Introduction :

Cold is used as a means of preserving perishable food products (milk, dairy products, meat, fish, vegetables, prepared meals, etc.). In the 18th century, the engineer Charles Tellier created the first technological refrigeration machines. Today, refrigeration is considered an almost essential method for storing food until consumption, both at the household and industrial levels. The temperatures applied are low: when they are above 0°C, it is called **positive cold** (refrigeration); when they are below 0°C, it is called **negative cold** (freezing).

The application of cold is the most widely used preservation technique. Low temperatures delay the growth of microorganisms as well as the chemical and enzymatic reactions that spoil the product. When properly applied, cold preserves the natural characteristics of foods. The use of cold has had consequences at both the individual level (appearance of frozen foods) and the economic level (reduction of losses).

Each microorganism has an optimal, maximum, and minimum growth temperature. The minimum temperature corresponds to the lowest temperature that still allows growth; below this temperature, the microorganism is no longer able to grow and its metabolic activities slow down. When the temperature is sufficiently low, it is possible to inhibit microbial growth.

Since cold is not a sterilizing treatment like heat, it is therefore essential that the food intended for preservation be of good microbiological quality and have reached a stage of maturity suitable for consumption.

The three fundamental principles (Monvoisier's refrigeration tripod) form the basis of any use of cold:

1. **Product quality** (the product must be wholesome).
2. **Prompt application of cold** (the product must be cooled quickly).
3. **Continuity of cold** (from production to consumption). This requires maintaining the cold chain (cold storage warehouses, refrigerated trucks, cold rooms, and household refrigerators).

These cold processes are partly based on a reduction in the water activity of the food. Indeed, the water activity (Aw) of ice decreases as temperature decreases. It change from Aw = 1 at room temperature to Aw = 0.95 at –5°C and to Aw = 0.82 at –20°C.

.1 / Refrigeration (Positive Cold)

Refrigeration involves storage at temperatures above the freezing point (0°C). It includes two stages:

a) Cooling

Lowering the temperature to the desired level; this process must be rapid, especially if it follows cooking.

b) Storage at refrigeration temperature

This storage is limited in time, which explains the need for a **use-by date (expiry date)**. In refrigerated products, water remains in the liquid state. Enzymatic activity is only slowed down, and psychrophilic microorganisms (cold-tolerant bacteria) can still grow. Consequently, the storage period is short (a few days).

.1.1 / Action of Positive Cold

Cold does not destroy toxins or microorganisms present in food, but it can stop or slow down their development.

Examples of the effect of cold on microbial growth:

- **At 10–12°C:** Toxin production by Staphylococcus aureus and Clostridium botulinum (types A and B) stops.
- **At 6.7°C:** Multiplication of Staphylococcus aureus stops.
- **At 6.5°C:** Multiplication of Clostridium perfringens stops.
- **At 5°C:** Multiplication of Salmonella stops.
- **At 3.3°C:** Toxin production by Clostridium botulinum stops.

.1.2 / Evolution of Microflora During Refrigeration

At refrigeration temperatures, the microorganisms capable of developing are mainly **psychrophiles** (surface spoilage flora). Their growth is slowed between 0 and 4°C.

The main spoilage genera include:

- Pseudomonas ,Acinetobacter, Aeromonas, Enterobacter, Micrococcus, Streptococcus, Lactobacillus, Flavobacterium, Listeria

The activity of these microorganisms increases with temperature.

- An increase of **5°C** doubles microbial growth.
- An increase of **10°C** multiplies growth by four.

This explains why strict maintenance of the cold chain is essential during refrigeration.

On the other hand, this growth is regulated by the **water activity (Aw)** of the surface layers of the product. These microorganisms require a water activity of **0.96** or a relative humidity of **96%**. Consequently, the surface drying of the product (such as meat) that occurs during refrigeration limits the growth of these contaminants.

At low temperatures and in dry air, only a few mold species develop, such as:

- Aspergillus, Penicillium, Cladosporium

In conclusion, for effective preservation by refrigeration, it is important to sufficiently lower the refrigeration temperature and reduce water activity.

Figure II.1 shows the evolution of the microflora of refrigerated milk. The growth of these bacteria may contribute to the development of significant defects. After 48 hours at 4°C, psychrophilic flora becomes dominant. These microorganisms produce heat-resistant lipolytic and proteolytic enzymes. These enzymes are responsible for the solubilization of casein and also act on the milk fat.

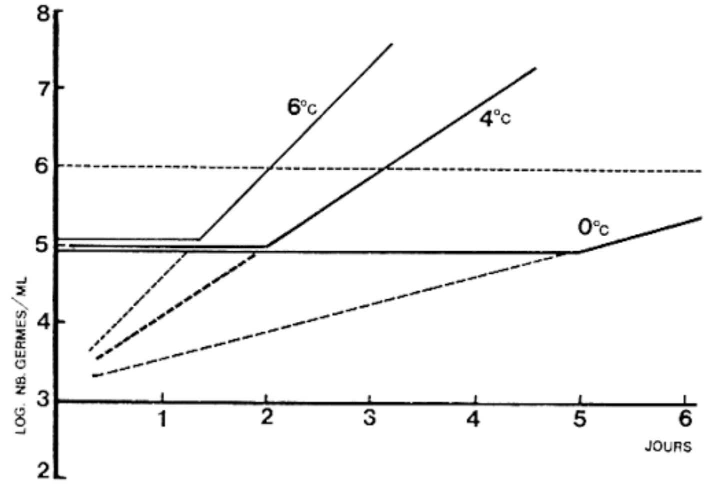

Figure II.1: Curve Representing the Evolution of Milk Microflora During Refrigeration

.1.3 / Parameters Influencing Bacterial Activity During Refrigeration

.1.3.1 / Temperature

The storage duration is longer when the refrigeration temperature is close to the **minimum growth temperature** of the microorganisms.

Example:

- Contaminants in beef increase **10-fold** when the temperature rises from 4°C to 9°C.
- They increase **100-fold** when the temperature rises from 9°C to 15°C.

This illustrates the critical importance of maintaining strict refrigeration temperatures to slow microbial growth.

La température de réfrigération permet également une sélection des germes contaminants.

Exemple : à 1°C, la flore dominante du poulet est *Pseudomonas*, à 15°C c'est les

Enterobactéries et les *Acenitobacter*.

.1.3.2 / Cooling Rate (Réfrigération Vitesse)

To prevent spoilage originating from the inner parts of the product (caused by deep contaminants responsible for putrefaction), it is important that the core of the product reaches the refrigeration temperature as quickly as possible.

However, this must be done without causing cryo-shock to the surface layers (see Figure II.2).

Half-Cooling Time (t½cooling)

- Defined as the time required to reduce by half the temperature difference between the core of the product and the cooling medium.

Example:

- t½cooling = 20 min: Slow refrigeration
- t½cooling = 8 min: Rapid refrigeration

A faster cooling rate helps limit microbial growth in the core and maintains product quality, but excessive speed may damage surface tissues.

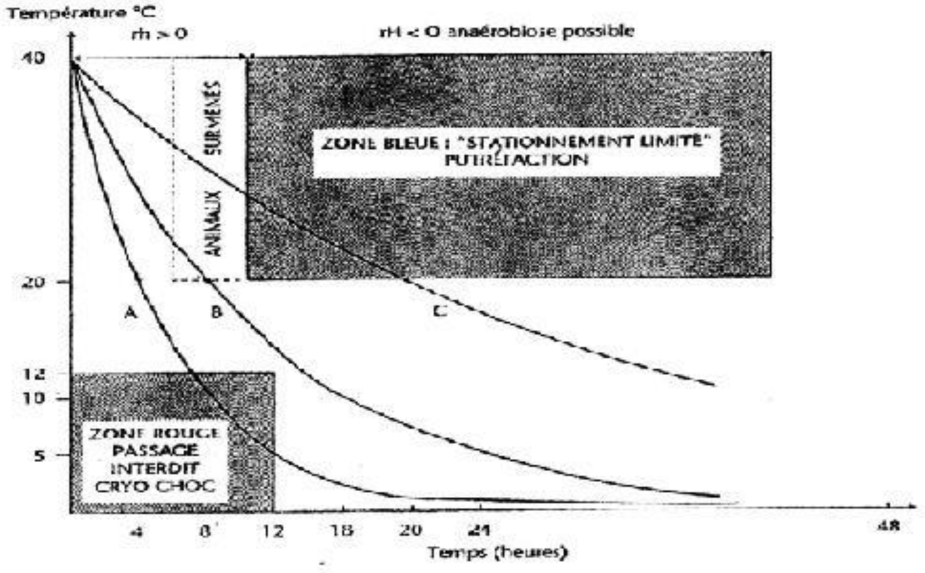

Figure II.2: Theoretical Refrigeration Curves of Beef

.1.4 / Cooling Systems and Techniques

.1.4.1 / Cooling Systems

a) Direct Expansion and Indirect Cooling

Vapor-compression cooling systems are the most widely used (see Figure II.3):

- **Direct expansion:** The evaporator is placed **directly in contact** with the medium to be cooled.
- **Indirect cooling system:** Cooling is achieved via an **intermediate fluid**, which is itself cooled by a refrigerant such as:
    - **CFCs** (ChloroFluorocarbons)
    - **HCFCs** (HydroChloroFluorocarbons)
    - **HFCs** (HydroFluorocarbons)

These refrigerants can have a **harmful effect on the ozone layer**.

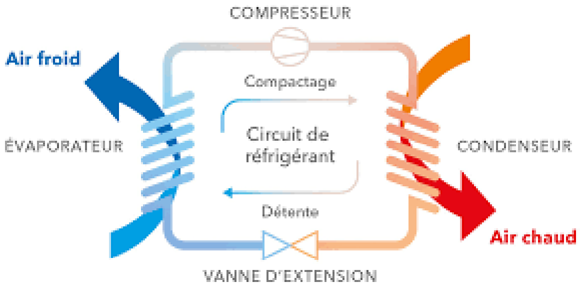

Figure 3: Diagram of a Direct Expansion Cooling System (a) and an Indirect Cooling System (b)

Main Techniques Used for Food Preservation by Cooling

a) Slow Refrigeration

- Cooling occurs at ambient air, around 15°C.

b) Rapid Refrigeration

- Conducted in a cooling chamber with **forced air circulation** at 0–5°C.
- Prevents microbial growth in the core of the product.
- However, it can cause **cryo-shock** if applied too quickly.

c) Electrical Stimulation

- Meat carcasses are stimulated with an electric current.
- Contractions rapidly consume glycogen, lowering pH.
- Rigor mortis occurs on a relaxed muscle, improving tenderness.

d) Forced-Air Cooling

- High ventilation of cold air accelerates the cooling process.

e) Misting (Brumisation)

- Fine droplets of sterile water are sprayed on the product surface.
- Accelerates cooling and prevents weight loss.

f) Vacuum Cooling

- Water evaporates under low pressure, cooling the product efficiently.

g) Ice-Water Cooling

- The product is sprayed with or immersed in ice-cold water for rapid chilling.

These techniques are chosen based on the **type of food**, **desired shelf life**, and **sensitivity to temperature changes**.

.2 / Freezing (Negative Cold)

Freezing involves lowering the temperature of a product sufficiently to **transform its water content into ice** and maintaining this state throughout the storage period.

Freezing preserves food through **two main effects**:

1. **Elimination of liquid water**
    - Water is transformed into ice, which **prevents microbial activity** and **slows down enzymatic reactions**.
2. **Thermal effect**
    - The product is cooled to temperature zones where **all biological activity is greatly reduced**.

The quality of frozen products is related to the **amount of residual liquid water**.

Example – Meat:

- Freezing point: **-1.1°C** (due to mineral salts and protein interactions)
- The percentage of frozen water increases as temperature decreases, but a **proportion of liquid water always remains**:
    - **26% liquid water at -5°C**
    - **18% liquid water at -10°C**
    - **14% liquid water at -18°C**
    - **10% liquid water at -40°C**

Exemple : Storage Durations for Frozen Foods

The **freezing time and safe storage duration** vary depending on the type of food:

- **Bread:** ~1 month
- **Fatty fish and shellfish:** ~3 months
- **Lean fish:** ~6 months
- **Lamb and veal:** 6–8 months
- **Cheeses, fruits, and vegetables:** 8–10 months
- **Beef and poultry:** up to 12 months

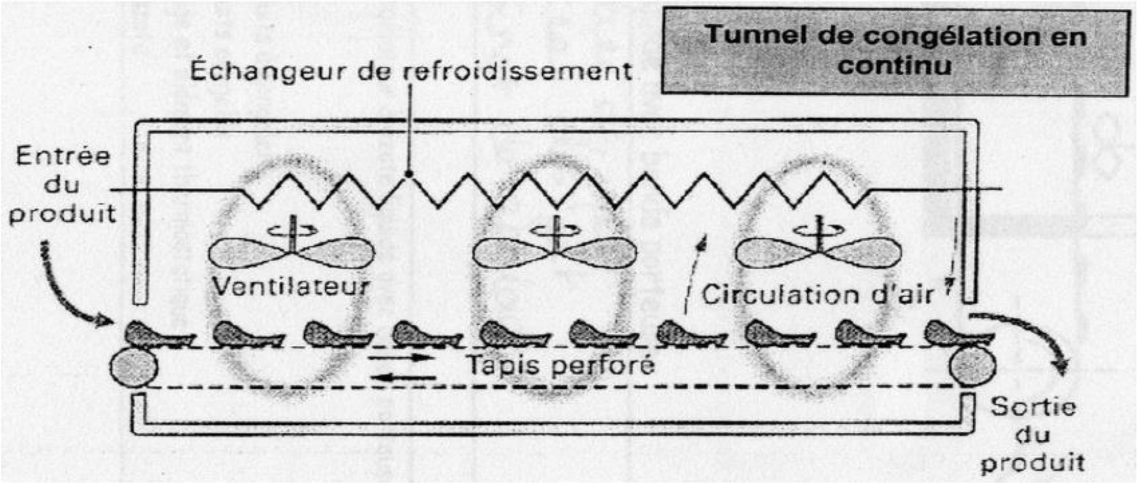

Diagram of a Freezing Tunne

C. Quick Freezing (Surgélation)

Quick freezing, also called **rapid freezing**, is an industrial process that **cools food very quickly** (from a few minutes up to an hour) by exposing it to extremely low temperatures, typically **below -18°C** (sometimes -35 to -196°C).

Key Points

- This process causes the **water inside the cells to crystallize finely**, which limits cell damage.
- Once frozen, products must be **stored at ≤ -18°C**.
- During thawing, **only a small amount of liquid loss (exudate)** occurs.

Freezing Times (examples)

- Green beans: 5–7 minutes
- Whole chicken: ~15 minutes

Advantages of Quick Freezing

- Preserves **texture, flavor, and quality** of the food

- Extends shelf life (e.g., vegetables up to **30 months**)
- Frozen foods are the same types as those suitable for conventional freezing

Equipment

- Quick freezing is typically carried out in a **freezing tunnel** (Figure 10).

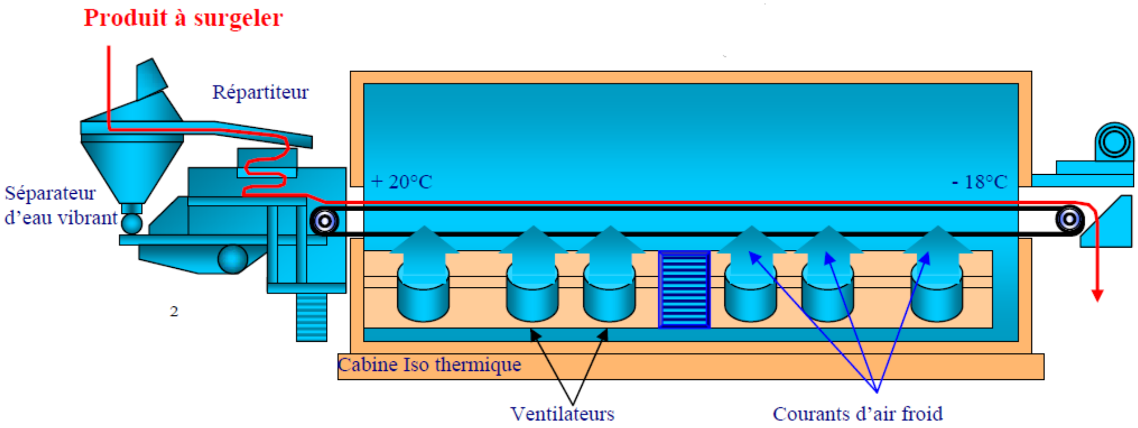

Figure 10: Diagram of a Quick-Freezing (Surgélation) Tunnel

.2.1/ Effect of the Freezing Process on Microorganisms

Freezing affects the microbial flora in different ways.

a) The decrease in temperature reduces the rate of microbial growth.

b) The transformation of water into ice reduces the amount of water available to microorganisms; therefore, freezing inhibits their multiplication.

c) The change of state from liquid water to ice causes structural or metabolic alterations in microorganisms, which may lead to the death of some of them.

-Influence of Freezing Temperature

During freezing at **-10°C**, all bacterial multiplication stops, including that of psychrophilic and psychrotrophic bacteria. At **-12°C**, the growth of molds stops, and at **-18°C**, yeast multiplication ceases.

It is important to emphasize that even freezing at -18°C does not have a bactericidal effect. It only reduces the microbial population to a limited extent. In this regard, some microorganisms are more sensitive than others.

Highly sensitive microorganisms include budding yeasts and molds, as well as Gram-negative bacteria, especially enterobacteria. Moderately sensitive microorganisms include Gram-positive bacteria such as *Enterococcus*, *Staphylococcus*, *Micrococcus*, and *Lactobacillus*. Resistant microorganisms include vegetative cells of yeasts and molds and bacterial spores.

While some microorganisms can resist cold temperatures, parasites, on the other hand, can be eliminated by freezing. The larvae of tapeworms (*Taenia*) and *Trichinella* die after five weeks at -18°C.

Therefore, it is essential that freezing, frozen storage, and temporary storage temperatures after thawing be strictly controlled in order to prevent the proliferation of dangerous microorganisms.

.2.2/ The Stages of Freezing

Freezing is divided into three main stages.

a) Pre-freezing: This stage consists of cooling the product down to its freezing temperature, also called the “initial crystallization temperature.”

b) Freezing phase (crystallization): This phase corresponds to the change of state of water into ice, during which ice crystals form and grow through ice nucleation.

c) Cooling (final cooling/storage): This stage refers to maintaining the product at the freezing temperature for preservation .

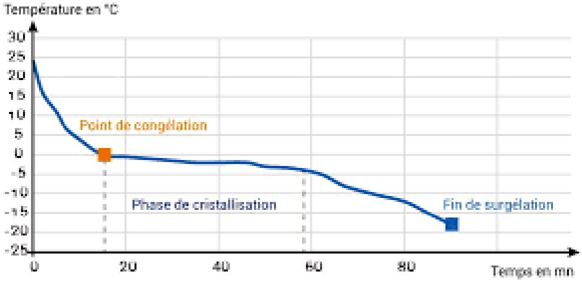

Figure II.4: The Phases of Freezing

.2.3/ Influence of Freezing Rate

Depending on the freezing rate, two types can be distinguished:

a) Slow freezing: This method has a more harmful effect on the survival of microorganisms because the cells are exposed for a longer time to cryoconcentration. As water freezes, the concentration of extracellular liquids increases. Water gradually leaves the cells, which progressively undergo plasmolysis and dehydration. In addition, ice crystals formed during slow freezing are larger, increasing the risk of membrane damage.

b) Rapid freezing: This method is characterized by extra- and intracellular crystallization, with the formation of small ice crystals due to the phenomenon of supercooling within the cell. For yeasts, rapid freezing is considered more favorable.

The destruction of microorganisms by cold is also influenced by the composition of the food product. Substances such as salt, glucose, and glycerol act as cryoprotectants.

Ultra-rapid freezing, which produces cells with a vitrified appearance, is reserved for the preservation of grafted tissues.

.2.4/ Effects of Freezing on Food

Frozen products are not inert; their quality gradually decreases during storage due to chemical and physical changes. The storage temperature is specific to each product depending on the intended shelf life. Most foods are stored at **-18°C**. Table I shows the maximum storage times of food products according to storage temperature.

.2.4.1/ Physicochemical Changes

✓ **Increase in water volume (9%):** This increase may create stress within tissue structures.

✓ **Tissue dehydration:** This is particularly noticeable in plant products (possible plasmolysis of cells) and leads to dehydration by sublimation (freezer burn). Water losses result in weight loss and depend on the surface area exposed relative to volume. They are more significant for small-sized products and for irregular surfaces. Therefore, it is recommended to package products before freezing and to ensure that the packaging adheres perfectly to the product in order to avoid any risk of frost formation.

✓ **Increase in salt concentration of solutions:** This leads to an increase in the ionic strength of the solutions.

✓ **Possible denaturation of myofibrillar proteins** in meat, especially in fish, resulting in a loss of water-holding capacity.

✓ **Modification of the structure of egg lipoproteins.**

Table .1 provides the maximum storage duration of some food products (in months).

Produit	**-18°C**	**-12°C**
Orange jus	10	4
struberrie	12	2,5
peas	10	3
Leon fish	3-5	<2
Fat fish	2	<1,5
Raosted chicken	3	<1
Beef's muscle	13	5

.2.4.2/ Biochemical Changes

Not all enzymes are completely inhibited during freezing. As a result, there may be **lipid hydrolysis**, **oxidation of certain vitamins**, and **protein denaturation**. It should also be noted that some fruits, such as **apples** and **peaches**, may **brown** during freezing.