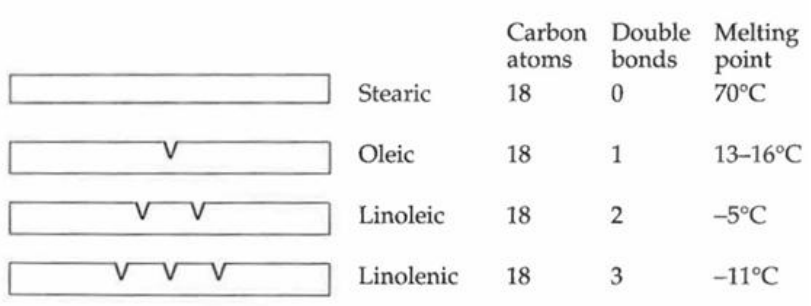
1) Monounsaturated fatty acids

Sometimes the carbon atom chain contains what chemists call a double bond. A fatty acid

containing one double bond is said to be monounsaturated, the most common example being oleic acid which, like stearic acid, has 18 carbon atoms.

2) Polyunsaturated fatty acids

Some fatty acids have two or three double bonds and these are said to be polyunsaturated fatty acids. Linoleic and linolenic acids are common examples of polyunsaturated fatty acids. The relationship between the common fatty acids with 18 carbon atoms (C18 acids) can be represented as follows:



	Carbon atoms	Double bonds	Melting point
Stearic	18	0	70°C
Oleic	18	1	13–16°C
Linoleic	18	2	–5°C
Linolenic	18	3	–11°C

It can be seen that the presence of a double bond lowers the melting point. Thus, a triglyceride mixture containing a high proportion of monounsaturated or polyunsaturated fatty acids is likely to be liquid.

1.2. Glycerides (Glycerol Esters)

Glycerides derive from glycerol (a 3-carbon alcohol) esterified with 1–3 fatty acids: monoglycerides (one FA), diglycerides (two), and triglycerides/triacylglycerols (three, most common ~95% of dietary fat). Neutral and hydrophobic, triglycerides store energy efficiently (9 kcal/g) in adipose tissue droplets, mobilized via lipolysis for ATP production. Diglycerides aid emulsification in food processing; partial hydrolysis yields mono/diglycerides used as emulsifiers.

1.3. Phospholipids

These amphipathic lipids have a glycerol backbone with two fatty acids, a phosphate group, and a polar head (e.g., choline in phosphatidylcholine). The hydrophobic tails cluster inward while hydrophilic heads face water, spontaneously forming bilayers critical for cell membranes, liposomes, and myelin sheaths. Lecithin (from eggs/soy) is abundant; they facilitate signaling (e.g., PIP2 in second messengers) and transport (e.g., lipoproteins).

1.4. Steroids

Steroids feature a four-fused-ring structure (three 6-carbon, one 5-carbon) without fatty acid

chains. Cholesterol, the precursor, maintains membrane fluidity and synthesizes bile acids, vitamin D, and hormones (e.g., cortisol, estrogen, testosterone via enzymatic modifications). Plant sterols (phytosterols) compete with cholesterol absorption, aiding heart health.

2. Main fractions in fats and oils chemistry

2.1. Hydrolysis

Hydrolysis of triglycerides is a chemical reaction in which a triglyceride is broken down into glycerol and free fatty acids in the presence of water. Depending on the reaction conditions, one or more fatty acid chains may be released.

Hydrolysis occurs mainly through two pathways:

- Acid hydrolysis: This process uses a strong acid catalyst, such as sulfuric acid (H2SO4), to promote the cleavage of ester bonds.
- Enzymatic hydrolysis: This pathway involves specific enzymes called lipases, which catalyze the breakdown of triglycerides under physiological conditions, such as in the human digestive system.

2.2. Neutralization (Saponification)

In an alkaline medium, triglyceride hydrolysis leads to the formation of soaps, a process known as saponification. During this reaction, ester bonds are cleaved, releasing fatty acids in the form of their corresponding salts.

- When sodium hydroxide (NaOH) is used, the products are sodium salts of fatty acids, commonly referred to as hard (white) soaps.
- When potassium hydroxide (KOH) is used, potassium salts are formed, resulting in soft (black) soaps.

In the food industry, saponification is applied in the neutralization step to remove excess free fatty acids from crude edible oils, as well as in soap production.

The saponification index (SI) is defined as the amount of potassium hydroxide (in mg) required to saponify 1 g of lipid.

2.3. Esterification

Esterification is a condensation reaction between a carboxylic acid ($R1-COOH$) and an alcohol ($R2-OH$), resulting in the formation of an ester ($R1-COO-R2$) and water: $Acid + Alcohol \rightleftharpoons Ester + Water$

This reaction is significant for several reasons:

- Naturally, lipids are esters formed from fatty acids and alcohols (mainly glycerol).
- In analytical chemistry, fatty acids are converted into methyl or ethyl esters to facilitate their separation by gas chromatography, as these derivatives have boiling points approximately $30-40\circ C$ lower than those of the corresponding free fatty acids.
- In the food industry, esterification is used to determine the fatty acid composition of vegetable oils and animal fats, particularly for detecting adulteration or fraudulent mixtures.

3. Fats and Oils Technology: Oil extraction

Oils and fats technology, particularly in the oleaginous industry, centers on extracting oils from lipid-rich seeds or fruits such as soybean, sunflower, rapeseed, olive, or palm. This process converts agricultural raw materials into crude oils suitable for food, industrial uses, or biofuels, achieving yields up to 99% through physical or chemical methods.

Two primary oil production methods exist:

- Mechanical extraction (cold pressing): Seeds or fruits are cleaned, decorticated, and/or crushed, optionally steamed (up to 50°C), then pressed via screw presses. Post-centrifugation or filtration yields virgin cold-pressed first-press oil. This method produces premium "noble" oils like olive, walnut, or hazelnut.
- Industrial extraction: Involves high-heat pressing with solvent addition (e.g., hexane), followed by refining through chemical steps like degumming and neutralization. It delivers high yields for common oils such as sunflower, soybean, or rapeseed.

Vegetable oils are primarily defined by their fatty acid (FA) profile—esters of C12–C24 carboxylic acids (saturated or unsaturated) bound to glycerol. This composition dictates physical properties (melting point, oxidative stability), nutritional value (ω-3/ω-6 balance), and technological applications (frying, emulsions). Profiles vary due to:

- Intrinsic factors: Variety genetics (hybrids vs. traditional).
- Extrinsic factors: Growing conditions (soil, irrigation, fertilizers), climate (high

temperatures boost saturates), harvest season (early yields more unsaturates), and storage.

Typically, oils contain 95–98% triglycerides and 1–5% free/minor components (phospholipids, tocopherols, sterols).

Oils are grouped into four categories based on dominant FAs as followed:

Table 11: vegetable oil classification

Group	Dominant FA Characteristics	Examples	Typical Composition (% total FA)	Key Uses
Saturated (solid at RT)	>40% saturates (palmitic C16:0, stearic C18:0)	Palm kernel, coconut, cocoa butter	Palmitic 40–50%; lauric 45–55% (coconut)	Chocolate, margarines, cosmetics
Monounsaturated (ω-9)	60–85% oleic C18:1	Olive, avocado, peanut, canola	Oleic 70–80%; palmitic 10–15%	Heart-healthy oils, stable frying
Polyunsaturated (ω-6)	50–70% linoleic C18:2	Sunflower, corn, soybean, sesame	Linoleic 50–70%; oleic 20–30%	Balanced diets, paints
Balanced/ω-3	Blend, >10% linolenic C18:3	Flaxseed, chia, rapeseed, GMO soy	Linolenic 20–60% (flax); linoleic 15–20%	Cardiovascular nutrition, supplements

Vegetable oils are categorized into two types: seed oils, including soybean, palm kernel, and coconut oils, and mesocarp oils, such as olive oil and palm oil. The extraction of crude oil from vegetable source materials is accomplished through mechanical pressing and/or solvent extraction. Both processes may be implemented independently or in conjunction. Mechanical pressing yields residual oil concentrations of 3-25% in expeller cakes, whereas solvent extraction results in residual oil amounts of 0.5-1.0% in extracted meal. The solid, typically protein-rich residue left after solvent extraction functions, following appropriate processing, as a premium animal feed. Through process modification, these compounds can be transformed into substances with elevated protein solubility suitable for human ingestion.

3. 1. Crushing.

3.3.1.1. Pretreatment of oilseeds

a) Shelling, cracking, dehulling

The seed is usually enclosed in a shell or a tough outer covering (endocarp, as in the case of palm nuts), or a pod which encloses the seeds as in soybeans and groundnuts, which have to be broken in order to release the seeds. Some oilseeds, such as soybeans have a seed coat or hull (which constitutes about 8% of the soybean), which must be removed before oil extraction in a

process known as dehulling. The hard covering of palm nuts is cracked open to release the seeds (kernels). Manual removal of the pods enclosing the seeds, dehulling, and cracking are slow, and these are no longer practiced. Breaking of the endocarp and pods and the separation of the oilseeds, as well as dehulling are performed mechanically. In the processing of certain soft oilseeds by the use of expellers, dehulling may be omitted in order to improve the efficiency of extraction, or some seeds are left in the pods and pressed (as in the case of groundnuts) to aid oil extraction when using a small expeller (without this, peanut butter, and not oil would be produced). The resulting groundnut cake, in this case, is of low quality, being of high fiber content. In the case of soybeans, the seeds are dehulled in order to obtain a high protein meal of high digestibility after solvent extraction.

b) Cleaning

The processing steps involved in oil extraction are determined by the nature of the oil-bearing material. Oilseeds require several preliminary steps. The prime task of any seed preparation plant is to process seeds in such a way that, under normal circumstances, the expeller or solvent extraction plant can remove the oil in an economical way (Figure 27).

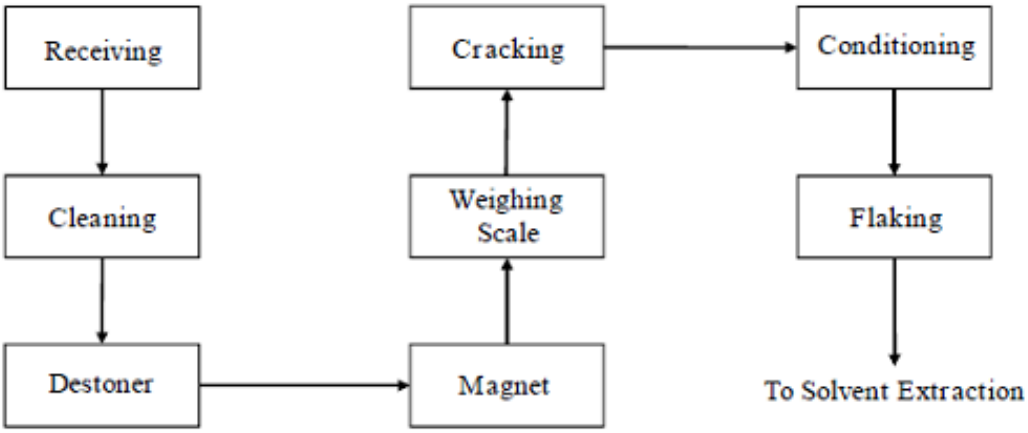


Figure 27: oilseeds preparation for oil extraction

It is very important that care be taken in the handling and shipment of oilseeds, due to their susceptibility to microbial infection resulting in the build-up of free fatty acid and/or rancidity. Infestation by pests can also lead to losses and contamination. Oilseeds are usually screened to remove stones, straw dust and other impurities. The first step of the cleaning is the removal of tramp metal by means of a rotary type magnet separator. This is followed by screening in which the first on-stream cleaner should be provided with a rough scalping screen or perforated metal sheet to separate oversize trash and below that a second sieve to get rid of the sand. To separate light-weight particles, mainly hulls and dust, the second sieve must also be provided with an

aspiration channel. As an average one can estimate 1% impurities will be obtained in this cleaning section. In small mills tramp iron is removed manually or by magnetic separators. Screening to remove other extraneous material is carried out by shaking the oilseeds manually or mechanically in a sieve.

c) Size reduction

First the oilseeds are passed through roller mills for preliminary size reduction (Figure 28). This is done by cracking rolls. Most cracking rolls comprise an integral feeder with a permanent magnet and two pairs of corrugated rolls arranged one on top of the other so that the first set of rolls feeds the second set. Milled oilseed is cooked to break down the walls of the oil-bearing cells followed by drying to reduce moisture content. It is further passed through plain roller mills for further size reduction, before extraction. In small-scale facilities, smaller equipment is employed for crushing and cooking. Usually, a hammer or attrition mill will suffice for size reduction while a shallow open pan with a mechanical stirred, or a cabinet dryer, will suffice for cooking of ground oilseed and drying to suitable moisture content. Size reduction exposes more surface for the subsequent heat treatment (scorching or cooking), which serves to break down the cell walls and facilitate oil extraction.

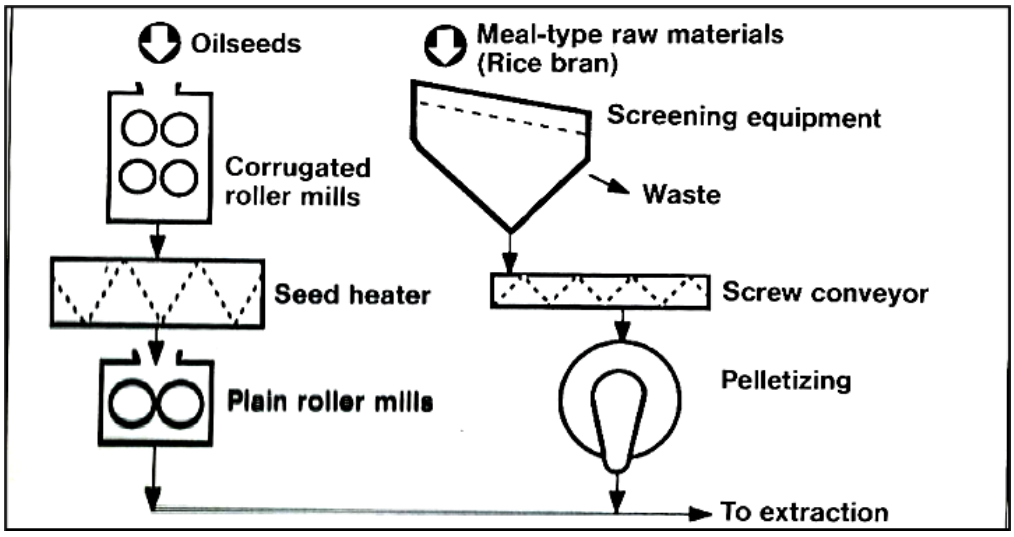


Figure 28: Size reduction and heat treatment of oilseeds prior to oil extraction

d) Conditioning

Oilseeds, which have high phosphatide content, may be subjected to an additional conditioning treatment. In this process, moisturizing media (preferably steam) are added to the oilseed flakes from the roller mills in the conditioner until the moisture content is above 15%.

The temperature rises to approximately 100°C. The conditioning parameters are then kept constant for approximately 15 minutes. Simultaneously, an agglomeration effect arises, which increases the bulk density. The phospholipases are inactivated by this treatment; the phosphatides in the extracted crude soybean oil thereby remain hydratable, and the conditions for physical refining are created by the low residual phosphatide content of approximately 10-15 ppm in the degummed oil. Advantages claimed for the process are as follows:

- ✓ Higher bulk density
- ✓ Larger extraction capacity
- ✓ Higher percolation speed
- ✓ Lower hexane retention
- ✓ Better hydration of phosphatides
- ✓ Higher yield of lecithin
- ✓ Lower residual phosphatide content in crude oil
- ✓ Crude oil suitable for physical refining
- ✓ Better meal quality

e) Expanding

This process, was introduced by the Anderson International Corp, and has been in use since the 1960s. The expander consists of a cylindrical horizontal housing, with a rotating shaft which has a screw-like shape (Figure 29).

The product - typically cracked and flaked oilseeds are introduced at one end and the motor-driven worm shaft conveys the product to the other end. Here it has to pass through a die plate or a narrow annular gap. This reduction in free cross-sectional area leads to a considerable pressure build-up and high shear forces within the product layer. Shearing generates heat in the product. The temperature increase may be supported by additional injection of sparge steam through special pins bolted onto the housing extending into the product. During the expanding process the temperature may rise above 150°C starting from ambient temperature. Due to a very short retention time of the product in the expander (approximately 1 minute), this heat treatment has hardly any negative impact on the protein quality.

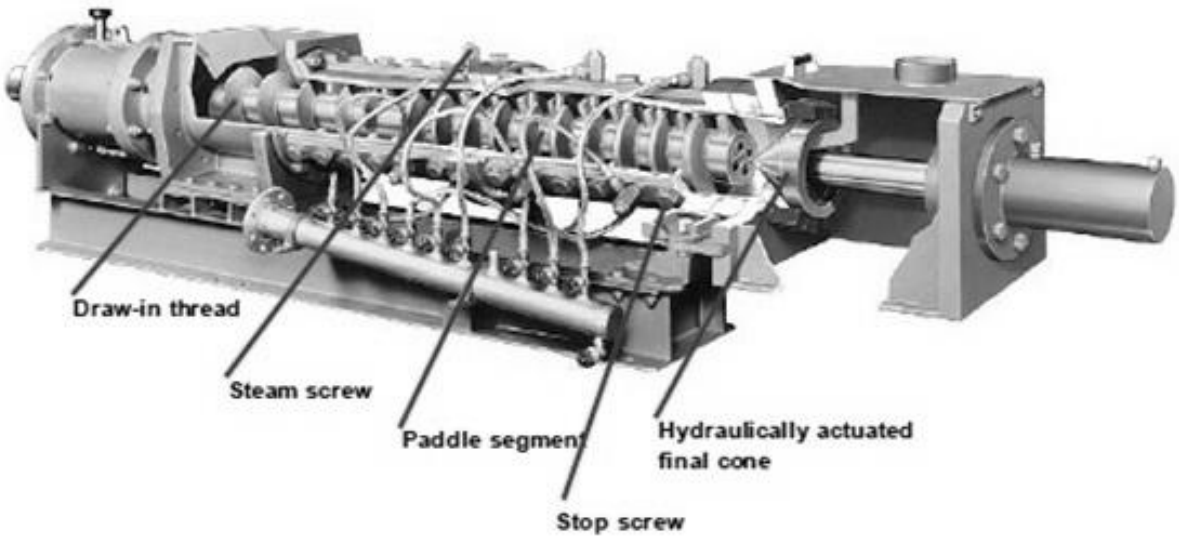


Figure 29: Annular gap expander with hydraulic cone

f) Oil extraction from pre-processed oilseeds

These steps are followed by oil extraction using an expeller and/or solvent. Expellers for oil extraction from oleaginous material operate continuously and automatically. The expeller consists of a screw or worm, which pushes the oil rich material forward continuously in a horizontal barrel or cage, exerting at the same time, sufficient pressure to force oil through openings in the cage.

g) Pressing of pre-processed oilseeds

A screw press is an oil extraction device that uses a continuous screw conveyor to feed raw material through a cylindrical cage while subjecting it to increasing pressure. The cage consists of bars with spacers whose diameter decreases toward the outlet, allowing oil to flow out while a compressed cake of oil-poor solid residue forms at the exit. The oil yield of the screw press depends on proper seed preparation, including mechanical rolling to a thickness of 0.38 to 0.50 mm before cooking at 115 °C for 60 minutes with 10% moisture, followed by drying to less than 2.5% moisture. The pressing process is used either in combination with solvent extraction (pre-pressing, leaving 15 to 18% residual oil), or as pure mechanical extraction by full pressing (reducing the oil content to 3–15%). Screw presses are ideal for small and medium-sized operations, with capacities ranging from less than 100 kg to more than 100 tonnes per day, while large pre-pressing units can process over 600 tonnes of oilseeds per day. The extraction method depends largely on the texture and oil content of the seeds; high-oil seeds require pre-

pressing before final pressing or solvent extraction, while low-oil materials such as soybeans can be extracted directly by solvent to achieve a residual oil content of 0.5 to 1%.3.2. Solvent extraction.

3.2. Solvent extraction

Oil extraction with expellers leaves 3-15% residual oil in the solids, the process uses considerable horse power, there is considerable wear and maintenance, and it takes several machines for high capacity. In comparison, solvent extraction with hexane (the primary solvent used worldwide) will remove all but about 0.5-1.0% of residual oil, uses less horse power, and requires less maintenance. It is relatively efficient and reliable, and this is one reason why solvent extraction is the primary means of separating large tonnages of oil from protein meal. Hexane is a commonly used extraction solvent because it boils at 69°C, making it easy to remove with relatively low energy. It forms an azeotrope with water or steam, which helps during solvent recovery from meal.

It is widely used because it is less irritating and less acutely toxic than many other solvents, and it has a tolerable odor. Since it is immiscible with water and non-polar, it efficiently dissolves oils while leaving proteins, sugars, and gums mostly in the meal.

Flake thickness and solvent temperature have profound effects on extraction rate, and empirical relationships have been observed between these factors and extraction time. The moisture content of the flakes also affects the rate of solvent extraction, and a moisture content of 9-11% is recommended.

The extractor is an enclosed vessel designed to wash, extract, and drain flakes. Countercurrent flow of the solvent and flakes serves to reduce the amount of solvent used in extractors, with the new flakes making contact with the oldest solvent, and progressing through the process until nearly oil-free flakes contact the fresh solvent. Two principal types of extractors have been employed over the years. These are as follows:

1) The immersion extractor

The immersion extractor immerses and soaks the material in the solvent (rather like the operation of a laboratory Soxhlet extractor).

2) The percolation extractor

In the percolation extractor, the solvent percolates by gravity through a bed of material. The solvent flows over the surface of the particles and diffuses through the material. Miscella flows

in successive passes, through the bed, while the solvent spray and the bed move in opposite direction to each other.

Generally, more solvent usage is required by immersion extractors. Few immersion extractors remain in use, and percolation extractors now dominate.

III.3.3. Refining

Refining of crude oils is a set of physicochemical processes aimed at removing undesirable compounds (impurities) while preserving the valuable components of the oil. The objective is to obtain a product with appropriate quality for consumption, storage stability, and potential industrial applications in the agri-food sector.

On one hand, refining ensures that the final oil meets consumer expectations in terms of clarity, light color, neutral taste, and oxidative stability. On the other hand, it guarantees that the oil complies with strict industrial specifications required for further processing and formulation.

Refining is regulated by national legislation, which defines it as a lawful treatment intended to maintain or improve the organoleptic properties and stability of edible fats and oils.

To achieve these objectives, refining involves a sequence of controlled physicochemical operations, performed using authorized processing aids and in accordance with established limits for residual substances.

The main stages of oil refining typically include:

- Degumming or acid conditioning (removal of phospholipids and mucilaginous substances)
- Neutralization (removal of free fatty acids)
- Bleaching (decolorization and removal of pigments and trace contaminants)
- Deodorization (elimination of volatile compounds responsible for odor and taste)
- Winterization (optional step to remove waxes and improve clarity at low temperature).

III.3.3.1. Chemical refining

Chemical refining is the traditional method used since ancient times. It can be used for all fats and oils even when they have been slightly degraded. Each step of the refining process has

specific functions for removing some undesirable compounds (Figure 30).

1) Degumming or Acid Conditioning

This operation allows for the elimination of phospholipids, instability factors that tend to cloud the oil and induce discoloration during heating.
For certain oils, an initial degumming (or demucilagination) can be carried out with water beforehand. The crude oil heated to 80°C receives an addition of about 3% water before passing thru a rapid mixer followed by a slow contactor before centrifugation: this technique is particularly used for soybean oil. The gums are recovered during centrifugation and can thus be valorized after drying; this results in "crude lecithin."
For crude oils less rich in phospholipids (rapeseed, sunflower, peanut), they are not specifically recovered by centrifugation; in this case, we refer to a step of mucilage conditioning, which is generally done by heating the oil to 60 - 80°C, adding 0.1 to 0.3% of 75% phosphoric acid, passing thru a rapid mixer and then a slow contactor; the mixture is then sent to the neutralization step. Phosphoric acid is by far the most widely used acid industrially at this stage.

2)Alkaline Neutralization

This step essentially allows for the elimination of free fatty acids by transforming them into soaps and separating them, as well as various residual compounds (phospholipids, proteinaceous compounds, etc.).

The method produces neutralization pastes (which can be utilized in soap production, lipochemistry, etc.) and washing fluids that require pretreatment before to discharge. The quantity of soda utilized is determined by the oil's acidity, often measured in oleic or palmitic acid content.

3)Whitening

The primary objective of this process is to remove the colored pigments present in the oil. Decolorization entails the use of an adsorbent agent (such as bleaching earths or silica, with or without activated carbon), involving physical processes, but some chemical alterations may be linked to the process.

This agent not only serves a decolorizing function by binding colored pigments but also exhibits a "cleaning" effect by adsorbing numerous unwanted chemicals found in the oil.

The adsorbent or the agent mixture is incorporated (ranging from 0.2% to 2%) into the decolorizer. The oil is heated to around 90° to 110°C and is aggressively stirred under vacuum; the interaction duration between the earth and the oil is roughly 30 minutes; subsequent to treatment, the oil is cooled and filtered.

4)Deodorization

This step often represents the concluding phase of refinement. The process requires no technological aids and involves the straightforward injection of steam into oil heated to elevated temperatures (180-240°C) under a high vacuum. Through steam distillation, volatile compounds responsible for the oil's flavors (such as aldehydes and ketones) are removed, along with any pesticide and mycotoxin residues. Upon completion of this phase, the oil attains a neutral flavor and is subsequently packaged under nitrogen to safeguard against oxidation.

5)Winterization

This operation pertains to specific oils abundant in waxes (ranging from 400 to 1400 mg/kg), including sunflower and grape seed oil. Waxes are esters formed from fatty alcohols and long-chain fatty acids that crystallize at ambient temperature, resulting in drawbacks when utilizing oils, such as cloudiness and sedimentation. Winterization, or dewaxing, entails promoting the crystallization of waxes by cooling the oil to approximately 5 - 10 °C and permitting the crystals to grow. The subsequent separation process is often performed through filtering utilizing a filtration aid (about 0.2 to 1%), identical to that employed in the decolorization phase.

The bleaching procedure often occurs between decolorization and deodorization. A first deodorization stage may be incorporated into the neutralization process: the oil is cooled to around 30°C, aged at this temperature, and the crystallized wax portion is subsequently separated during centrifugation, together with the neutralization pastes.

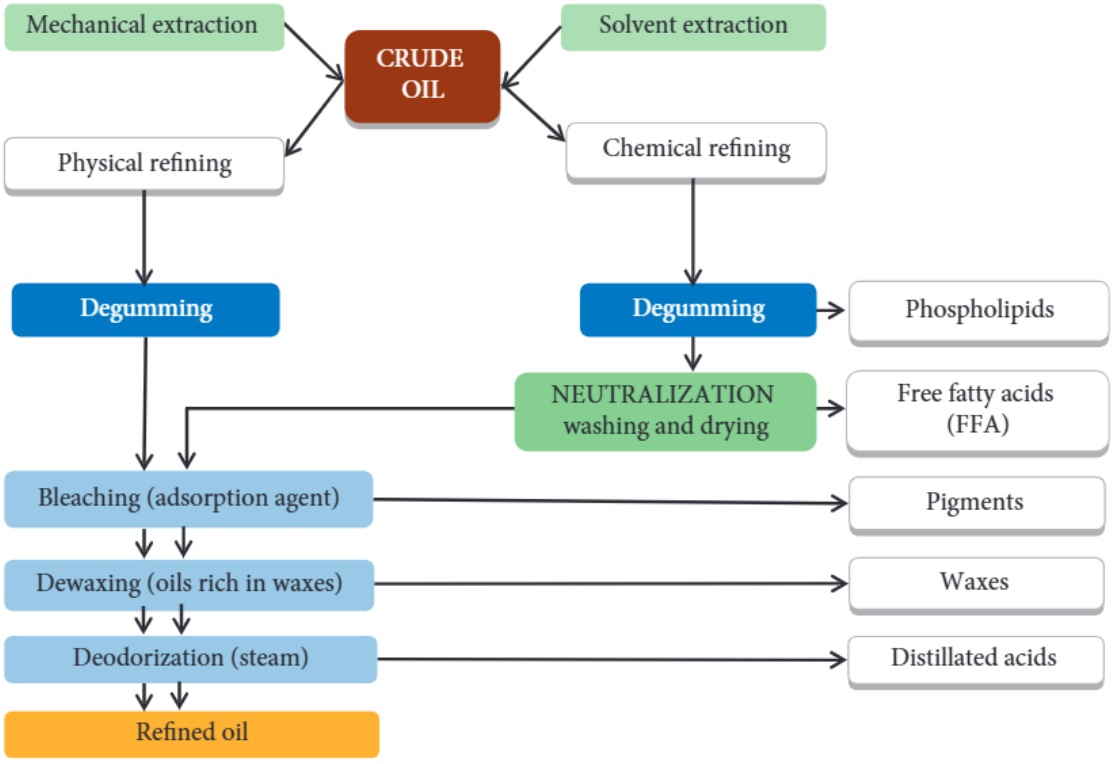


Figure 30: General overview of chemical and physical refining process of crude oil

III.3.3.2. Physical refining

The process consists of the same steps described in chemical refining, except for the alkali neutralization process. The difference between chemical and physical refining is illustrated in Figure 30. Chemical refining consists of removing free fatty acids by adding caustic soda and separating the soap by centrifugation (mechanical separation), while physical refining, in the last step, removes free fatty acids and other compounds by steam distillation. This process is also known as steam refining. Physical refining of crude oils, therefore, overcomes the disadvantages of neutralization by sodium hydroxide. Indeed, this process, which is deemed to be eco-friendly, minimizes liquid effluents generation. Another advantage of this process over chemical refining is that it is more economical (e.g., fewer chemicals used, lower investment cost, lesser energy input, and improved yield). However, this process is not suitable for all types of oils since it is hypersensitive to the crude oil quality. Indeed, physical refining is used for oils with high acidity. In general, physical refining includes the following three main processing steps:

(1) Degumming to remove phosphatides

(2) Bleaching and filtration to eliminate color pigments

(3) Deodorization allows the elimination of free fatty acids and other volatile compounds

III. 4. Margarine production

Margarine is a water-in-oil (W/O) emulsion derived from vegetable and/or animal fats, with a fat content of between 80% and 90% and a milk fat content of no more than 3%. The emulsion remains solid at 20 °C. Other W/O emulsions with a fat content of 39–41% may be designated as minarine or halvarine, according to the Codex Stan 256-2007. In addition to these two kinds of emulsions, there are others with fat contents outside the limits mentioned, which could be described as fat spreads. Table 12 shows the different kinds of margarines and related products and their denominations according to their fat content. Moreover, depending on their composition and texture, they have been described as hard, soft, and semisoft margarines.

Table 12: Kinds of margarines and related products according to their fat content (Council Regulation (EC) No. 1234/2007)

Denomination	**Fat content (%)**
Margarine	**≥ 80 to < 90**
Fat spreads X %	**> 62 to < 80**
Three-quarter fat margarine	**≥ 60 to ≤ 62**
Fat spreads X %	**> 41 to < 60**
Half-fat margarine	**≥ 39 to ≤ 41**
Fat spreads X %	**< 39**

III.4.1. Raw Materials and Formulation

III.4.1.1. Fat phase (80%)

A blend of refined vegetable oils and fats selected for the target consistency and melting profile. Common components include palm oil, palm olein, palm stearin, rapeseed oil, soybean oil, sunflower oil, and coconut or palm kernel oil.

The blend must achieve the desired solid fat content curve the proportion of fat in solid form

at different temperatures to give the product the right consistency at refrigerator temperature (4°C), room temperature (20°C), and body temperature (37°C, complete melting).

III.4.1.2. Fat modification techniques

Raw oils are often modified before blending to achieve the correct solid fat content:

A. Hydrogenation

Addition of H_2 to double bonds of unsaturated fatty acids converts liquid oils into semi-solid or solid fats with higher melting points. Full hydrogenation produces hard, stable base stocks with no trans fats; partial hydrogenation produces trans fatty acids, now widely regulated or prohibited due to cardiovascular health concerns.

B. Interesterification (chemical or enzymatic)

Fatty acids are redistributed among triglyceride molecules by a catalyst (sodium methoxide, chemical; sn-1,3 specific lipase, enzymatic). This modifies the solid fat content and crystallization behavior of the fat blend without generating trans fatty acids, and is the current preferred alternative to partial hydrogenation in trans-fat-free margarine production.

C. Fractionation

Physical separation of a fat or oil into fractions of different melting points by controlled crystallization and filtration (e.g., palm oil → palm stearin + palm olein). Provides natural hard and soft fractions without chemical modification.

III.4.1.3. Aqueous phase (16–19%)

Water or skim milk (for flavored margarine), acidified to pH 4.4–4.7 with lactic acid to inhibit microbial growth, and salted (NaCl, 1–2%) for flavor and preservation.

III.4.1.4. Minor ingredients (1–2%)

Emulsifiers (lecithin 0.1–0.5%, mono- and diglycerides 0.1–0.5%) to stabilize the W/O emulsion and control droplet size; salt; preservatives (potassium sorbate, benzoic acid); vitamins A and D (legally required in many countries at butter equivalent levels); colorants (β-carotene for yellow color) and flavors (diacetyl, butter flavor).

III.4.2. Manufacturing Process

To ensure the development of a proper margarine emulsion prior to the crystallization process, two distinct phases, aqueous and oil, must be prepared individually, prior to blending (Figure 31). The composition of the phases is designed for the three basic types of margarines:

(1) stick or regular margarine,

(2) soft or tub margarine, and

3) diet or calorie reduced margarine.

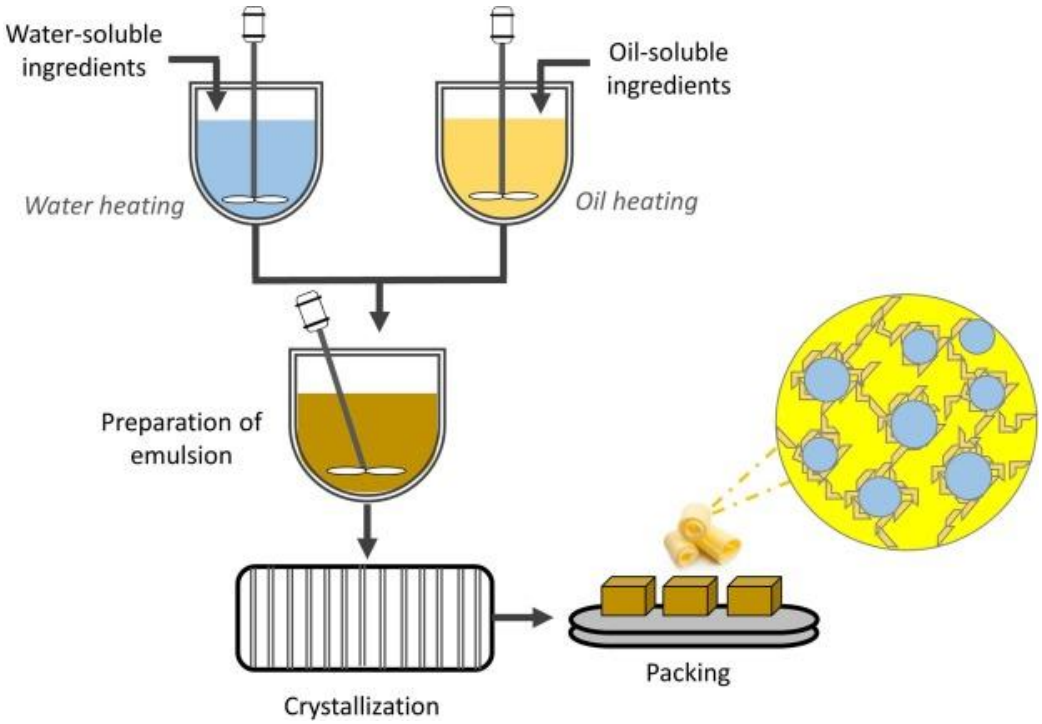


Figure 31: Conventional margarine production process and schematic representation of its microstructure.

1) Fat phase preparation: Oils and solid fats are blended at 40–50°C (above the melting point of all components) to form a homogeneous liquid fat blend. Fat-soluble ingredients (emulsifiers, vitamins A and D, colorants, fat-soluble flavors) are dissolved in the fat phase.

2) Aqueous phase preparation: Water or milk is heated to 40–45°C; salt, water-soluble flavors, and preservatives are dissolved. pH is adjusted with lactic acid.

3) Emulsification: The fat and aqueous phases are combined in a proportioning unit and mixed in a continuous emulsification tank under controlled agitation to form a homogeneous W/O pre-emulsion (droplet size 5–20 μm). The temperature is maintained above the melting point of all fats (typically 40–55°C) to keep the fat phase fully liquid.

4) Cooling and crystallization: The liquid emulsion is pumped at high pressure through A-units (scraped-surface heat exchangers, SSHE), where it is rapidly chilled to 10–22°C under intense agitation by scraped-surface blades. Rapid cooling induces fat crystallization in the β' polymorphic form, which confers the desired smooth, plastic texture. The temperature of the SSHE tubes is the single most critical processing parameter, directly controlling product consistency and crystal structure.

5) Working / pin-working: The partially crystallized emulsion passes through B-units (pin-workers or resting tubes), where mechanical working breaks up crystal agglomerates, distributes water droplets uniformly, and develops the final smooth, plastic, spreadable texture. Residence time in the B-unit (10–60 seconds) and pin-worker speed are adjusted to control product consistency.

6) Packaging: The margarine is filled into tubs (soft margarine) or extruded into foil-wrapped blocks (hard margarine) at the exit of the B-unit, while still semi-plastic. It is then held at cold storage (5–15°C) for final crystal stabilization before distribution.

III.5. Microbiological aspects

Pure, refined oils and anhydrous fats are intrinsically inhospitable to microbial growth due to the near-complete absence of water (water activity, $a_v \leq 0.10$). Consequently, refined oils per se do not support bacterial, yeast, or mold proliferation, and their main deterioration pathway is chemical (oxidative and hydrolytic rancidity) rather than microbiological. However, microbiological concerns are relevant in several specific contexts:

a) Raw oilseeds and crude oils

Oilseeds may carry mold contamination (particularly *Aspergillus flavus* and *A. parasiticus*), leading to aflatoxin (B_1, B_2, G_1, G_2) production in the seed. Aflatoxins are highly stable lipophilic compounds that can partition into the oil during extraction. Bleaching earth adsorbs some aflatoxins during refining (up to 70% reduction), but strict raw material control and monitoring are essential. EU Regulation 1881/2006 sets a maximum aflatoxin B_1 limit of 2 μg/kg in edible vegetable oils.

b) Margarine and emulsified fat products

Margarine contains an aqueous phase (16–20% water at $a_v \approx 0.92–0.94$), making it microbiologically vulnerable. The key spoilage microorganisms are:

1) *Pseudomonas* spp. and other Gram-negative bacteria cause putrid off-flavors in low-acid, unsalted margarines.

2) Molds (*Peucilium, Cladosporium*) surface mold growth, particularly at the interface between margarine and packaging.

3) Yeasts fermentative spoilage producing CO_2, off-flavors, and gas in tub margarines.

Microbial control in margarine is achieved through a combination of acidification (pH 4.4–4.7, which inhibits most spoilage bacteria), addition of chemical preservatives (potassium sorbate at ≤0.1%, benzoic acid), NaCl (1–2%), small water droplet size (<5 μm, limiting microbial access to the aqueous phase), and cold chain maintenance during distribution and retail (5°C).

c) Lipase-producing microorganisms

Lipolytic bacteria and molds (e.g., *Pseudomonas fluorescens*, *Penicillium roqueforti*) produce extracellular lipases that catalyze hydrolysis of triglycerides to free fatty acids (FFA) and glycerol, causing hydrolytic (soapy) rancidity in high-moisture fat products stored at elevated temperatures. Heat-stable microbial lipases can persist in refined oils even after pasteurization or UHT treatment if oilseed raw materials were heavily contaminated before processing.

d) Oxidative rancidity (chemical, not microbial)

The primary deterioration mode for refined oils. Unsaturated fatty acids undergo autoxidation via free-radical chain reactions (initiation → propagation → termination), producing hydroperoxides, aldehydes, ketones, and short-chain fatty acids responsible for rancid off-flavors. Oxidation is accelerated by light, heat, oxygen, and pro-oxidant metals (Fe, Cu). Prevention relies on antioxidants (tocopherols, BHA, BHT, rosemary extract), metal chelators (citric acid, EDTA), inert gas (N_2) blanketing, and opaque/dark packaging.

III.6. Legislation

The fats and oils sector are regulated at multiple levels: internationally by the Codex Alimentarius Commission (CAC), at the European level by EU regulations, and nationally by each member state's food law. Key regulatory frameworks are summarized below.

III.6.1. Codex Alimentarius Standards

The Codex Alimentarius (FAO/WHO) has established several standards relevant to fats and oils:

a) CXS 19-1981 (rev. 2019) — Standard for Edible Fats and Oils Not Covered by Individual Standards: Sets general quality parameters (acid value, peroxide value, moisture, impurities, unsaponifiable matter, soap content) and labeling requirements applicable to all food-grade vegetable oils.

b) CXS 33-1981 (rev. 2019) — Standard for Olive Oil and Olive Pomace Oil: Defines grade categories, physicochemical parameters (acidity, peroxide value, UV absorbance, fatty acid composition, wax content), and sensory requirements for each grade.

c) CXS 256-2007 (rev. 2019) — Standard for Named Vegetable Oils: Individual specifications for palm, soybean, rapeseed, sunflower, cottonseed, peanut, corn, sesame, and other named oils.

d) CXS 32-1981 (rev. 2017) — Standard for Margarine: Defines margarine as a food with a minimum fat content of 80%, sets limits on specific fatty acid composition, requires addition of vitamins A and D, and regulates permitted emulsifiers, preservatives, and colorants.

e) GSFA (Codex General Standard for Food Additives, CXS 192-1995): Regulates permitted additives in edible oils and emulsified fat products, including antioxidants, emulsifiers, and preservatives with specified maximum use levels (e.g., BHA, BHT max. 200 mg/kg fat; potassium sorbate max. 1,000 mg/kg in margarine).

III.6.2. European Union Legislation

a) EU Regulation 1308/2013 (Common Market Organisation): Defines fat spread categories — margarine (≥80% fat), fat spread (≥60% and <80% fat), low-fat spread (≥41% and <60% fat), and half-fat spread (≥10% and <41% fat). Mandates addition of vitamin A (min. 800 µg/100g) and vitamin D (min. 5 µg/100g) to margarine sold in the EU.

b) EU Regulation 1169/2011 (Food Information to Consumers): Requires mandatory nutrition labeling for fats and oils, including declaration of saturates, monounsaturates, and polyunsaturates per 100g. Trans fat content declaration is now mandatory under EU Regulation 2019/649, which sets a maximum limit of 2g trans fatty acids per 100g fat in food products sold to the final consumer.

c) EU Regulation 1881/2006 (Maximum Levels of Contaminants): Sets maximum levels of mycotoxins, polycyclic aromatic hydrocarbons, and heavy metals (arsenic, lead, cadmium) in edible oils.

d) EU Regulation (EEC) 2568/91 (as amended — Olive Oil): The most detailed fat regulation in the EU; defines physico-chemical parameters (free acidity, peroxide value, UV absorbance coefficients K_{232} and K_{270}, wax content, fatty acid composition, sterol composition, etc.) and sensory panel assessment requirements for each olive oil category.

III.6.3. International Olive Council (IOC) Standards

The **International Olive Council (IOC / COI)** is the intergovernmental body responsible for establishing international trade standards for olive oil. Its standard (COI/T.15/NC no. 3/Rev. 14, 2019) defines eight commercial categories of olive oil and olive pomace oil, including physicochemical and sensory thresholds for each, and is the reference standard for non-EU olive oil trading nations.

III.6.4. Algerian legislation

Algeria regulates fats and oils through national food legislation aligned with Codex Alimentarius standards and adapted to local requirements. Key regulatory instruments include:

III.6.4.1. Legal Framework

a) Law 00-07 (2000) — Law on Food Safety: Establishes general food safety principles, including requirements for food production, processing, storage, and distribution. Defines responsibilities for food business operators and sets the basis for food control systems.

b) Law 18-01 (2018) — Law on Consumer Protection: Strengthens consumer rights, including mandatory labeling requirements, prohibition of adulterated products, and protection against misleading information.

c) Executive Decree 19-63 (2019) — Defines hygienic and sanitary conditions for food business establishments, including those involved in fat and oil processing.

III.6.4.2. Quality Standards (ICSA Norms)

The Institut Algérien de Normalisation et de la Protection du Consommateur (IANOR) establishes Algerian standards for fats and oils:

Standard	Scope

NA 19001	General quality requirements for edible vegetable oils
NA 19002	Extra virgin olive oil — physicochemical parameters and sensory requirements
NA 19003	Virgin olive oil — specifications and quality criteria
NA 19004	Refined olive oil and olive pomace oil
NA 19010	Margarine — composition, fat content (≥80%), vitamin fortification
NA 19015	Sunflower oil — quality parameters and purity requirements
NA 19020	Peanut oil — specifications and quality criteria

III.6.4.3. Key Algerian Quality Parameters

- Edible vegetable oils (general):

Parameter	Limit
Free acidity (as oleic acid)	≤0.5% for refined oil
Peroxide value	≤10 meq O_2/kg
Moisture and volatile matter	≤0.1%
Insoluble impurities	≤0.05%
Unsaponifiable matter	≤1.5%

- Olive oil (extra virgin):

Parameter	Limit
Free acidity	≤0.8%
Peroxide value	≤20 meq O_2/kg
K_{232} (UV absorbance)	≤2.50
K_{270} (UV absorbance)	≤0.22
Sensory score	>0 (no defects)

III.6.4.4. Contaminant Limits

Algerian regulations align with Codex and EU limits for key contaminants:

Contaminant	Maximum Level
Aflatoxin B_1	2 µg/kg
Total aflatoxins	4 µg/kg
Ochratoxin A	10 µg/kg
Lead	0.1 mg/kg
Cadmium	0.05 mg/kg
Arsenic	0.1 mg/kg
Benzo[a]pyrene (PAH)	≤2 µg/kg

III.6.4.5. Labeling Requirements (Algerian Food Law)

Mandatory labeling information for fats and oils sold in Algeria includes the product name (e.g., "extra virgin olive oil," "sunflower oil"), net weight or volume, list of ingredients (including additives), nutritional information (energy, fat, saturates, carbohydrates, protein, salt), expiration date ("best before" or "use by"), storage conditions, name and address of the manufacturer or importer, country of origin (for imported products), batch or lot number, and allergen information (if applicable).

III.6.4.6. Margarine Regulations

Algerian standards for margarine (NA 19010) require a minimum fat content of 80%, fortification with vitamin A and vitamin D (similar to EU requirements), sodium chloride (salt) at 1–2%, preservatives such as potassium sorbate at a maximum of 0.1%, and a pH between 4.4 and 4.7.

III.7. Olive oil technology

Virgin olive oil (VOO) occupies a unique position among edible vegetable oils: it is obtained exclusively by mechanical means from the fruit of *Olea europaea* L. without the use of solvents or chemical treatments, and it can be consumed directly in the unrefined state, thus retaining its complement of minor bioactive components (polyphenols, tocopherols, squalene, sterols). The manufacturing process encompasses four main stages: fruit reception and preparation, paste preparation (crushing and malaxation), solid-liquid separation, and oil clarification/storage.

III.7.1. Olive Oil Production Technologies

The main extraction systems are the traditional press system and the modern continuous centrifugal systems (figure 32, 33), which include two-phase and three-phase decanters. The choice of technology strongly affects oil yield, quality, water use, and the amount of waste produced.

III.7.1.1. Traditional Discontinuous Press System

In the traditional system, olives are first crushed with stone mills, then the paste is spread on fiber disks and pressed to separate oil and water. This method can produce high-quality oil, but it is slow, discontinuous, and needs more manual labor. It is now largely replaced by modern continuous systems because of lower capacity and higher labor costs.

III.7.1.2. Continuous Centrifugal Extractions

Modern olive oil production uses centrifugal decanters, which allow continuous processing of large amounts of olives. The three-phase system adds water and produces oil, pomace, and wastewater, while the two-phase system uses little or no added water and produces oil plus a wetter pomace. Two-phase systems reduce wastewater and environmental impact, but their by-product is harder to treat and dry.

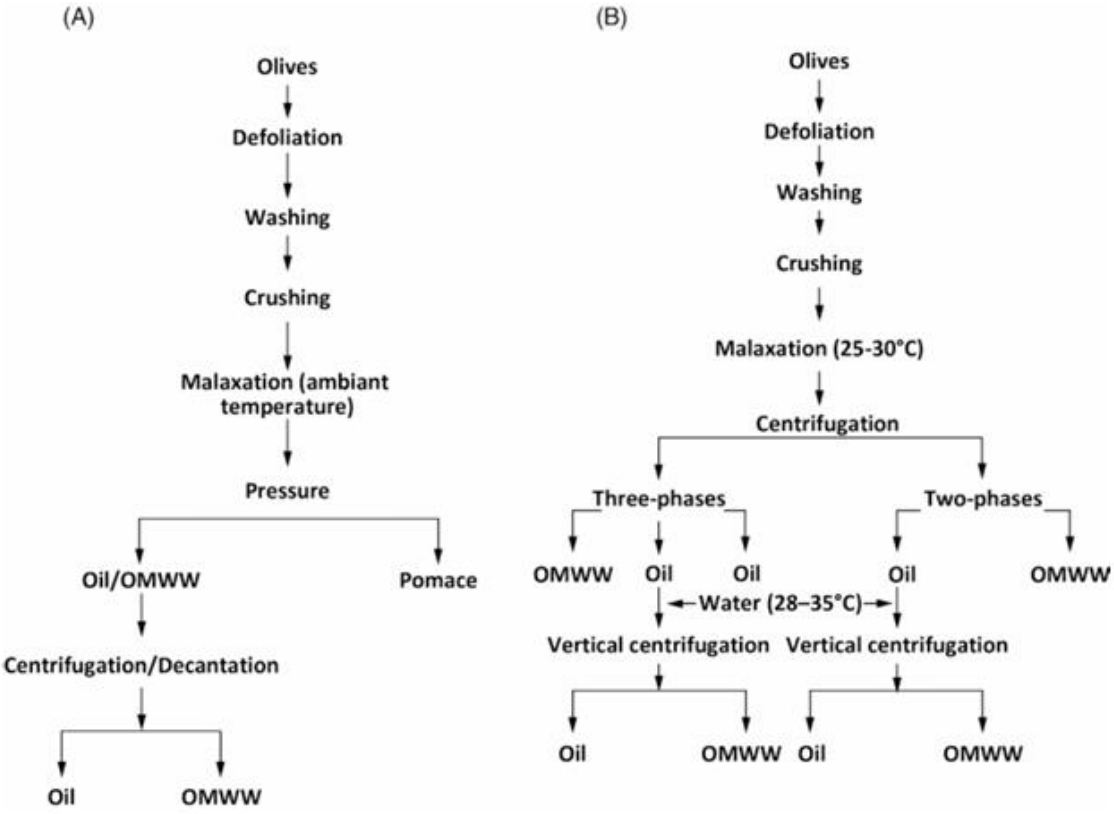


Figure 32: Extraction Processes of Virgin Olive Oil

III.7.1.3. Feeding, Leaf Removal, and Washing

This first processing step removes leaves, stems, twigs, dust, soil, and pesticide residues. Washing helps improve oil quality and prevents contamination of the equipment and paste. However, storage of olives before processing can reduce sensory quality because of changes in phenolics and volatile compounds.

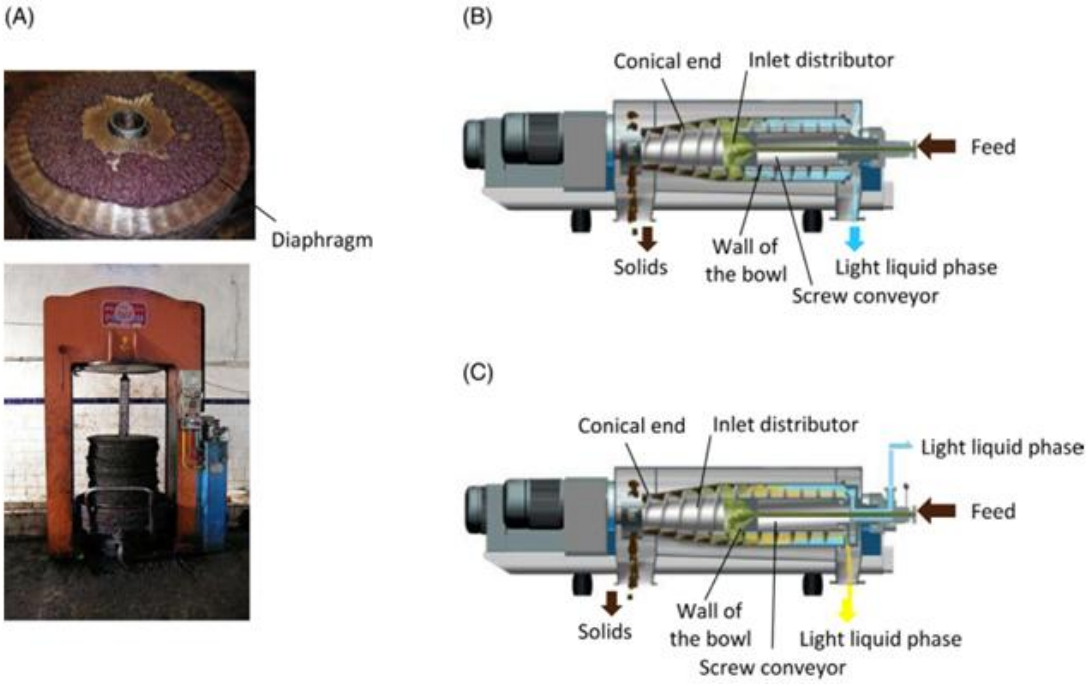


Figure 33: Extraction Processes of Virgin Olive Oil

(A) Press system. (B) Decanter (two-phases). (C) Decanter (three-phases). Decanters photos courtesy of Flottweg Separation Technology, Germany flottweg.com.

III.7.1.4. Crushing

Crushing breaks the olive cell structure and releases the oil droplets. It is a critical step because it affects phenolic compounds, volatile compounds, and final oil quality. Different crushers such as stone mills, hammer crushers, and disk crushers give different results, and destoning can improve oil quality by reducing oxidation from enzymes present in the seed (figure 34).

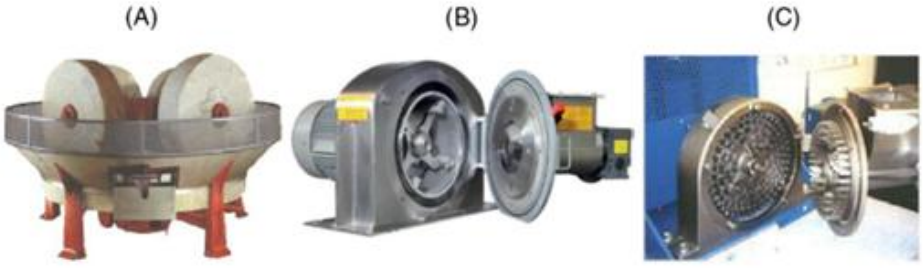


Figure 34: Types of Crushers (A) Stone Miller. (B) Disc Crusher. (C) Hammer Miller.

III.7.1.5. Malaxation

Malaxation is the slow kneading of the olive paste to help oil droplets merge into larger droplets that are easier to separate. Time, temperature, oxygen level, and paste composition are the main factors controlling yield and quality. Lower temperature and shorter time usually preserve phenols and aromas better, while excess oxygen can increase oxidation and reduce quality.

III.7.1.6. Centrifugation and Separation

The centrifugation step separates oil from solids and water based on density differences. In two-phase decanters, the oil and wet pomace are separated with no extra dilution water, while three-phase decanters produce oil, pomace, and olive mill wastewater. Two-phase systems usually preserve more phenols and generate less wastewater, but the wet pomace is more difficult to manage.

III.7.1.7. Oil Clarification

After separation, the oil still contains small water droplets and suspended solids, so it must be clarified. This is usually done by filtration or vertical centrifugation (figure 35).

Filtration is the most common method used to clarify olive oil. A steel prefilter can be added before the plate filter-press to retain part of the suspension, so the main filter only removes the remaining solids and water. This improves processing capacity and can handle about 1.8 times more oil per batch.

Vertical centrifugation removes the last water and solid particles, but it also increases dissolved oxygen in the oil and can speed up oxidation. To reduce this effect, inert gas can be used around the centrifuge. Natural sedimentation is a slower alternative, but it better limits oxygen exposure and can improve quality indices such as peroxide value, phenols, chlorophyll, carotenoids, turbidity, and K232. It may also extend shelf life.

Clarification improves shelf stability and prevents fermentation, hydrolysis, and oxidation, but filtration can also slightly reduce phenolic compounds and modify sensory characteristics.

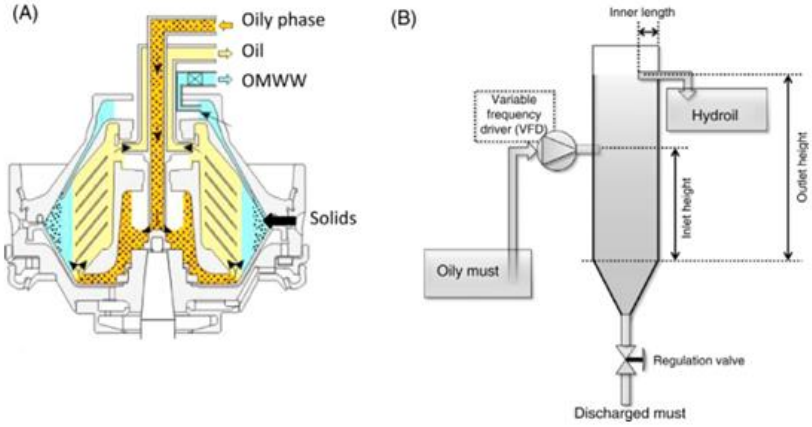


Figure 35: Systems Used for Oil Clarification Process. (A) Vertical centrifuge system and (B) Hydrocyclone prototype used for oil clarification

III.7.2. Olive Oil Categories and Grades

EU Reg. (EEC) 2568/91 and IOC standards define the following main commercial categories, determined by the extraction process and physicochemical / organoleptic parameters (Table 13):

Table 13: Olive oil categories and grades

Category	Production Method	Max. Free Acidity (%)	Max. Peroxide Value (meq O_2/kg)	Sensory
Extra Virgin Olive Oil (EVOO)	Mechanical extraction only	≤0.8	≤20	Zero defects; positive fruitiness required
Virgin Olive Oil (VOO)	Mechanical extraction only	≤2.0	≤20	Minor defects permitted; positive fruitiness required
Lampante Virgin Olive Oil	Mechanical extraction	>2.0	—	Major defects; not fit for direct consumption; must be refined
Refined Olive Oil	Refining of lampante oil	≤0.3	≤5	Neutral; no organoleptic character
Olive Oil (blend)	Refined + virgin olive oils	≤1.0	≤15	Mild organoleptic character
Olive Pomace Oil (refined)	Hexane extraction from pomace + refining	≤0.3	≤5	Neutral; solvent-extracted

Part 4. Beverages

I. Economic Overview of the Fruit Juice Industry

The fruit juice industry represents one of the most dynamic segments of the global non-alcoholic beverage sector. Driven by rising health consciousness, growing disposable incomes, urbanization, and continuous product innovation, the sector has experienced sustained growth over the past two decades and is expected to expand further in the coming years, both at the global level and in emerging markets such as Algeria.

I.1. Global Market

The global fruit juice market was valued at approximately USD 159.65 billion in 2024 and is projected to reach USD 229.59 billion by 2034, growing at a CAGR of 3.7% (2025–2034). This growth reflects a structural shift from carbonated soft drinks toward natural, nutrient-rich beverages aligned with health and wellness lifestyles.

Europe dominates the market (2024), led by Germany, France, Spain, and Poland, with mature consumption habits and strong demand for organic and functional juices. North America ranks second, driven by high per capita consumption and premium offerings. Asia Pacific is the fastest-growing region (China, India), fueled by urbanization and rising health awareness. Latin America benefits from exceptional fruit biodiversity (Brazil, Argentina, Mexico).

By product type, juice drinks (juice + water/additives) are the largest segment due to affordability, while 100% fruit juice is projected to grow fastest as clean-label products gain traction. By flavor, orange juice remains the global leader, followed by apple and mango. Mango is the fastest-growing flavor, particularly in tropical and emerging markets.

The industry is highly concentrated, dominated by Coca-Cola (Minute Maid, Simply), PepsiCo (Tropicana, Naked Juice), Nestlé, Del Monte, and Ocean Spray. In 2021, PepsiCo sold Tropicana for USD 3.3 billion, reflecting sector consolidation.

I.1.2. The Fruit Juice Industry in Algeria

Algeria, with 46 million inhabitants, is a growing market for fruit juices in Africa. Juice consumption reached 1 billion liters in 2024 and is projected to grow 9% to 1.16 billion liters by 2028, driven by a young, health-aware population and Ramadan peaks.

Algeria ranks fifth in Africa for soft drinks (3.5 billion liters) but remains a net importer, with imports of USD 12.7 million versus exports of USD 3.73 million in 2024, mainly from Italy, Greece, and Thailand. This import dependence signals opportunities for local investment. Food machinery exports to Algeria exceeded €415 million in 2024, reflecting expanding production capacity. Growth is driven by urbanization (73% urban), health awareness, and cultural traditions, while constraints include inflation, reduced purchasing power, and limited cold chain infrastructure. Algeria's USD 24 billion agricultural sector provides raw materials (citrus, date, fig, apricot, grape) to support local juice processing aligned with food sovereignty policies.

2. The classic stages of manufacture

2.1. Definition of a juice

Fruit juice is the unfermented but fermentable liquid obtained from the edible part of sound appropriately mature and fresh fruit or of fruit maintained in sound condition by suitable means including post-harvest surface treatments applied in accordance with the applicable provisions of the Codex Alimentarius Commission. Codex Alimentarius defines juice as “unfermented but fermentable juice, intended for direct consumption, obtained by the mechanical process from sound, ripe fruits, preserved exclusively by physical means. The juice may be turbid or clear. The juice may have been concentrated and later reconstituted with water suitable for the purpose of maintaining the essential composition and quality factors of the juice. The addition of sugars or acids can be permitted but must be endorsed in the individual standard”. Some common juice designations are given in Table 14.

Table 14: Jus categories

Term used	Criteria	Remarks
Pure juice 100%	All juice	No adjustment, not from concentrate
Fresh squeezed	Not pasteurized	Held refrigerated, food safety concerns
Chilled, ready to serve	All juice	Held refrigerated, made from concentrate or pasteurized juice
Not from concentrate	Single strength	Pasteurized after extraction
From concentrate	Made from concentrate	Reconstituted and pasteurized
Fresh frozen	Unpasteurized	Single strength, frozen after extraction
Juice blend	All juice	A mixture of pure juices
Puree	Pulp-containing	More viscous than juices, totally fruit
Nectar	Pulpy or clear	Sugar, water and acid added, 25 to 50% juice
Nectar base	Requires reconstitution	Possesses sufficient flavor, acid and sugar to require water dilution for consumption

Juice drink	Low in juice	Contains 10 to 20% juice
Juice beverage	Low in juice	Contains 10 to 20% juice
Juice cocktail	Low in juice	Contains 10 to 20% juice
Fruit + ade	Lemonade	Contains >10% fruit juice, sugar and water
Juice extract	Water extract	Fruit extracted by water, then concentrated
Fruit punch	Token juice	1% juice, + natural flavors
Natural flavored	Token juice	Usually >1% juice

2.2. Production line

The industrial fruit juice production line follows a generalized sequence applicable to most fruit types, with specific adaptations depending on the botanical characteristics of the raw material (texture, skin, seeds, pectin content). The principal stages are summarized in Figure 36.

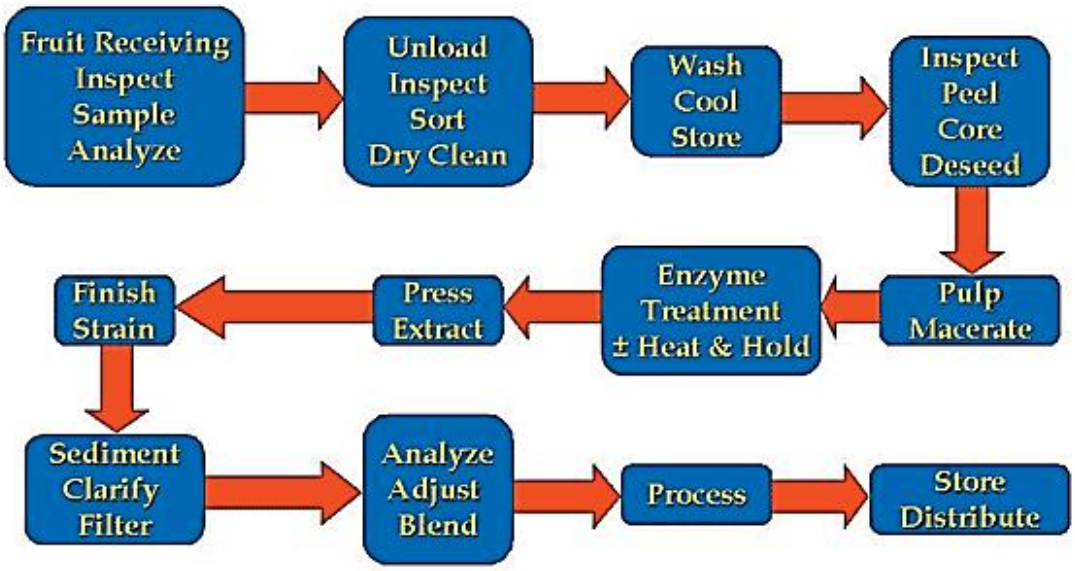


Figure 36: Generalized juice flow scheme.

Modern juice plants are largely automated and operate as continuous systems, replacing the earlier labor-intensive batch configurations. Automation has enabled the implementation of Clean-in-Place (CIP) systems, which allow sanitation of process equipment without disassembly, significantly reducing downtime and contamination risk. A typical CIP cycle consists of a pre-rinse with water, an alkaline detergent wash (NaOH, 0.5–2%), a hot water rinse, an acid rinse (HNO_3 or H_3PO_4, 0.5–1%), and a final sanitizing rinse.

2.3. Fruit Preparation

Before extraction, raw materials undergo several preparatory steps that are critical for both yield and product safety.

2.3.1. Reception and quality control

Upon delivery, a representative sample is analyzed for soluble solids content (°Brix), titratable acidity, pH, color, pesticide residues, aflatoxin levels, and total microbial count. Lots failing these criteria are rejected to prevent contaminating entire production batches.

2.3. 2. Dry cleaning and washing

Dust and surface debris are removed first by air jets and brushes (dry pre-cleaning), followed by water washing. Wash water is typically chlorinated (50–200 ppm free chlorine) and recycled to minimize consumption. Inadequate sanitation at this stage can raise the microbial load entering the extraction step.

2.3.3. Sorting and inspection

Manual or automated optical sorters (using computer-controlled sensors and cameras) detect and remove defective, diseased, or undersized fruits. This step is particularly critical because a single contaminated fruit, once juiced, can spoil an entire processing lot.

2.3.4. Peeling, coring, and de-seeding

Fruits with inedible or bitter skin, cores, or seeds (e.g., apples, pineapple, citrus, mango) require removal of these parts before comminution to prevent extraction of undesirable compounds such as bitter limonoids (citrus), tannins (apple seeds), and toxic amygdalin (stone fruit kernels).

2.3.5. Controlled storage

When the processing capacity cannot absorb the entire harvest at once, fruit may be held under controlled atmosphere storage adjusting O_2, CO_2, and ethylene levels or frozen for long-term preservation prior to juicing.

2.4. Extraction

Juice extraction is the central operation in which the liquid fraction is separated from the solid fruit matrix. The choice of extraction method depends on the botanical structure of the fruit (soft vs. firm flesh, presence of peel/seeds), the desired juice type (cloudy vs. clear), and the scale of production.

2.4.1 Crushing and comminution

The first step in juice extraction is size reduction of the fruit into a pulp or crush. Equipment used includes hammer mills, roller crushers, and knife mills, selected according to fruit consistency. The degree of comminution is a critical parameter: insufficient crushing lowers juice yield, while excessive comminution extracts undesirable compounds from seeds, skins, and cores, resulting in elevated bitterness and browning.

2.4.2 Pressing

After crushing, the juice is separated from the solid pomace by pressing. Several types of pressing equipment are used industrially:

a) Batch hydraulic rack-and-cloth presses: The crush is placed in cloth-lined frames stacked in a hydraulic press. Multiple pressings with cake redistribution between cycles are performed to maximize yield. These are labor-intensive but offer gentle treatment suitable for delicate fruits.

b) Pneumatic bladder presses: Used for grapes and apples; a flexible membrane is inflated by air or water to press the crush against a perforated drum. Gentle action minimizes extraction of harsh compounds from seeds and skins.

c) Continuous screw presses: High-throughput auger-type systems capable of handling several tones per hour. Require careful control of applied pressure to avoid excessive shear that can rupture seeds and introduce off-flavors.

d) Belt presses: The pulp is distributed between two porous conveyor belts and subjected to progressively increasing pressure by a series of rollers. Provide a gentler action than screw presses, with good yield and juice clarity.

2.4.3 Reaming (citrus-specific)

For citrus fruits (orange, lemon, grapefruit), a specialized extraction system using reaming heads (rotating conical reamers pressed against the halved fruit) is used. This method limits contamination from the bitter essential oils of the peel. Industrial citrus extractors (e.g., the Brown or FMC systems) can process hundreds of fruits per minute.

2.4.4 Infusion extraction

An alternative technique used for certain minor fruits; the crushed flesh is mixed with water to

dissolve soluble solids, which are then separated from the insoluble pulp. Counter-current extraction systems maximize efficiency by contacting fresh water with the most spent pulp stage. A subsequent concentration step is required to restore the original °Brix.

2.5. Juice Treatment

After extraction, the raw juice contains suspended solids, colloidal particles, pectin, starch, proteins, and a variable microbial load. A series of treatments is applied to achieve the desired clarity, stability, and safety.

2.5.1 Enzymatic treatment

Pectins and starches form a network that increases viscosity and impedes pressing and filtration. Pectinolytic enzymes (pectinase, polygalacturonase, pectinmethylesterase) are added to hydrolyze these polysaccharides, reducing viscosity dramatically and facilitating subsequent clarification steps. Typical conditions: 0.01–0.05% enzyme preparation, 40–55°C, 30–120 minutes holding time. For starchy fruits such as apple, amylase is also added to hydrolyze residual starch that would otherwise cause post-filling haze.

2.5.2 Fining

Colloidal haze-forming substances (proteins, polyphenols, tannins) are removed by fining agents: bentonite (negatively charged clay mineral) adsorbs positively charged proteins; gelatin forms insoluble complexes with tannins and polyphenols; isinglass and casein are also used for specific applications. The flocculated material settles or is removed by centrifugation.

2.5.3 Centrifugation

A continuous disc centrifuge (3,000–12,000 rpm) or decanting centrifuge separates the bulk of suspended solids from the clarified juice. Centrifugation is a prerequisite to fine filtration, substantially reducing the particulate load and protecting downstream filters from rapid clogging.

2.5.4 Filtration

Several filtration systems are employed depending on the target clarity:

a) Diatomaceous earth (DE) filtration: A body feed of DE is mixed into the juice and a filter aid pre-coat is applied to a rotary vacuum drum or plate-and-frame filter. The continuously renewed DE bed traps colloidal particles and achieves brilliant clarity.

b) Microfiltration: Ceramic or polymeric membranes that retain yeast, bacteria, and colloidal particles while allowing sugars, acids, and vitamins to pass. Produces a microbiologically stable juice without thermal treatment, important for premium cold-filtered products.

c) Ultrafiltration: Removes proteins, high-molecular-weight polyphenols, and colloidal pectins, producing an extremely bright and stable juice. Often combined with diafiltration to optimize sugar recovery from the retentate.

2.5.5 Deaeration

Dissolved oxygen in juice promotes enzymatic browning (via polyphenol oxidase), non-enzymatic Maillard reactions, degradation of vitamin C, and oxidative off-flavors. Deaeration is performed either by vacuum flashing (heating to 70–80°C and flashing into a vacuum chamber) or by inert gas sparging (bubbling N_2 or CO_2 through the juice). Following deaeration, all subsequent operations must be conducted under inert atmosphere protection.

2.6. Equipment

The key equipment items in a juice production line are summarized below:

Table 15: key equipment used for fruit jus production

Operation	Equipment	Key Parameters
Washing	Brush washers, spray washers, flotation tanks	Water flow rate, chlorine concentration (50–200 ppm), contact time
Sorting / Inspection	Roller conveyors, optical sorters (machine vision)	Line speed, rejection rate
Crushing / Milling	Hammer mills, roller crushers, knife mills	Rotor speed, screen aperture
Pressing	Belt press, bladder press, screw press	Applied pressure, belt speed, number of press cycles
Centrifugation	Disc centrifuge, decanting centrifuge	Rotational speed (rpm), feed rate, sludge discharge frequency
Enzymatic treatment	Insulated holding tanks with agitators	Enzyme dosage, temperature (40–55°C), holding time (30–120 min)
Filtration	Plate-and-frame filter, rotary vacuum filter, MF/UF membranes	Pore size / MWCO, transmembrane pressure (TMP), flux
Deaeration	Vacuum deaerator, inert gas sparger	Vacuum level (–0.8 to –0.95 bar), N_2 or CO_2 flow
Heat exchange	Plate heat exchanger (PHE), tubular heat exchanger, scraped-surface HE	Inlet / outlet temperatures, flow rates, hold time
Aseptic filling	Aseptic filler, Tetra Pak or PET blow-fill-seal systems	Sterility assurance, container sterilization (H_2O_2, UV)

2.7. Continuous Unit Operations

Modern industrial juice plants are designed as continuous-flow systems, where the product moves uninterruptedly from one operation to the next via a series of interconnected process equipment items. This contrasts with older batch systems, which required filling, treating, and emptying individual vessels sequentially.

In a continuous production line, flow rates, temperatures, pressures, and residence times are controlled in real-time by Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems. The key advantages of continuous operation over batch processing include: higher throughput capacity (measured in tons of fruit or liters of juice per hour); consistent product quality due to steady-state operating conditions; reduced labor requirements; and compatibility with automated CIP cleaning cycles.

Critical continuous unit operations in juice manufacture include:

2.7.1. Continuous Pressing

Continuous pressing separates juice from solids using mainly belt presses and screw presses. Belt presses apply increasing pressure through rollers, achieving 75–90% yield with capacities up to 40 tons/hour. Screw presses use a rotating screw to compress mash and extract juice but must avoid excessive shear to prevent quality loss. Counter-current diffusion is also used, especially for citrus fruits, though it dilutes the juice and requires later concentration.

2.7.2. Continuous Centrifugation

Disc-stack centrifuges remove suspended solids after extraction. High-speed rotation separates particles efficiently, with solids discharged automatically through self-cleaning systems. This ensures continuous operation and stable clarification. Centrifugation reduces the load on downstream filtration and is often sufficient alone for cloudy juices such as orange or pineapple.

2.7.3. Continuous Enzymatic Treatment

Pectin is broken down using enzymes, mainly pectinases, to reduce viscosity and prevent haze formation after bottling. Optimal conditions include a temperature range of 40–55°C, a naturally suitable pH for most fruit juices, and a residence time of 30–120 minutes depending on enzyme dose and pectin content. Enzymes are added continuously via metering pumps and are later inactivated by heat treatment at 80–95°C.

Immobilized enzymes in packed-bed or fluidized-bed reactors are an emerging alternative, allowing continuous use without the need for enzyme recovery or heat inactivation.

2.7.4. Continuous Evaporation

Falling-film evaporators concentrate juice under vacuum with a very short residence time to preserve heat-sensitive quality compounds. Multi-effect systems reuse the latent heat of evaporation multiple times, dramatically improving energy efficiency. Typical concentration ranges from 10–12° Brix up to 65–72° Brix. The process operates at low temperatures, typically 40–70°C, to avoid thermal damage such as non-enzymatic browning or loss of aroma and color. Industrial evaporators include aroma recovery systems that capture volatile compounds and re-add them during reconstitution to restore fresh-juice flavor. Alternative technologies like reverse osmosis exist but are less widely used at industrial scale due to membrane fouling and throughput limitations.

2.7.5. Continuous Pasteurization

HTST pasteurization ensures product safety by achieving a minimum 5-log reduction in pathogenic microorganisms. Plate heat exchangers are used for clear, low-viscosity juices, while tubular systems are preferred for viscous products such as fruit purées or pulpy juices. The process includes four functional stages: regeneration (heat recovery), heating to target temperature, holding in an insulated tube for the required time, and final cooling to 4–8°C before filling. Precise control of temperature and time is essential to guarantee microbial destruction. After pasteurization, the cooled juice is filled either aseptically into sterilized packaging under a sterile atmosphere or hot-filled at 82–85°C.

2.8. Thermal and Enzymatic Treatment of Juice

2.8.1 Thermal treatment

Heat treatment of juice serves several simultaneous purposes: inactivation of native fruit enzymes (particularly polyphenol oxidase / PPO and peroxidase / POD, which cause browning and off-flavor development); inactivation of industrially added enzymes (pectinase) at the end of the enzymatic clarification step; reduction of microbial load; and improvement of juice stability during storage.

2.8.2 Hot break vs. cold break

Two distinct thermal strategies are used prior to or during extraction, each with different objectives and effects on the quality of the final product.

a) Hot break

involves rapidly heating the crushed fruit mash to a temperature of 85–95°C before pressing. This thermal operation immediately inactivates polyphenol oxidase (PPO), an enzyme responsible for oxidation and browning of the juice. Hot break also maximizes color development, which is particularly desirable for tomato juice where an intense red color is preferred. Additionally, heating softens the fruit cell walls, allowing for increased juice extraction yield. However, this method has a major drawback: it can destroy delicate volatile aroma compounds, reducing the complexity and freshness of the final juice flavor.

b) Cold break

Involves pressing at ambient temperature, typically below 15–20°C. This low-temperature approach preserves delicate flavors and vitamins in the fruit, as it avoids thermal degradation of sensitive compounds. Enzyme inactivation (such as PPO) is deferred to a post-extraction pasteurization step, where the juice is heated after extraction. Juice obtained by cold break tends to have a lighter color and to be richer in volatile aroma compounds, making it particularly suitable for fruit juices where flavor freshness and natural aroma are priorities, such as white fruit juices or certain exotic fruit juices.

The choice between hot break and cold break depends on the type of fruit being processed and the desired quality characteristics of the final product: hot break for maximum yield and intense color (tomato), cold break for preserving natural aroma and flavor freshness (delicate fruits).

2.8.3 Enzymatic treatment

Enzymes play a key role in fruit juice processing by breaking down the cellular matrix of fruits (pectins, cellulose, hemicellulose), thereby increasing extraction yield, facilitating clarification, and reducing viscosity (Table 16). They primarily act on the cell walls, which are composed of more than 90% structural polysaccharides, preventing the efficient extraction of intracellular juice.

Industrial pectinases and hemicellulases are added to the crushed fruit or extracted juice to

hydrolyze the pectin matrix. The result is a dramatic reduction in viscosity and a corresponding increase in press throughput, filtration flux, and final juice clarity. The enzymatic activity is terminated by the subsequent pasteurization step (above 75–80°C), which denatures the enzyme proteins.

Table 16: Main Enzymes and Their Targets

Enzyme	Main Target	Action	Typical Fruits
Pectinases (pectinesterases, polygalacturonases, pectin lyases)	Pectic substances (protopectin → pectin → pectic acid)	Depolymerization, demethylation, clarification	Apple, pear, citrus, mango, apricot
Cellulases (endo/exo-cellulases)	Cellulose (β-1,4-glucans)	Hydrolysis into glucose/oligosaccharides	Pineapple, kiwi, carrot, banana
Hemicellulases (xylanases, mannases)	Hemicellulose (xylans, mannans)	Degradation of branched polysaccharides	Stone fruits (peach, plum), dates
Lignases (laccases, peroxidases)	Lignin (aromatic polymer)	Oxidation/degradation	Limited use (phenolic clarification)

2.9. Physical Treatment

Alongside conventional thermal pasteurization, several non-thermal and mild thermal physical technologies have been developed to inactivate spoilage microorganisms and enzymes while better preserving the sensory and nutritional quality of juice.

1. High-Pressure Processing (HPP)

The packaged or bulk juice is subjected to isostatic pressures of 300–600 MPa for 1–6 minutes at near-ambient temperature. This inactivates vegetative bacteria, yeasts, and molds (5-log reduction) and partially inactivates PPO and PME, while preserving heat-labile vitamins, aroma compounds, and pigments. HPP is widely used for premium cold-pressed NFC juices. Products require refrigeration and have a shelf life of 30–90 days.

2. Pulsed Electric Fields (PEF)

Short, high-intensity electric field pulses (20–80 kV/cm, 1–300 μs pulse duration) are applied to juice flowing through a treatment chamber. The electric field causes electroporation (irreversible membrane rupture) of microbial cells without significant heating. PEF also facilitates extraction by disrupting cell walls in the comminution step, increasing juice yield by 5–20%.

3. Ultraviolet (UV) treatment

UV light at 254 nm irradiates juice flowing as a thin film through UV-transparent quartz tubes. It is particularly effective against *Cryptosporidium* and *E. coli* O157:H7 in apple juice and cider. UV treatment is most effective in optically clear juices; turbidity significantly reduces UV penetration depth.

4. Membrane sterile filtration (MF, 0.1–0.2 µm)

The microfiltration physically removes microorganisms without any heat input, producing a "cold-sterilized" juice. Shelf life at refrigeration temperatures is 3–6 weeks.

5. Ohmic heating

An alternating electric current is passed directly through the juice, generating heat uniformly throughout the volume via electrical resistance. Particularly suited to viscous, particulate-containing juices that are difficult to heat uniformly in conventional heat exchangers.

2.10. Pasteurization

Pasteurization is the primary and most widely applied thermal process in the juice industry, aimed at reducing pathogen load and inactivating spoilage enzymes to acceptable levels for consumer safety and adequate shelf life.

2.10.1 Thermal principles.

Pasteurization is governed by two key parameters: the temperature and the holding time. Their relationship is described by the pasteurization unit and the D-value (decimal reduction time : the time required at a given temperature to reduce the target microbial population by 90%). The z-value (temperature change producing a 10-fold change in D) is approximately 7–9°C for most juice pathogens. For juices with a pH below 4.6, *Alicyclobacillus acidoterrestris* (a heat-resistant, spore-forming spoilage bacterium) is the relevant target organism.

2.10.2 HTST pasteurization (High-Temperature Short-Time)

The most common industrial process: 72–95°C for 15–30 seconds (depending on fruit type, pH, and target organism). The juice flows continuously through a plate heat exchanger with three sections: regeneration (pre-heating by the outgoing pasteurized juice), heating (via hot water or steam), and cooling (via chilled water). Regenerative heat recovery typically captures 80–90%

of the energy used.

2.10.3 UHT (Ultra-High Temperature) treatment

Applied when ambient-temperature, long-shelf-life (6–12 months) products are required: 120–140°C for 2–15 seconds in a tubular or plate heat exchanger, followed by aseptic filling into pre-sterilized containers. UHT treatment achieves commercial sterility ($F_0 \geq 3$ minutes equivalent at 121°C) while limiting heat damage to flavor and nutrients due to the very short exposure time.

2.10.4 Hot-fill

An alternative to aseptic processing; juice is pasteurized and then filled into containers at a temperature of 85–95°C. The hot product itself sterilizes the inner container surface. Containers are then inverted briefly to sterilize the closure and subsequently cooled by tunnel spray. Hot-fill is simpler and less capital-intensive than full aseptic systems, but the elevated temperature during filling and cooling may cause heat-induced flavor changes and partial degradation of thermolabile vitamins.

3. Carbonated Beverages

Soft carbonated beverage is a nonalcoholic, sweet, light, flavored, water-based drink that have carbon dioxide added to them to make them bubbly or fizzy. The flavoring agents used may be artificial or natural, are often colored and can also contain fruit pulp, fruit juice or caffeine. The sweetener may be fruit juice, fructose corn syrup, sugar or sugar substitutes. These are also known as fizzy drink, soda pop, coke, pop etc varying from region to region.

Soft Carbonated beverages may be classified as:

- Flavored and sweetened carbonated beverages.
- Carbonated water or soda with or without permitted flavors
- Flavored and sweetened carbonated water with dietetic/ electrolyte mixtures in formulation
- Flavored and sweetened carbonated water with fruit juice, fruit pulp and fruit concentrate

3.1. Composition

A carbonated beverage is essentially a multi-component system in which carbon dioxide is dissolved under pressure in an aqueous flavored medium. The main components are:

1) Water (90–99%): The principal solvent and carrier medium. Must be of high purity free from off-odors, excess hardness (Ca^{2+}, Mg^{2+}), chlorine, iron, and microbial contamination. Treated successively by sand filtration, activated carbon adsorption, ion exchange softening, UV sterilization, and reverse osmosis or membrane filtration to meet process specifications.

2) Sweeteners: Traditional beverages use sucrose or high-fructose corn syrup at concentrations of 8 to14° Brix (80–140 g/L). Diet variants use non-nutritive sweeteners: aspartame (E951), acesulfame-K (E950), sucralose (E955), stevia glycosides (E960), or combinations thereof to replicate the sensory profile of sugar at much lower caloric contribution.

3) Carbon dioxide (CO_2): The gas responsible for carbonation and the characteristic effervescence. Industrial CO_2 used for food-grade carbonation must meet purity standards (≥99.9% CO_2, residual impurities below permitted limits). Carbonation levels vary by product category: sparkling water (3.5–4.5 volumes CO_2); cola drinks (3.5–4.0 volumes); fruit-flavored CSDs (2.5–3.5 volumes); energy drinks (2.0–3.0 volumes). One volume of CO_2 = 1.96 g CO_2 per liters at 20°C.

4) Acids (acidulants): Provide tartness and act as preservative aids by lowering pH. The most commonly used are: phosphoric acid (H_3PO_4, used in cola-type drinks; imparts a sharp, clean acidity); citric acid (lemon/fruit-flavored drinks; contributes a softer, fruity tang); malic acid (apple-flavored drinks); and tartaric acid (grape drinks). Final beverage pH is typically 2.5–4.0.

5) Flavorings: Either natural (derived from fruit extracts, essential oils, spices) or artificial flavoring compounds, used at very low concentrations (0.005–0.3%). Cola flavor is a complex blend of citrus oils, cinnamon, vanilla, and other proprietary aromatic compounds. natural fruit flavors are typically added as with other natural flavors or not from concentrate extracts.

6) Colorants: Added to provide visual identity. Examples: caramel color (E150) for cola drinks; tartrazine (E102) for yellow/lemon drinks; Red 40 / Allura Red (E129) for red-fruit variants. Natural colorants (beta-carotene, anthocyanins, curcumin) are increasingly preferred in clean-label formulations.

7) Preservatives: Sodium benzoate (E211) and potassium sorbate (E202) are the most widely used preservatives in CSDs, effective at the low pH conditions of these beverages (pH < 4.0). The inherent low pH and dissolved CO_2 already confer significant microbial stability;

preservatives provide an additional safety margin.

8) Other functional ingredients: Caffeine (stimulant, 8–20 mg/100 mL in cola drinks); quinine (bittering agent in tonic water, regulated at ≤83 mg/L in the EU); taurine and B-vitamins (in energy drinks).

3.2. Different Treatments

The production of carbonated beverages follows a sequence of carefully controlled operations:

3. 2.1. Water treatment

Impurities such as suspended particles, organic matter and bacteria may degrade the taste and color. They are removed through the traditional process of a series of coagulation, filtration and chlorination (Figure 37). Coagulation involves mixing a gelatinous precipitate, or floc (ferric sulphate or aluminum sulphate) into the water. The floc helps in absorbing suspended particles, thus making them bigger in size so that they are easily entrapped by filters. The clarified water is then made to pass through sand filter aiding the removal of fine floc particle.

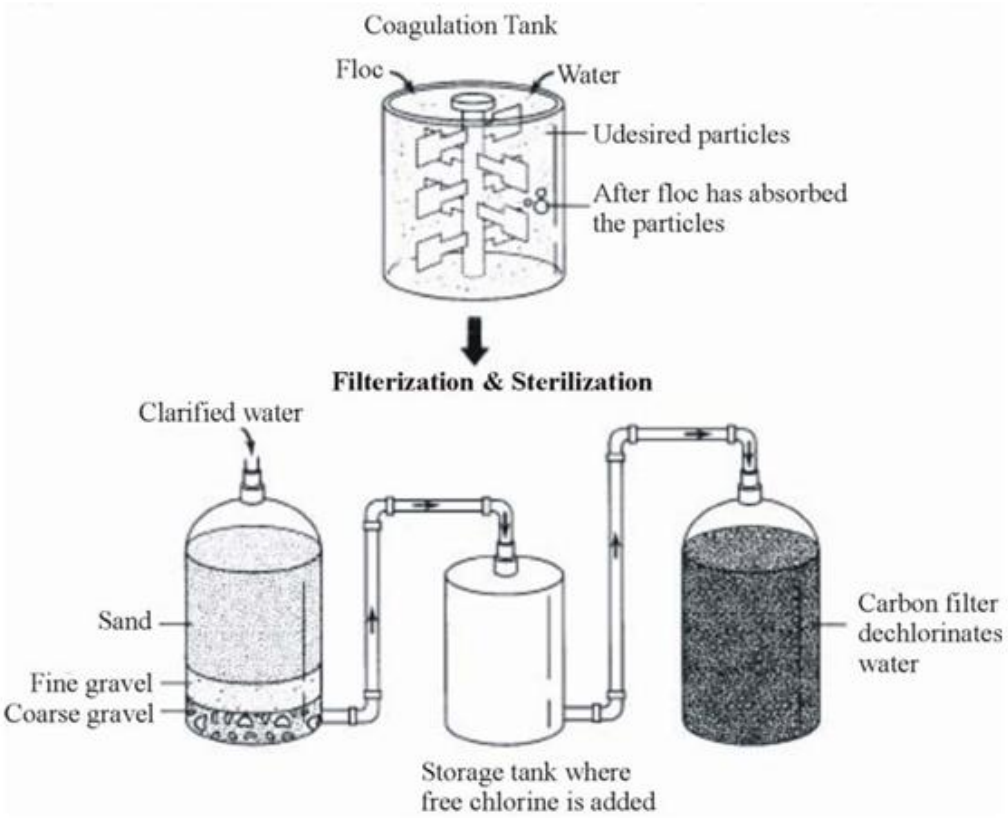


Figure 37: Water purification process by coagulation, filtration, and sterilization.

Microbiological quality of water is also taken into consideration. The presence of bacteria and organic compounds hamper the organoleptic quality of water. For disinfecting, water is treated with small quantity of chlorine and kept in the tank for at least two hours to complete the reaction. After that it is passed through activated carbon filter which helps in dechlorinating the water and also the remaining organic matter. This is followed by deaeration of water by pumping it through vacuum pump. The water which is to be used should be either soft (<50 mg/l as CaCO3) or medium soft (50–100 mg/l as CaCO3).

3.2.2. Syrup preparation (simple syrup and finished syrup)

Basic ingredient of most of the soft carbonated beverages is sugar syrup, which can be prepared by combining cane sugar or beet sugar with water. Sugar used may be in granulated or liquid form. Liquid sugar dissolves directly in water however if it is granulated then it requires special conditions for dissolution such as increased temperature which hasten the rate of solubility. Cane or beet sugar can also be replaced by high fructose corn syrup (HFCS). HFCS is a sweetener derived from enzymatically treated corn starch so as to increase its fructose content. Syrup is produced in concentrated form in the syrup rooms. It includes mixing of all the ingredients in proportions either manually or automatically with required ratio of water. Finally, the syrup is diluted with addition of carbonated water and bottled (figure 38).

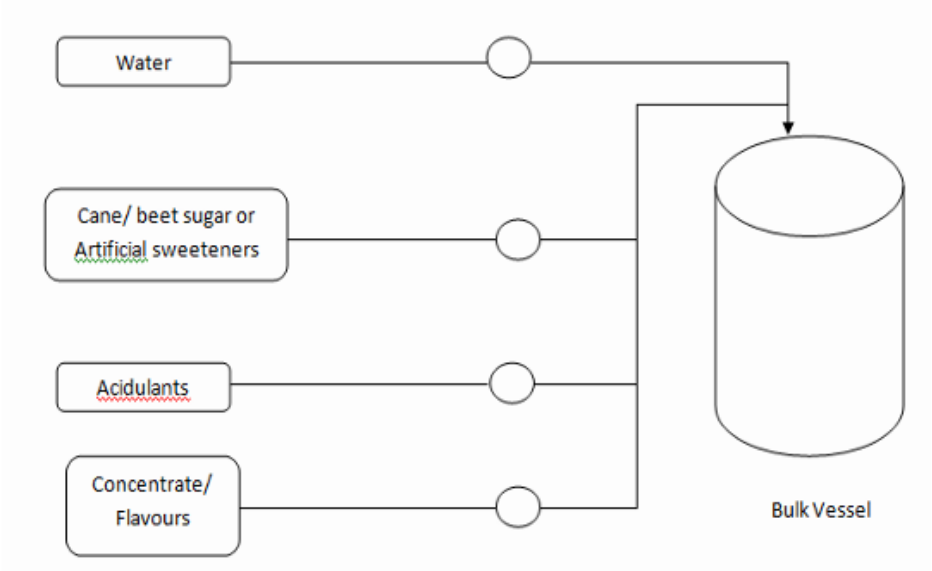


Figure 38: Process of preparation of syrup

3.2.3. Blending (syrup proportioning)

The finished syrup is proportioned with treated water at a precise volumetric ratio using an automated proportioning system (also called a "blender" or "Brix control unit"). The ratio is determined by the target °Brix of the final beverage. The blended, pre-carbonation stream (called the deaerated water-syrup blend) must be chilled to 4–8°C before carbonation, since CO_2 solubility in water increases significantly with decreasing temperature.

3.2.4. Deaeration

Dissolved oxygen in the water-syrup blend must be reduced to the lowest possible level (<0.1 mg/L) before carbonation, as O_2 competes with CO_2 for absorption, impairs carbonation efficiency, promotes oxidative flavor deterioration, and reduces shelf life. Deaeration is accomplished by vacuum treatment combined with gentle agitation in a vacuum deaerator vessel.

3.2.5 Carbonation

The chilled, deaerated blend is brought into intimate contact with food-grade CO_2 under pressure in a carbonator. Two main techniques are used:

- **Forced (artificial) carbonation:** Used for all non-fermented CSDs. CO_2 at a controlled pressure (typically 2–6 bar depending on the target volumes) is injected into the chilled blend through a sparger or a packed column. The Henry's Law equilibrium between dissolved CO_2 concentration and partial pressure determines the final CO_2 level:

$C = kH \times PCO_2$, where kH is the temperature-dependent Henry's constant.

- **Natural carbonation:** Applies to fermented beverages (beer, certain soft drinks) where the CO_2 produced biologically during fermentation is retained under sealed conditions. The CO_2 dissolves in the liquid under the pressure of the closed fermentation vessel.

3.3. Packaging

The filling and packaging of carbonated beverages requires specialized equipment specifically designed to maintain carbonation during container filling and to ensure hermetic sealing against CO_2 loss and microbial contamination.

3.3.1. Container types

Carbonated beverages are packaged in four main container formats:

- **PET (polyethylene terephthalate) bottles:** The most widely used format globally. PET is lightweight, shatter-resistant, and recyclable. However, PET has a finite CO_2 permeability; high-barrier treatments (MXD6 coatings, active barrier layers) are applied for small-format or long-shelf-life applications where CO_2 loss during storage is critical.
- **Aluminum cans:** Two-piece cans (drawn and wall-ironed) offer a complete gas and light barrier, rapid chilling, and a high strength-to-weight ratio. They are extensively recycled. End (lid) seaming with a seamer machine creates the hermetic closure.
- **Glass bottles:** Returnable or non-returnable. Provide an inert, impermeable barrier with no flavor interaction. Sealed with crown caps (non-returnable) or ROPP closures. Heavier and more fragile than PET; used for premium products.
- **Bag-in-box and post-mix systems:** Beverage syrup concentrate is packaged separately from CO_2 and water; mixing occurs at the point of dispensing (e.g., fountain drinks in restaurants). Offers logistical advantages and freshness.

3.3.2. Filling technologies

Carbonated beverages are filled using isobaric filling to prevent loss of CO_2 and excessive foaming. The process includes container rinsing or sterilization, pre-pressurization with CO_2, controlled filling, snifting to release excess pressure, and immediate capping or seaming to ensure airtight sealing. After filling, containers undergo date coding, labeling, secondary packaging, palletizing, and stretch wrapping. In some cases, tunnel pasteurization is applied after sealing to extend shelf life for PET bottles or cans stored at ambient temperature.

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