Paper No.: 02

Paper Title: The Principles of the Food Processing & Preservation

Module No. : 12

Module Title: Low Temperature Preservation and Processing

12.0 Introduction

The preservation of food by refrigeration is based on a very general principle in physical chemistry: *molecular mobility is depressed and consequently chemical reactions and biological processes are slowed down at low temperature*. In contrast to heat treatment, low temperature practically does not destroy microorganisms or enzymes but merely depresses their activity. Therefore:

- Refrigeration retards spoilage but it cannot improve the initial quality of the product, hence the importance of assuring particularly high microbial quality
- Unlike thermal sterilization, refrigeration is not a method of ópermanent preservation. Refrigerated and even frozen foods have a definite óshelf lifeô, the length of which depends on the storage temperature
- The preserving action of cold exists only as long as low temperature is maintained, hence the importance of maintaining a reliable ó*cold chain*ô all along the commercial life of the product
- Refrigeration must often be combined with other preservation processes (the óhurdleô principle).

12.1 History of mechanical refrigeration

Natural ice, snow, cold nights and cool caves have been used for preserving food since pre-history. However, to become a large-scale industrial process, low temperature preservation had to await the development of mechanical refrigeration in the late 19th century. Frozen food made its appearance shortly before World War 2. Following are milestones in the history of mechanical refrigeration:

- 1748: W. Cullen demonstrates refrigeration by vacuum evaporation of ether
- 1805: O. Evans. First vapor compression system
- 1834: J. Perkins. Improved vapor compression machine
- 1842: J. Gorrie uses refrigeration to cool sick room
- 1856: A. Twinning. First commercial application of refrigeration
- 1859: F. Carre. First ammonia machine
- 1868: P. Tellier attempts refrigerated transatlantic maritime transport of meat
- 1873: C. von Linde. First industrial refrigeration systems in brewery
- 1918: First household refrigerators
- 1920: W. Carrier. Start of commercial air conditioning
- 1938: C. Birdseye. Start of the frozen food industry
- 1974: S. Rowland and M. Molino. Refrigerant gases in the atmosphere suspected of destroying the ozone layer.

Food preservation at low temperature comprises two distinct processes: chilling and freezing. Chilling is the application of temperatures in the range of 0°C to 8°C, i.e. above the freezing point of the food, while freezing uses temperatures well below the freezing point, conventionally below 18°C. The difference between the two processes goes beyond the difference in temperature. The stronger preserving action of freezing is due not only to the lower temperature but also and mainly to the depression of water activity as a result of conversion of part of the water to ice. The use of refrigeration in the food industry is not limited to preservation. Refrigeration is applied for a number of other purposes such as hardening (butter, fats), freeze concentration, freeze drying, air conditioning including air dehumidification and cryo-milling.

12.2 Effect of Temperature on Food Spoilage

The relationship between the temperature and the rate of chemical reactions is described by the Arrhenius equation:

$$k = A\, e^{-\frac{E}{RT}} \Rightarrow \ln k = \ln A - \frac{E}{RT}$$

where:
k - rate constant of the chemical reaction
E - energy of activation, J/mol
T - absolute temperature, K
R - gas constant
A - frequency factor, almost independent of temperature therefore constant for a given reaction.

The kinetics of chemical spoilage reactions such as non-enzymatic browning and loss of some vitamins during storage is found to fit the Arrhenius model quite closely within a fairly wide temperature range. The Arrhenius model is therefore widely used for the prediction of chemical spoilage during storage, following non-monotonous time temperature profiles. Attention should be paid to the possibility of discontinuity in the Arrhenius model due to phase transition phenomena.

12.2.1 Effect of low temperature on enzymatic spoilage

The relationship between enzymatic activity and temperature follows the well-known bell-shaped curve, with maximum activity corresponding to the optimal temperature characteristic to each enzyme (Figure. 1). On first sight, this behavior may seem to be in contradiction with the Arrhenius model. In reality, however, the bell-shaped behavior is the result of two simultaneous and contrary processes, *both* depressed by low temperature. The first is the enzyme-catalyzed reaction itself. The second is the thermal inactivation of the enzyme (Figure. 2).

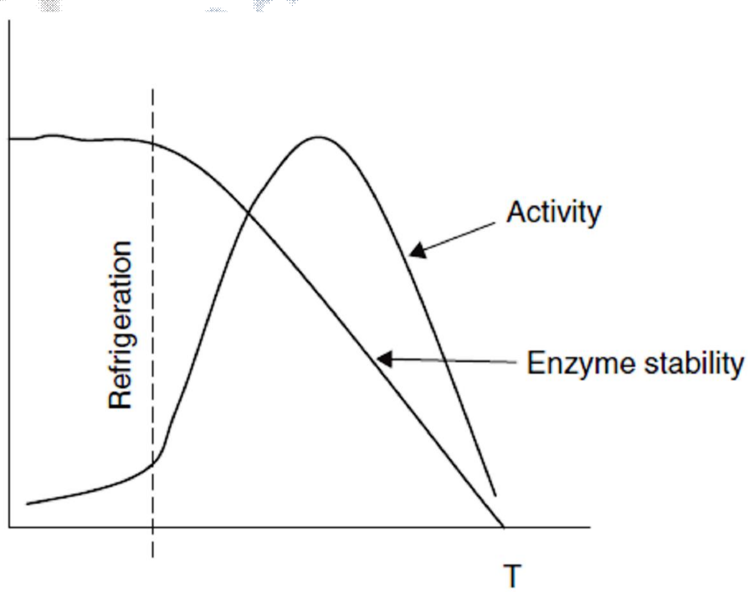

Figure 1: Effect of temperature on enzyme activity and stability

Enzyme activity is strongly slowed down but not totally eliminated by refrigeration, even below freezing temperature. This is the reason for the need to inactivate the enzymes by blanching, particularly in frozen vegetables. Enzymatic activity in chilled and frozen foods is of considerable technological significance. Such activity may be desirable, as in the case of the aging of chilled meat or in the development of flavor in many kinds of cheeses but it can also be a source of deterioration such as the activity of proteases in fish or lipases in meat etc.

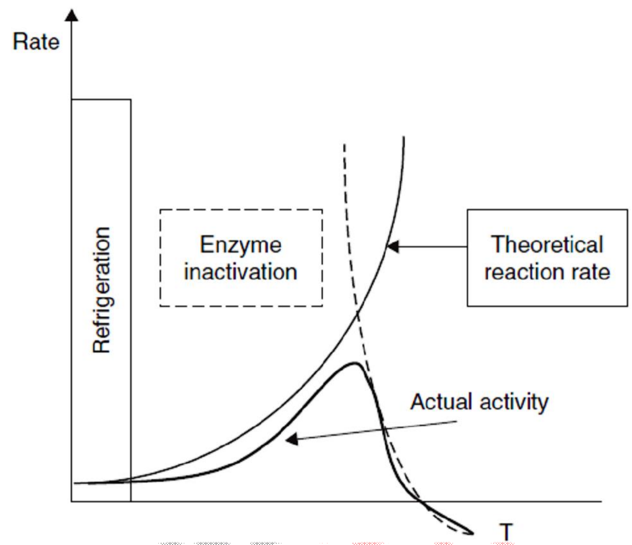

Figure 2: Bell shaped activity curve

12.2.2 Effect of low temperature on microorganisms

With respect to the effect of temperature on their activity, microorganisms are grouped into four categories: thermophiles, mesophiles, psychrotropes and psychrophiles. Typical growth temperature ranges corresponding to the four groups are given in Table.1. The four groups differ not only in their temperature requirement for growth but also in their rate of growth. Figure.3 shows qualitatively the dependence of growth rate (generations per hour) and temperature for thermophiles, mesophiles and psychrophiles. Psychrophilic bacteria grow much more slowly, even at their optimal temperature. In refrigerated foods, psychrotropic and psycrophilic microorganism are obviously the main reason for concern.

Group	Growth temperature (°C)		
	Minimum	Optimum	Maximum
Thermophiles	34 to 45	55 to 75	60 to 90
Mesophiles	5 to10	30 to 45	35 to 47
Psychrotropes	−5 to 5	20 to 30	30 to 35
Psychrophiles	−5 to 5	12 to 15	15 to 20

Table.1: Bacteria, grouped by their growth temperature

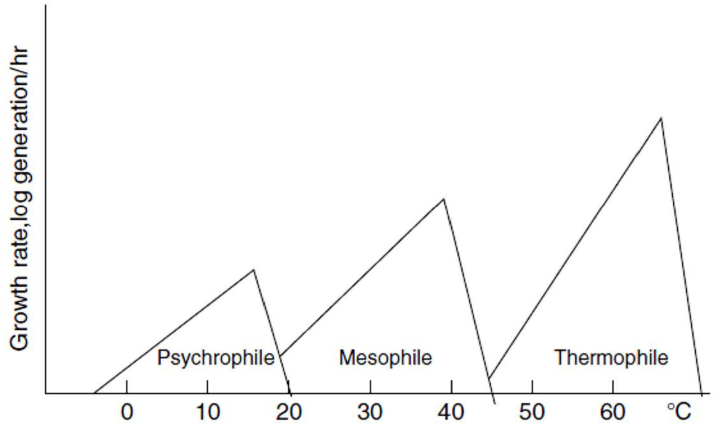

Figure.3: Classification of microorganisms by their response to temperature

The relationship between temperature and shelf life is evident from the graph in Figure.4. It can be seen that, at lower temperature:

- The induction period (lag phase) is longer
- Growth rate in the logarithmic phase is slower
- As a result of the above, the bacterial count after a given storage time is considerably lower.

The microbiological quality of a refrigerated food depends therefore on the time temperature profile of the life of the product. Obviously, additional factors such as pH and water activity play an important role in the microbial processes in foods. Predictive microbiology is a new science, trying to develop tools for the prediction of the microbiological quality of foods, as a function of storage conditions.

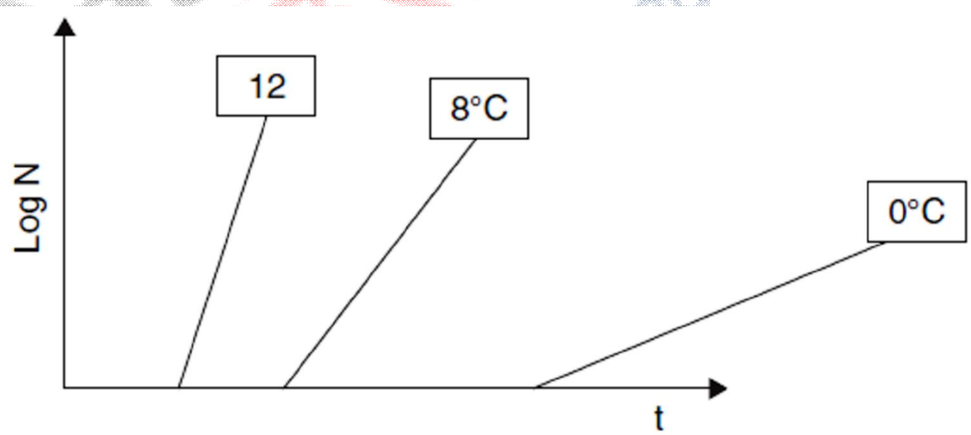

Figure.4: Schematic representation of the effect of storage temperature on the microbial load of a food

12.2.3 Effect of low temperature on biologically active (respiring) tissue

By óactive tissuesô, we refer to foods such as fruits and vegetables after harvest or meat after dressing, in view of their biochemical activity. The principal biochemical post-harvest process that occurs in fruits and vegetables is *respiration*, whereby sugars are óburnt ô, oxygen is consumed and carbon dioxide is evolved. The rate of respiration is usually determined by measuring the rate of oxygen consumption or carbon dioxide release. Respiration is the most important (but not the only) cause of deterioration of fruits and vegetables during storage. It is usually said that the shelf life of fresh produce is inversely related to the rate of respiration. The rate of respiration is closely related to the temperature. The rate of respiration increases by 2 to 4 fold for every 10°C increase in the temperature within the range of usual storage temperatures. However, too low storage temperatures may cause a condition known as óchill injuryô in certain commodities and must be avoided. Fruits and vegetables differ in the intensity of their post-harvest respiration rate. Following is a rough classification of some fresh produce with respect to their respiration rate during storage:

- High respiration rate: avocado, asparagus, cauliflower, berries
- Medium respiration rate: banana, apricot, plums, carrot, cabbage, tomatoes
- Low respiration rate: citrus, apples, grapes, potatoes.

Many crops undergo a process of post-harvest ripening during storage. These are called ćclimactericô species, because their rate of respiration increases to a maximum in the process. Ethylene is produced and acts as a ripening hormone. Apples, bananas and avocado are climacteric, while citrus and grapes are non-climacteric. It is possible to control the rate of respiration of fruits, vegetables and cut flowers with the help of refrigeration alone or through the combination of refrigeration and ćcontrolled atmosphereô storage. ćControlled atmosphereô consists of long-range refrigerated storage in closed chambers where the atmosphere has been artificially modified so as to depress the rate of respiration to the desired level. The optimum composition of the atmosphere depends on the commodity and often on the particular variety of the commodity. Table.2 shows typical optimal storage conditions for selected fruits and vegetables.

Fruits in controlled atmosphere

Produce	Temperature	Atmosphere	
		% oxygen	% CO_2
Pineapple	10–15	5	10
Avocado	12–15	2–5	3–10
Pomelo	10–15	3–10	5–10
Lemon	10–15	5	0–10
Mango	10–15	5	5
Papaya	10–15	5	10
Melon (cantaloupe)	5–10	3–5	10–15

Vegetables in ordinary cold storage

Produce	Temperature (°C)	Relative humidity (%)
Artichoke	0–2	90–95
Asparagus	0–2	95–100
Broccoli	0–2	95–100
Carrot	0–2	98–100
Eggplant	10–14	90–95
Onion	0–2	65–75
Potato	8–12	90–95

Table 2: Optimal storage conditions for some fruits and vegetables

Respiration is an exothermic process. The heat released by respiring commodities during refrigerated storage and transportation must be taken into account in calculating the refrigeration load required. Table.3 gives the approximate rate of heat evolution during storage of selected commodities. Low temperature alone is not always sufficient for extending the shelf life of fruits and vegetables. Another important condition that must be controlled in post-harvest storage is relative humidity. Loss of water is often the cause of texture deterioration, wilting, shriveling etc. Water loss may be minimized by storing at high relative humidity, but humidity levels that can promote growth of mold must be avoided.

Commodity	Heat evolution rate, Watts per ton, when stored at:			
	0°C	5°C	10°C	15°C
Apple	10–12	15–21	41–61	41–92
Cabbage	12–40	28–63	36–86	66–169
Carrot	46	58	93	117
Sweet corn	125	230	331	482
Green peas	90–138	163–226	–	529–599
Orange	9	14–19	35–40	38–67
Strawberry	36–52	48–98	145–280	210–275

Table 3: Approximate rate of heat evolution during refrigerated storage of selected commodities, according to storage temperature

12.2.4 The effect of low temperature on physical properties

Numerous changes in physical properties caused by exposure to low temperatures may have significant effects on food quality. Some of these changes are:

- Increase in viscosity
- Decrease in solubility, resulting in crystallization, precipitation, cloudiness (e.g.in beer)
- Hardening, transition to rubbery and glassy state in carbohydrate systems
- Hardening of fats
- Decomposition of colloidal systems such as emulsions and gels

12.3 Freezing

Freezing is one of the most widespread industrial methods of food preservation today. The transition from chilling to freezing is not merely a continuous change that can be explained on grounds of the lower temperature alone. On the contrary, freezing represents a point of sharp discontinuity in the relationship between temperature and the stability and sensory properties of foods.

- The exceptional efficiency of freezing as a method of food preservation is, to a large extent, due to the depression of water activity. Indeed, when food is frozen, water separates as ice crystals and the remaining non-frozen portion becomes more concentrated in solutes. This ófreeze concentrationô effect results in the depression of water activity. In this respect, freezing can be compared to concentration and drying
- On the other hand, the same phenomenon of ó freeze concentration ô may accelerate reactions, inducing irreversible changes such as protein denaturation, accelerated oxidation of lipids and destruction of the colloidal structure (gels, emulsions) of the food
- The *rate of freezing* has an important effect on the quality of frozen foods. Physical changes, such as the formation of large ice crystals with sharp edges, expansion, disruption of the osmotic equilibrium between the cells and their surroundings, may induce irreversible damage to the texture of vegetables, fruits and muscle foods. It has been established that such damage is minimized in the case of quick freezing.

12.3.1 Effect of freezing and frozen storage on product quality

For a very large number of food products, freezing represents the best preservation method with respect to food quality. The nutritional value, the flavor and color of foods are affected very slightly, if at all, by the process of freezing itself. The main quality factor that may be adversely affected by freezing is the texture. On the other hand, unless appropriate measures are taken, the deleterious effect of long-term frozen storage and of thawing on every aspect of product quality may be significant.

12.3.2 Effect of freezing on texture

In a vegetal or animal tissue, the cells are surrounded by a medium known as the extracellular fluid. The extracellular fluid is less concentrated than the protoplasm inside the cells. The concentration difference results in a difference in osmotic pressure which is compensated by the tension of the cell wall. This phenomenon, known as turgor, is the reason for solid appearance of meat and the crispiness of fruits and vegetables. When heat is removed from the food in the course of freezing, the extracellular fluid, being less concentrated, starts to freeze first. Its concentration rises and the osmotic balance is disrupted. Fluid flows from the cell to the extracellular space. Turgor is lost and the tissue is softened. When the food is thawed, the liquid that was lost to the extracellular space is not reabsorbed into the cell, but is released as free juice in the case of fruits or ódripô in the case of meat.

It is generally believed that freezing damage to the texture of cellular foods is greatly reduced by accelerating the rate of freezing. This is explained by the fact that the condition of osmotic imbalance, created at the onset of freezing, disappears when the entire mass is frozen. Furthermore, rapid freezing results in the formation of smaller ice crystals, presumably less harmful to the texture of cellular systems. Another probable reason for the deterioration of the texture is the volumetric expansion caused by freezing. The specific volume of ice is 9% higher than that of pure water. Because cellular tissues are not homogeneous with respect to water content, parts of the tissue expand more than the others. This creates mechanical stress that may result in cracks. Obviously, this effect is particularly strong in foods with high water content such as cucumbers, lettuce and tomatoes. This kind of texture damage is partially prevented by adding solutes. Adding sugar to fruits and berries before freezing was a widespread practice before the development of ultra-rapid freezing methods.

The rate of freezing affects the size of ice crystals. Slow freezing produces large crystals. It has been suggested that large crystals with sharp edges may break cell walls and contribute to texture deterioration in cellular foods subjected to slow freezing. There is no controversy as to the fact that slow freezing results in higher percentage of drip in meat and fish. It is also accepted that rapid freezing causes less damage to the texture of particularly fragile fruits. On the other hand, the *general* applicability of the theory stating the superiority of rapid freezing seems to be questionable. Nevertheless, quick freezing continues to be the practical objective of food freezing process design.

12.3.3 Effect of frozen storage on food quality

Frozen storage, even at fairly low temperature, does not mean the absence of deteriorative processes. On the contrary, frozen foods may undergo profound quality changes during frozen storage. While the rate of reactions is generally (but not always) slower in frozen foods, the expected shelf life, and therefore the time available for the reactions to take place, is long. Some of the frequent types of deterioration in frozen foods are protein denaturation resulting in toughening of muscle foods, proteinï lipid interaction, lipid oxidation and oxidative changes in general (e.g. loss of some vitamins and pigments).

Extensive studies on the effect of frozen storage on product quality were undertaken in the 1960s by researchers. A large number of commodities were tested for changes in chemical composition and sensory characteristics. A concept known as ótime temperature toleranceô (TTT) was developed. The studies showed a linear relationship between the storage temperature and the logarithm of storage time for equal reduction in quality (loss of a certain vitamin, loss of color or loss of organoleptic score). The logical conclusion of these studies could be that lower storage temperature *always* results in higher quality. This is not always the case, however. Reactions may be accelerated by the ófreeze concentrationô effect more than they are attenuated by the lower temperature. In this case, the rate of deterioration (e.g. lipid oxidation) may increase as the storage temperature is lowered, passing through a maximum and then diminishing at very low temperatures. Mass transfer phenomena during frozen storage (oxygen transfer, loss of moisture) may be a major cause of quality loss. The quality of packaging is, therefore, particularly important in frozen foods. The PPP (productï processï package) approach consists of paying attention of all three factors in evaluating and predicting the effect of frozen storage on product quality.

Another type of change in frozen foods during storage is the process of recrystallization. Smaller crystals are more soluble than large ones. Equally, small ice crystals have a lower melting point then large ones. Consequently, if the storage temperature undergoes fluctuations, small ice crystals may melt and then solidify on the larger crystals. This may be the reason why foods frozen rapidly and those frozen slowly sometimes show similar ice crystal size distribution after storage. Recrystallization is particularly objectionable in ice cream, where conversion of small ice crystals to large ones results in loss of the smooth, creamy texture. The remedy is, of course, avoiding temperature fluctuation during storage as much as possible.

12.4 Freezing Methods

There are three major methods of freezing foods:

Air Freezing

- Still-air 'sharp' freezer
- Air blast freezer
- Fluidized-bed freezer (IQF)

Indirect Contact Freezing

- Single plate
- Double plate
- Pressure plate
- Slush freezer

Immersion and Cryogenic Freezing

- Heat exchange fluid
- Compressed gas
- Refrigerant spray

12.4.1 Air Blast Freezing: Air freezing is the oldest and most common type of freezing used. The freezer section of household refrigerator and the deep freezer are examples of still air freezers or low air velocity systems.

Air blast freezing is a moderately fast freeze because of vigorous circulation of cold air. The product is placed on trays or mesh belts and passed slowly through an insulated tunnel. In different systems the temperature may range from -18°C to -34°C, with an air velocity of 100-3500 lineal feet per minute, with a counter current air flow. Air blast freezers operate at lower temperatures than still air freezers and rely on movement of the cold air at high velocity over the food in order to achieve rapid removal of heat and to maximize the freezing rate.

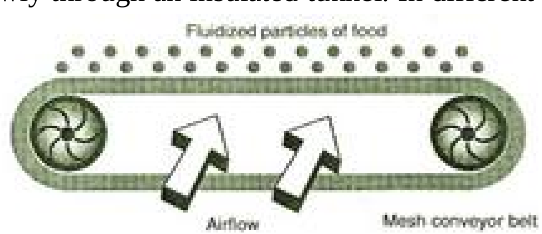

Figure.5: Air Blast freezing

12.4.2 Fluidized-bed Freezer: In this type of air freezing, solid particles ranging in size from peas to strawberries are being exposed through a movement of the cold air (-18°C to -34°C) at high velocity as they pass along a conveyor belt. This will impart a vibratory motion to food particles, accelerating the freezing rate. The cold air being forced upward through the bed lifts and suspends the food particles, thus fluidization occurs. In this way, a rapid freezing rate is accomplished and an

IQF (individually quick frozen) product is produced. In other words, food items are frozen as individual pieces and are not stuck together.

Advantages and Disadvantages of Air blast freezing; Fluidize-bed freezing (IQF)

Advantages:

- Economical
- Can freeze various sizes and shapes of food
- IQF has more efficient heat transfer, increased rate of freezing

Disadvantages:

- Possible excess dehydration (freezer burn)
- Undesirable bulging of the packages (by expansion of the product) may occur
- Non-uniform products can not be fluidized (IQF) easily

12.4.3 Indirect Contact Freezers

Indirect Contact freezers are used in the production of various frozen food commodities. In these freezers, food is placed on belts or trays and a refrigerant circulates through a wall beside the food. As the food comes into "contact" with the cold wall, it quickly cools down and freezes. **Plate** and **slush freezers are** some examples of indirect contact freezers.

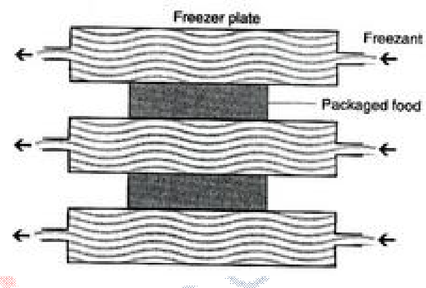

Figure.6: Plate Freezer

During plate freezing food products are placed in contact with a metal surface which is cooled by a cold brine, or a vaporizer refrigerant such as ammonia. The packaged food either rests on, slides against or is pressed between the cold metal plates. These plates maintain firm contact with two major surfaces of packages to facilitate heat transfer and prevent bulging of the packages during the freezing process. Fish sticks and frozen fish fillets are commonly frozen in plate contact freezers.

Another type of indirect contact freezer is the **slush freezers** or **scraped surface heat exchangers**. These freezers can be used only for fluid food products. A common example of a scraped surface freezer is the machine used to convert ice cream mix to soft ice cream in restaurants and ice cream shops. The same principle is used in the commercial production of ice cream that is sold as hard ice cream. In the case of ice cream, the rotator not only aids in promoting rapid freezing and the development of small ice crystals, but it also aids in the incorporation of air bubbles into the freezing mix which results in the formation of a solid foam.

Advantages and Disadvantages of Indirect Contact Freezing

Advantages:

- Economical
- Minimal dehydration
- Minimal package bulging

Disadvantages:

- Slow freezing process
- Products must be of uniform thickness

12.4.4 Immersion and Cryogenic Freezing

12.4.4.1 Immersion freezing involves the immersion of packaged or un-packaged food products directly in a non-toxic refrigerant fluid. The refrigerant fluids commonly used are propylene glycol, glycerol, sodium chloride, calcium chloride, and mixtures of salt

Fig. 7.4 Cryogenic freezing process

and sugar. Canned citrus juice, turkeys and chickens are often frozen in immersion freezing units. Ice cream popsicles can also be frozen using this method.

Figure.7 : Cryogenic Freezing

12.4.4.2 Cryogenic freezing is accomplished with cryogenic liquids, with liquid nitrogen being the most commonly used. This is a very rapid freezing method in which un-packaged or thinly packaged foods are exposed to extremely cold freezant. In contrast to the liquid immersion freezing, heat removal is accomplished during a change of state by the freezant. Products such as TV dinners, preformed patties and other high value food products are frozen in cryogenic freezers because of the excellent retention of quality imparted by the rapid rate of freezing and small ice crystal formation. The figure on the right illustrates a cryogenic process.

12.4.4.3 Liquid nitrogen cryogenic freezing: The product is first placed on a conveyor belt and is moved into the pre-cooling part of the freezing unit. Once the food is cooled, the food is sprayed by liquid nitrogen as it is being moved through the conveyor belt; here is where the freezing process takes place, by the nitrogen boiling as it contacts the food. Finally, the food is allowed to equilibrate to the desired final temperature (between -18°C to -30°C).

Advantages and Disadvantages of Immersion/ Cryogenic Freezing

Advantages:

- Rapid freezing process
- Almost no dehydration
- Oxygen is excluded, decreasing oxidative spoilage
- Individual freezing pieces have less freezing damage

Disadvantages:

- Difficult to find suitable freezants
- Cost of operating is high

12.5 Conclusion

Freezing and low temperature preservation provides longer shelf life of food. It is carried out at temperatures well below 0°C. Freezing slows/stops microbial growth. However, storage of food at freezing temperatures does not kill all microorganisms and in fact many disease-causing and spoilage-causing microorganisms can survive in frozen foods for many years (e.g. *Listeria monocytogenes*). Once the food is thawed, the surviving microorganisms can resume their growth and function, causing disease or spoilage if the proper conditions for microbial growth prevail. When freezing of food is properly done, it can preserve the quality of the food without causing major changes in appearance, texture and flavour. Frozen foods are generally of higher nutritional and aesthetic quality than thermally processed foods. The faster the rate of freezing, the better the retention of quality, both sensory and nutritional.