ISSN 1010-1365

FAO
AGRICULTURAL
SERVICES
BULLETIN

158

Freezing of fruits and vegetables

An agribusiness alternative for rural and semi-rural areas

Freezing of fruits and vegetables

An agribusiness alternative for rural and semi-rural areas

FAO
AGRICULTURAL
SERVICES
BULLETIN

158

by
Gustavo V. Barbosa-Cánovas
Washington State University
Pullman, Washington, United States of America

Bilge Altunakar
Washington State University
Pullman, Washington, United States of America

Danilo J. Mejía-Lorío
Food and Agriculture Organization of the United Nations
Rome, Italy

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2005

ISBN 92-5-105295-6

Foreword

Freezing methods for food are convenient and easily applied. Since the invention freezing is one of the few methods which allow the preservation of food attributes such as taste, texture whilst maintaining the nutritional value. Frozen products are very similar to the original fresh product, particularly if good handling and safety practices are utilized both before and after freezing. Retention of quality and safety are better achieved when frozen foods are kept at maximum temperatures of -18 °C or even lower. At these temperatures micro-organisms cannot grow and any deteriorative reactions take place at very slow rates. Frozen agricultural products can retain their quality over long storage periods if the correct procedures are applied.

In developed countries the freezing of foods represents a major industry. However, in developing countries it is hardly developed. The frozen foods industry is considered expensive, mainly due to the high initial investment cost for the equipment, but the freezing process and storage costs per se only represent about 10 percent of the total cost of production. In many developing countries the cost of energy for industrial use is relatively high, highlighting the need for governments in developing countries to consider establishing lower energy tariffs in order to promote agro-food processing industries such as freezing.

In this technical manual fundamental knowledge and socio-economic issues concerning freezing are presented, with coverage extending from large-scale freezing to freezing on a micro- or small-scale. The manual consists of five chapters containing basic concepts and operations to give a better understanding of the application of freezing preservation. Chapter one presents an introduction to freezing technology, emphasizing the importance of the frozen food industry with general recommendations on the application of technology for fruits and vegetables. Chapter two gives specific examples of freezing preservation applied to selected food prototypes. Chapter three focuses on raw material selection and freezing equipment. Chapter four presents general recommendations regarding final product quality whilst Chapter five presents cost estimates and product prices for selected frozen products.

The freezing of fruits and vegetables on a small scale could be developed in many developing countries, by using the standard household freezer. It is also a good option for potential entrepreneurs interested in developing this technology which is often technically and economically feasible under a variety of circumstances.

Agricultural and Food Engineering Technologies Service
Agricultural Support Systems Division
FAO of the U.N.

Glossary

AFFI	American Frozen Food Institute.
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers. Assets expenses. Expense for any item of economic value owned by an individual or corporation, especially that which could be converted to cash.
Average product temperature	Temperature of the product as an average of temperatures at local freezing sites.
Blanching	Heat treatment by hot water, steam or microwave for a brief period to inactivate enzymes.
Carnot cycle	An idealized reversible thermodynamic cycle, first proposed in 1824 by French engineer Sadi Carnot, is composed of four reversible processes-two isothermal and two adiabatic, and can be executed either in a closed or a steady-flow system.
CFU	Colony Forming Units. The number of viable microbial cells per gram or per milliliter.
Clarence Birdseye	Food technologist who developed quick freezing process and equipment known as a revolution in the freezing industry.
Compressor	Pump of a refrigerating mechanism that draws low pressure on the cooling side of the refrigerant cycle and compresses the gas into the high-pressure side of the cycle.
Condenser	A heat exchanger in which the refrigerant, compressed to a hot gas, and is condensed to liquid by rejecting heat.
Contact freezing	Freezing of a product either direct or indirect contact with the freezing medium.
Controlled atmosphere storage	A common method of storage for some fruits prior to freezing.

Cryogenic	Conditions where temperatures are low enough for gases to condense to become liquids or solids.
Developing countries	Countries in which the average annual income is low, most of the population is usually engaged in agriculture.
Equilibrium Production Rate	The production rate at which minimum unit quantity of product to be sold in order to cover production cost.
Evaporator	The component in a refrigeration system that absorbs heat into the system and evaporates the liquid refrigerant.
Expansion valve	Temperature-sensitive valve located between the condenser and the evaporator to control the refrigerant flow to the evaporator by maintaining the pressure difference.
FAO	Food Agriculture Organization of the United Nations.
Fixed cost	Costs that do not change in the short term as a function of changes in production volumes, distribution volumes, labor or machine hours.
Freezer burn	The loss of moisture from food during freezing, resulting in surface texture changes on the food; dry, grainy-textured white or brown colored spots are visible and the food's flavor decreases in quality.
Freezing capacity (tonnes/h)	Ratio of the quantity of the product that can be loaded into the freezer to the holding time of the product in that particular freezer.
Freezing period	Second stage after pre-freezing while phase change occurs with the transformation of water to ice.
Freezing point depression	The decrease in the freezing point of a solvent caused by the presence of a solute.
Freezing point	The temperature at which first ice crystal appears in the solution.
Freezing rate (°C/h)	The ration of the difference between initial and final temperature of product to freezing time.
Freezing time	Time required to lower product temperature from its initial temperature to a given temperature.

HCFC	Hydrochlorofluorocarbon
IIR	International Institute of Refrigeration
Investment cost	The cost of a purchase or ownership of a security to make money by gaining income, increasing capital, or both.
IQF	Individually quick frozen foods.
LIN	Liquid nitrogen
Local freezing rate (°C/h)	Freezing rate defined at a particular location within the product.
Minimally Processed Foods	Food preservation technology with processing as little as possible, but as much as necessary to achieve safe products with the highest quality.
Moisture-vapor-proof	The property of packaging material for frozen foods to prevent evaporation.
Nucleation	The initial stage in a phase transformation that is evidenced by the formation of small particles (nuclei) of the new phase, which are capable of growing.
Osmosis	The diffusion of water through a semi-permeable membrane from an area of higher concentration of water to an area of lower concentration of water.
Oxidation	A chemical reaction that occurs when a substance is combined with oxygen; oxidation may lead to degradation or deterioration of the substance.
Pre-freezing stage	Time interval between the starting of freezing process and the appearance of first ice crystal.
Pre-operation expenses	A cost item including licenses, training of workers, which depends on the application.
Primary packaging	A form of packaging which is in direct contact with the food.
Quick-freezing	Freezing sufficiently rapid to retain flavor and nutritional value.
Secondary packaging	A form of packaging used to handle packages together for sale.

Semi-batch freezers	Mode of freezing process in which the product is carried through on trucks that are stationary except when a new truck enters one end of the tunnel moving the others along to release a finished one at the exit.
Surface heat transfer coefficient	The ratio of heat transfer rate to surface area and temperature difference.
Tertiary packaging	The outer package of frozen foods used for bulk transportation.
Thermal center	Geometrical center of the product accepted as reference point for temperature distribution studies.
Thermal conductivity	An intrinsic physical property of a substance, describing its ability to conduct heat as a consequence of molecular motion.
Unfrozen water	A fraction of water remains unfrozen during the freezing process.
USDA	United States Department of Agriculture.
Variable cost	Cost for material, labor or overhead that changes in a traceable and measurable way due to changes in the volume of production units or operating hours in a given period.
WTO	World Trade Organization. The (WTO) World Trade Organization was established in 1995 to enforce the international trade rules established by GATT.

Table of contents

Chapter 1

Introduction to freezing

Freezing is one of the oldest and most widely used methods of food preservation, which allows preservation of taste, texture, and nutritional value in foods better than any other method. The freezing process is a combination of the beneficial effects of low temperatures at which microorganisms cannot grow, chemical reactions are reduced, and cellular metabolic reactions are delayed (Delgado and Sun, 2000).

1.1 The importance of freezing as a preservation method

Freezing preservation retains the quality of agricultural products over long storage periods. As a method of long-term preservation for fruits and vegetables, freezing is generally regarded as superior to canning and dehydration, with respect to retention in sensory attributes and nutritive properties (Fennema, 1977). The safety and nutrition quality of frozen products are emphasized when high quality raw materials are used, good manufacturing practices are employed in the preservation process, and the products are kept in accordance with specified temperatures.

The need for freezing and frozen storage

Freezing has been successfully employed for the long-term preservation of many foods, providing a significantly extended shelf life. The process involves lowering the product temperature generally to -18 °C or below (Fennema *et al.,* 1973). The physical state of food material is changed when energy is removed by cooling below freezing temperature. The extreme cold simply retards the growth of microorganisms and slows down the chemical changes that affect quality or cause food to spoil (George, 1993).

Competing with new technologies of minimal processing of foods, industrial freezing is the most satisfactory method for preserving quality during long storage periods (Arthey, 1993). When compared in terms of energy use, cost, and product quality, freezing requires the shortest processing time. Any other conventional method of preservation focused on fruits and vegetables, including dehydration and canning, requires less energy when compared with energy consumption in the freezing process and storage. However, when the overall cost is estimated, freezing costs can be kept as low (or lower) as any other method of food preservation (Harris and Kramer, 1975).

Current status of frozen food industry in U.S. and other countries

The frozen food market is one of the largest and most dynamic sectors of the food industry. In spite of considerable competition between the frozen food industry and other sectors, extensive quantities of frozen foods are being consumed all over the world. The industry has recently grown to a value of over US$ 75 billion in the U.S. and Europe combined. This number has reached US$ 27.3 billion in 2001 for total retail sales of frozen foods in the U.S. alone (AFFI, 2003). In Europe, based on U.S. currency, frozen food consumption also reached 11.1 million tons in 13 countries in the year 2000 (Quick Frozen Foods International, 2000). Table 1 represents the division of frozen food industry in terms of annual sales in 2001.

Advantages of freezing technology in developing countries

Developed countries, mostly the U.S., dominate the international trade of fruits and vegetables. The U.S. is ranked number one as both importer and exporter, accounting

Table 1. **Frozen food industry in terms of annual sales in 2001**
(Source: Information Resources)

Food items	Sales US$ (million)	% Change vs. 2000
Total Frozen Food Sales	26 600	6.1
Baked Goods	1 400	9.0
Breakfast Foods	1 050	4.1
Novelties	1 900	10.5
Ice Cream	4 500	5.7
Frozen Dessert/Fruit/Toppings	786	5.4
Juices/Drinks	827	-9.7
Vegetables	2 900	4.3

for the highest percent of fresh produce in world trade. However, many developing countries still lead in the export of fresh exotic fruits and vegetables to developed countries (Mallett, 1993).

For developing countries, the application of freezing preservation is favorable with several main considerations. From a technical point of view, the freezing process is one of the most convenient and easiest of food preservation methods, compared with other commercial preservation techniques. The availability of different types of equipment for several different food products results in a flexible process in which degradation of initial food quality is minimal with proper application procedures. As mentioned earlier, the high capital investment of the freezing industry usually plays an important role in terms of economic feasibility of the process in developing countries. As for cost distribution, the freezing process and storage in terms of energy consumption constitute approximately 10 percent of the total cost (Person and Lohndal, 1993). Depending on the government regulations, especially in developing countries, energy cost for producers can be subsidized by means of lowering the unit price or reducing the tax percentage in order to enhance production. Therefore, in determining the economical convenience of the process, the cost related to energy consumption (according to energy tariffs) should be considered. Electricity prices for some countries are given in Table 2.

Increasing consumer demand in developing countries due to modernization

The proportion of fresh food preserved by freezing is highly related to the degree of economic development in a society. As countries become wealthier, their demand for high-valued commodities increases, primarily due to the effect of income on the consumption of high-valued commodities in developing countries. The commodities preserved by freezing are usually the most perishable ones, which also have the highest price. Therefore, the demand for these commodities is less in developing areas. Besides, the need for adequate technology for freezing process is the major drawback of developing countries in competing with industrialized countries. The frozen food industry requires accompanying developments and facilities for transporting, storing, and marketing their products from the processing plant to the consumer (Mallett, 1993). Thus, a large amount of capital investment is needed for these types of facilities. For developing countries, especially in rural or semi-rural areas, the frozen food industry has therefore not been developed significantly compared to other countries.

In recent years, due to the changing consumer profile, the frozen food industry has changed significantly. The major trend in consumer behavior documented over the last

Table 2. **Unit electricity prices for industry[1] (U.S. Dollars per Kilowatt-hour)**

Source: United States -- Energy Information Administration, Monthly Energy Review, July 2003.

Country	1999	2000	2001	2002
Argentina	n.a.	0.075	0.069	n.a.
Belgium	0.056	0.048	n.a.	n.a.
Bolivia	n.a.	0.062	0.069	n.a.
Chile	n.a.	0.052	0.056	n.a.
Chinese Taipei (Taiwan)	0.058	0.061	0.056	n.a.
Colombia	n.a.	0.052	0.042	n.a.
Costa Rica	n.a.	0.068	0.076	n.a.
Cuba	n.a.	0.080	0.078	n.a.
Ecuador	n.a.	0.036	0.061	n.a.
El Salvador	n.a.	0.111	0.110	n.a.
Finland	0.046	0.039	0.038	0.043
Germany	0.057	0.041	0.044	n.a.
Greece	0.050	0.042	0.043	0.046
Guyana	n.a.	0.082	0.080	n.a.
Hungary	0.055	0.049	0.051	0.060
India	0.081	0.080	n.a.	n.a.
Ireland	0.057	0.049	0.060	0.075
Italy	0.086	0.089	n.a.	n.a.
Korea (Korea, South)	0.056	0.062	0.057	n.a.
Mexico	0.042	0.051	0.053	n.a.
Netherlands	0.061	0.057	0.059	n.a.
New Zealand	0.030	0.030	0.028	0.033
Nicaragua	n.a.	0.117	0.115	n.a.
Paraguay	n.a.	0.032	0.036	n.a.
Peru	n.a.	0.056	0.057	n.a.
Poland	0.037	0.037	0.045	0.049
Portugal	0.078	0.067	0.066	0.068
Russia	0.012	0.011	n.a.	n.a.
South Africa	0.017	0.017	0.013	n.a.
Spain	0.049	0.043	0.041	n.a.
Switzerland	0.090	0.069	0.069	0.073
Turkey	0.079	0.080	0.079	0.094
United Kingdom	0.064	0.055	0.048	n.a.
United States [2]	0.044	0.046	0.050	0.048
Uruguay	n.a.	0.064	0.070	n.a.

n.a. = Not Available.

[1] Energy end-use prices including taxes converted using exchange rates.

[2] Electricity prices in the United States, including income taxes, environmental charges, and other charges.

half century has been the increase in the number of working women and the decline in the family size. These two factors resulted in a reduction in time spent preparing food. The entry of more women into the workforce also led to improvements in kitchen appliances and increased the variability of ready-to-eat or frozen foods available in the market. Besides, the increased usage of microwave ovens, affecting food habits in general and the frozen food market in particular, as well as allowing rapid preparation of meals and greater flexibility in meal preparation. The frozen food industry is now only limited by imagination, an output of which increases continuously to supply the increasing demand for frozen products and variability.

Market share of frozen fruits and vegetables

Today in modern society, frozen fruits and vegetables constitute a large and important food group among other frozen food products (Arthey, 1993). The historical development of commercial freezing systems designed for special food commodities helped shape the frozen food market. Technological innovations as early as 1869 led to the commercial development and marketing of some frozen foods. Early products saw limited distribution through retail establishments due to insufficient supply of mechanical refrigeration. Retail distribution of frozen foods gained importance with the development of commercially frozen vegetables in 1929.

The frozen vegetable industry mostly grew after the development of scientific methods for blanching and processing in the 1940s. Only after the achievement of success in stopping enzymatic degradation, did frozen vegetables gain a strong retail and institutional appeal. Today, market studies indicate that considering overall consumption of frozen foods, frozen vegetables constitute a very significant proportion of world frozen-food categories (excluding ice cream) in Austria, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland, UK, and the USA. The division of frozen vegetables in terms of annual sales in 2001 is shown in Table 3.

Commercialization history of frozen fruits is older than frozen vegetables. The commercial freezing of small fruits and berries began in the eastern part of the U.S. in about 1905 (Desrosier and Tressler, 1977). The main advantage of freezing preservation of fruits is the extended usage of frozen fruits during off-season. Additionally, frozen fruits can be transported to remote markets that could not be accessed with fresh fruit. Also, freezing preservation makes year-round further processing of fruit products possible, such as jams, juice, and syrups from frozen whole fruit, slices, or pulps. In summary, the preservation of fruits by freezing has clearly become one the most important preservation methods.

Future trends in freezing technology

Table 3. **Frozen vegetables in terms of annual sales in 2001**
(Source: Information Resources)

Vegetables	Sales US$ (million)	% Change vs. 2000
Broccoli	184	4.4
Corn/Corn on the Cob	312	3.5
Green Beans	115	6.0
Mixed Vegetables	450	7.2
Peas	207	3.9
Potatoes	1 070	4.4

The frozen food industry is highly based in modern science and technology. Starting with the first historical development in freezing preservation of foods, today, a combination of several factors influences the commercialization and usage of freezing technology. The future growth of frozen foods will mostly be affected by economical and technological factors. Growth in population, personal incomes, relative cost of other forms of foods, changes in tastes and preferences, and technological advances in freezing methods are some of the factors concerned with the future of freezing technology (Enochian and Woolrich, 1977).

Population growth and increasing demand for food has generated the need for commercial production of food commodities in large-scale operations. Thus, availability of proper equipment suitable for continuous processing would be valuable for freezing preservation methods. In addition depending on personal incomes, relative cost of frozen products is one of the most important of economical factors. Producing the highest quality at the lowest cost possible is highly dependent on the technology used. As a result, developments in freezing technology in recent years have mostly been characterized by the improvements in mechanical handling and process control to increase freezing rate and reduce cost (George, 1993).

Today an increasing demand for frozen foods already exits and further expansion of the industry is primarily dependent on the ability of food processors to develop higher qualities in both process techniques and products. Improvements can only be achieved by focusing on new technologies and investigating poorly understood factors that influence the quality of frozen food products. Improvements in new and convenient forms of foods, as well as more information on relative cost and nutritive values of frozen foods, will contribute toward continued growth of the industry (Desrosier and Tressler, 1977).

1.2 General recommendations on the freezing process

Freezing is a widely used method of food preservation based on several advantages in terms of retention of food quality and ease of process. Beginning with the earliest history of freezing, the technology has been highly affected over the years by the developments and improvements in freezing techniques. In order to understand and handle the concepts associated with freezing of foods, it is necessary to examine the fundamental factors governing the freezing process.

1.2.1 Freezing technology

Freezing has long been used as a method of preservation, and history reveals it was mostly shaped by the technological developments in the process. A small quantity of ice produced without using a “natural cold” in 1755 was regarded as the first milestone in the freezing process. Firstly, ice-salt systems were used to preserve fish and later on, by the late 1800’s, freezing was introduced into large-scale operations as a method of commercial preservation. Meat, fish, and butter, the main products preserved in this early example, were frozen in storage chambers and handled as bulk commodities (Persson and Lohndal, 1993).

In the following years, scientists and researchers continuously worked to achieve success with commercial freezing trials on several food commodities. Among these commodities, fruits were one of the most important since freezing during the peak growing season had the advantage of preserving fruit for later processing into jams, jellies, ice cream, pies, and other bakery foods. Although commercial freezing of small fruits and berries first began around 1905 in the eastern part of the United States, the commercial freezing of vegetables is much more recent. Starting from 1917, only private firms conducted trials on freezing vegetables, but achieving good quality in frozen vegetables was not possible without pre-treatments due to the enzymatic deterioration. In 1929, the necessity of blanching to inactivate enzymes before freezing was concluded by several researchers to avoid deterioration and off-flavours caused by enzymatic degradation.

The modern freezing industry began in 1928 with the development of double-belt contact freezers by a technologist named Clarence Birdseye. After the revolution in the quick freezing process and equipment, the industry became more flexible, especially with the usage of multi-plate freezers. The earlier methods achieved successful freezing of fish and poultry, however with the new quick freezing system, packaged foods could be frozen between two metal belts as they moved through a freezing tunnel. This improvement was a great advantage in the commercial large-scale freezing of fruits and vegetables. Furthermore, quick-freezing of consumer-size packages helped frozen vegetables to be accepted rapidly in late 1930s.

Today, freezing is the only large-scale method that bridges the seasons, as well as variations in supply and demand of raw materials such as meat, fish, butter, fruits, and vegetables. Besides, it makes possible movement of large quantities of food over geographical distances (Persson and Londahl, 1993). It is important to control the freezing process, including the pre-freezing preparation and post-freezing storage of the product, in order to achieve high-quality products (George, 1993). Therefore, the theory of the freezing process and the parameters involved should be understood clearly.

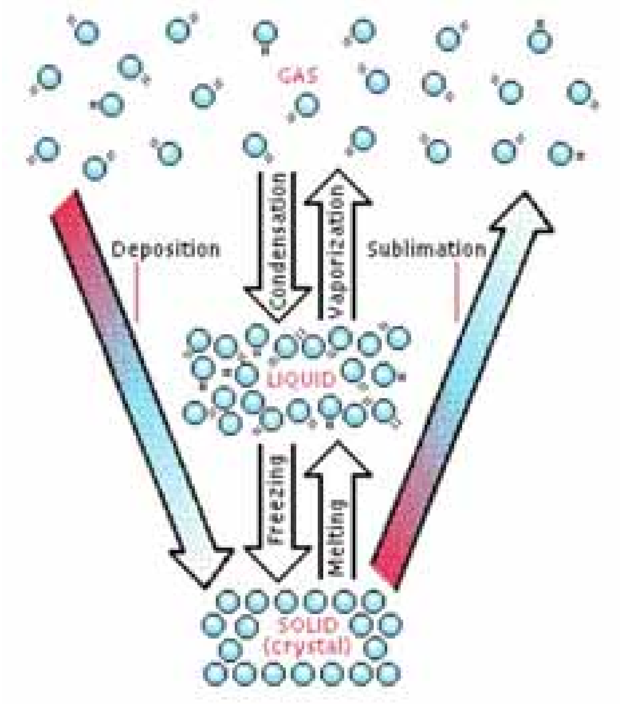
1.2.2 Freezing process

The freezing process mainly consists of thermodynamic and kinetic factors, which can dominate each other at a particular stage in the freezing process (Franks, 1985). Major thermal events are accompanied by reduction in heat content of the material during the freezing process as is shown in Figure 1. The material to be frozen first cools down to the temperature at which nucleation starts. Before ice can form, a nucleus, or a seed, is required upon which the crystal can grow; the process of producing this seed is defined as nucleation. Once the first crystal appears in the solution, a phase change occurs from liquid to solid with further crystal growth. Therefore, nucleation serves as the initial process of freezing, and can be considered as the critical step that results in a complete phase change (Sahagian and Goff, 1996).

Freezing point of foods

Freezing point is defined as the temperature at which the first ice crystal appears and the liquid at that temperature is in equilibrium with the solid. If the freezing point of pure water is considered, this temperature will correspond to 0 °C (273°K). However, when food systems are frozen, the process becomes more complex due to the existence of both free and bound water. Bound water does not freeze even at very low temperatures. Unfreezable water contains soluble solids, which cause a decrease in the freezing point of water lower than 0 °C. During the freezing process, the concentration of soluble solids increases in the unfrozen water, resulting in a variation in freezing temperature. Therefore, the temperature at which the first ice crystal appears is commonly regarded as the initial freezing temperature. There are empirical equations in literature that can calculate the initial freezing temperature of certain foods as a function of their moisture content (Levy, 1979).

Figure 1. **A schematic illustration of overall freezing process.**



There are several methods of food freezing, and depending on the method used, the quality of the frozen food may vary. However, regardless of the method chosen, the main principle behind all freezing processes is the same in terms of process parameters. The International Institute of Refrigeration (IIR) has provided definitions to establish a basis for the freezing process. According to their definition, the freezing process is basically divided into three stages based on major temperature changes in a particular location in the product, as shown in Figures 2 and 3 for pure water and food respectively.

Beginning with the prefreezing stage, the food is subjected to the freezing process until the appearance of the first crystal. If the material frozen is pure water, the freezing

Figure 2. **Practical definition of the freezing process for pure water (Mallett, 1993).**

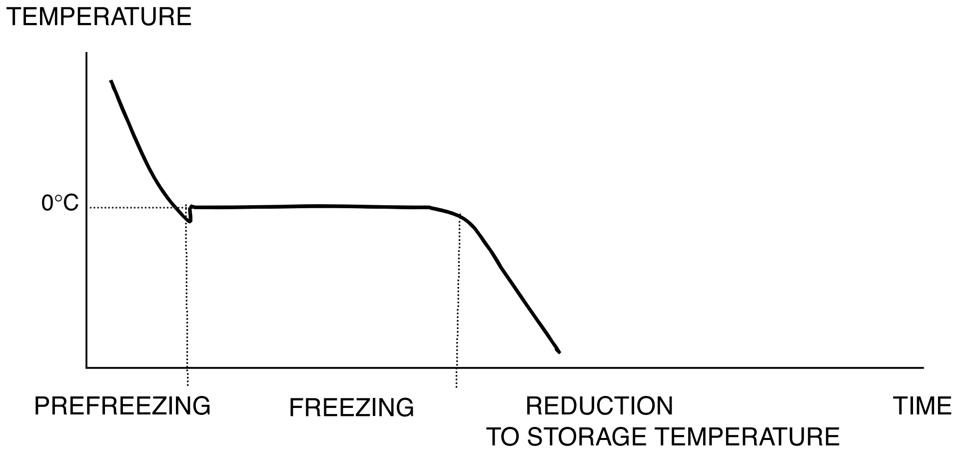
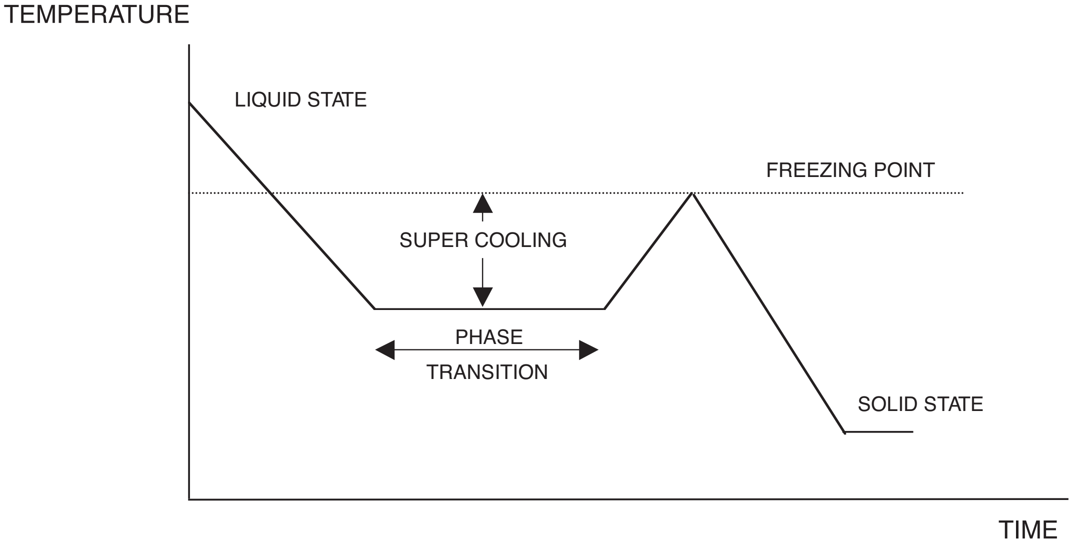


Figure 3. **Practical definition of the freezing process for foods (Mallett, 1993).**



temperature will be 0 °C and, up to this temperature, there will be a subcooling until the ice formation begins. In the case of foods during this stage, the temperature decreases to below freezing temperature and, with the formation of the first ice crystal, increases to freezing temperature. The second stage is the freezing period; a phase change occurs, transforming water into ice. For pure water, temperature at this stage is constant; however, it decreases slightly in foods, due to the increasing concentration of solutes in the unfrozen water portion. The last stage starts when the product temperature reaches the point where most freezable water has been converted to ice, and ends when the temperature is reduced to storage temperature (Persson and Lohndal, 1993).

The freezing time and freezing rate are the most important parameters in designing freezing systems. The quality of the frozen product is mostly affected by the rate of freezing, while time of freezing is calculated according to the rate of freezing. For industrial applications, they are the most essential parameters in the process when comparing different types of freezing systems and equipment (Persson and Lohndal, 1993).

Freezing time

Again, freezing time is one of the most important parameters in the freezing process, defined as time required to lower product temperature from its initial temperature to a given temperature at its thermal center. Since the temperature distribution within the product varies during freezing process, the thermal center is generally taken as reference. Thus, when the geometrical center of the product reaches the given final temperature, this ensures the average product temperature has been reduced to a storage value. Freezing time depends on several factors, including the initial and final temperatures of the product and the quantity of heat removed, as well as dimensions (especially thickness) and shape of product, heat transfer process, and temperature. The International Institute of Refrigeration (1986) defines various factors of freezing time in relation to both the product frozen and freezing equipment (Persson and Lohndal, 1993). The most important are:

- Dimensions and shape of product, particularly thickness
- Initial and final temperatures
- Temperature of refrigerating medium
- Surface heat transfer coefficient of product
- Change in enthalpy
- Thermal conductivity of product

Calculation of freezing time in food systems is difficult in comparison to pure systems since the freezing temperature changes continuously during the process. Using a simplified approach, time elapsed between initial freezing until when the entire product is frozen can be regarded as the freezing time. Plank's equation (Eq.1) is commonly used to estimate freezing time, however due to assumptions involved in the calculation it is only useful for obtaining an approximation of freezing time. The derivation of the equation starts with the assumption the product being frozen is initially at freezing temperature. Therefore, the calculated freezing time represents only the freezing period. The equation can be further modified for different geometries including slab, cylinder,

Table 4. **Coefficients P and R of Equation 1**

Geometry	P	R	Dimension
Infinite slab	1/2	1/8	thickness e
Infinite cylinder	1/4	1/16	radius r
Sphere	1/6	1/24	radius r

and sphere, where for each geometry, the coefficients are arranged in relation to the dimensions (Plank, 1980).

$$t_F = \frac{\rho\lambda_I}{T_F - T_e}\left[\frac{e^2 R}{k} + \frac{eP}{h}\right] \qquad (1)$$

where λ_I is the latent heat of frozen fraction, k and ρ are the thermal conductivity and density of the frozen layer, while h is the coefficient of heat transfer by convection to the exterior.T_f denotes the body temperature of the product when introduced into a freezer in wich the external temperature is T_e The coefficients R and P are given in Table 4 and arranged according to the geometry of the product frozen. where the letter e denotes the dimension (i.e. for infinite slab geometry, e is thickness of the slab and for infinite cylinder or sphere e is replaced by r which denotes the radius of the clylinder or sphere).

As mentioned earlier, the equation of Plank assumes the food is at a freezing temperature at the beginning of the freezing process. However, the food is usually at a temperature higher than freezing temperature. The real freezing time should therefore be the sum of time calculated from the equation of Plank and the time needed for the product's surface to decrease from initial temperature to freezing temperature (Barbosa-Canovas and Ibarz, 2002).

Several works have attempted to calculate real freezing time, as in one presented by Nagaoka *et al.,* (1955). Nagaoka's equation (Eq. 2) calculates the amount of heat elimination required to decrease a product's temperature from initial temperature to freezing temperature, as well as the amount of heat released during the phase change and the amount of heat eliminated to reach freezing temperature. Further empirical equations can be found in literature in detail (Chen, 1985; Levy, 1979; Succar and Hakayawa, 1983).

$$t_F = \frac{\rho \Delta H}{T_F - T_e}\left[\frac{Re^2}{k} + \frac{Pl}{h}\right]\left[1 + 0.008\left(T_i - T_F\right)\right]$$

(2)

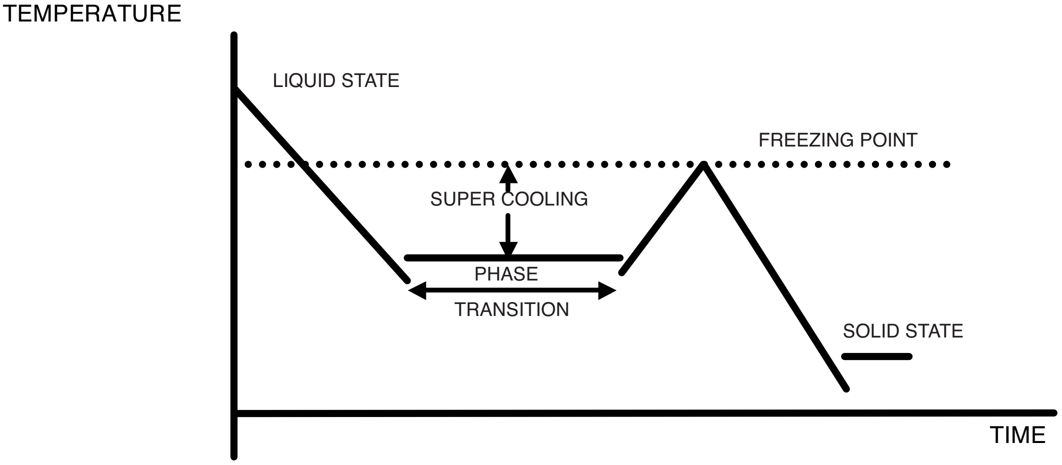
where Ti is the temperature of the food at the initiation of freezing, ΔH is the difference between the enthalpy of the food at initial temperature and end of freezing. Re and Pl are the dimensionless numbers, while k and h are the thermal conductivity and the coefficient of heat transfer, respectively.

For calculating freezing time of products with irregular shape, a common property of most food products—especially fruits and vegetables—a dimensionless factor has been employed in equations (Cleland *et al.,* 1987a,b).

Freezing rate

The freezing rate (°C/h) for a product or package is defined as the ratio of difference between initial and final temperature of product to freezing time. At a particular location within the product, a local freezing rate can be defined as the ratio of the difference between the initial temperature and desired temperature to the time elapsed in reaching the given final temperature (Persson and Lohndal, 1993). The quality of frozen products is largely dependent on the rate of freezing (Ramaswamy and Tung, 1984). Generally, rapid freezing results in better quality frozen products when compared with slow freezing. If freezing is instantaneous, there will be more locations within the food where crystallization begins. In contrast, if freezing is slow, the crystal growth will be slower with few nucleation sites resulting in larger ice crystals. Large ice crystals are known to cause mechanical damage to cell walls in addition to cell

Figure 4. **Freezing preservation dynamics curve.**



dehydration. Thus, the rate of freezing for plant tissues is extremely important due to the effect of freezing rate on the size of ice crystals, cell hydration, and damage to cell walls (Rahman, 1999). The figure 4 shows a general behavior of the dynamics curve of freezing preservation.

Rapid freezing is advantageous for freezing of many foods, however some products are susceptible to cracking when exposed to extremely low temperature for long periods. Several mechanisms, including volume expansion, contraction and expansion, and building of internal pressure, are proposed in literature explaining the mechanisms of product damage during freezing (Hung and Kim, 1996).

$$\Delta H = \left[1 - \frac{X_{SNJ}}{100}\right]\Delta H_i + 1.21\left[\frac{X_{SNJ}}{100}\right]\Delta T$$

Energy requirements

For fruits and vegetables, the amount of energy required for freezing is calculated based on the enthalpy change and the amount of product to be frozen. The following equation is reported by Riedel (1949) for calculation of refrigeration requirements for fruits and vegetables.

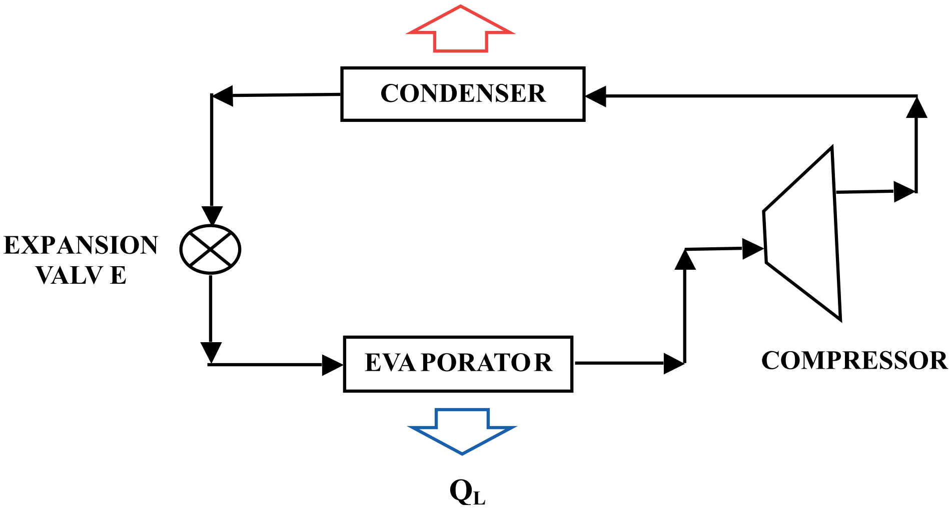
(3)

X_{SNJ}: Percentage of the product solids different from juice (Dry matter fraction of the juice)
ΔHj: Enthalpy change during freezing of the juice fraction
ΔT: Temperature difference between initial and final temperature of the product

1.2.3 Refrigeration

Refrigeration is defined as the elimination of heat from a material at a temperature higher than the temperature of its surroundings. The mechanism of refrigeration is a part of the freezing process and freezing storage involved in the thermodynamic aspects of freezing. According to the second law of thermodynamics, heat only flows from higher to lower temperatures. Therefore, in order to raise the heat from a lower to a higher temperature level, expenditure of work is needed. The aim of industrial refrigeration processes is to eliminate heat from low temperature points towards points with higher temperature. For this reason, either closed mechanical refrigeration cycles in which refrigeration fluids circulate, or open cryogenic systems with liquid nitrogen (LIN) or carbon dioxide (CO_2), are commonly used by the food industry.

Figure 5. **A simple scheme for a one-stage closed mechanical refrigeration system. (Adapted from Stoecker, W.F. and Jones J.W., Refrigeration and Air Conditioning, McGraw-Hill, New York, 1982)**



The main elements in a closed mechanical refrigeration system are the condenser, compressor, evaporator, and the expansion valve. The refrigerants hydrochlorofluorocarbon (HCFC) and ammonia are examples of the refrigerants circulated in these types of mechanical refrigeration systems. A simple scheme for the closed mechanical refrigeration system is shown in Figure 5.

Starting at the suction point of the compressor, fluid in a vapor state is compressed into the compressor where an increase in temperature and pressure takes place. The fluid then flows through the condenser where it decreases in energy by giving off heat and converting to a liquid state. After the phase, a change occurs inside the condenser, the fluid flows through the expansion valve where the pressure decreases to convert liquid into a form of liquid-gas mixture. Finally, the liquid-gas mixture flows through the evaporator where it is converted into a saturated vapor state and removes heat from the environment in the process of cooling. With this last stage the loop restarts again.

The other refrigeration system employed by the food industry is the cryogenic system with carbon dioxide or liquid nitrogen. The refrigerant in this system is consumed differently from the circulating fluid in closed mechanical systems.

Refrigerants

There are several refrigerants available for refrigeration systems.The selection of a proper refrigerant is based on physical, thermodynamic, and chemical properties of the fluid. Environmental considerations are also important in refrigerant selection, since leaks within the system produce deleterious effects on the atmospheric ozone layer. Some refrigerants, including halocarbons, have been banned to avoid potential hazardous effects (Stoecker and Jones, 1982). For industrial applications, ammonia is commonly used, while chlorofluoromethane and tetrafluoroethane are also recommended as refrigerants (Persson and Lohndal, 1993).

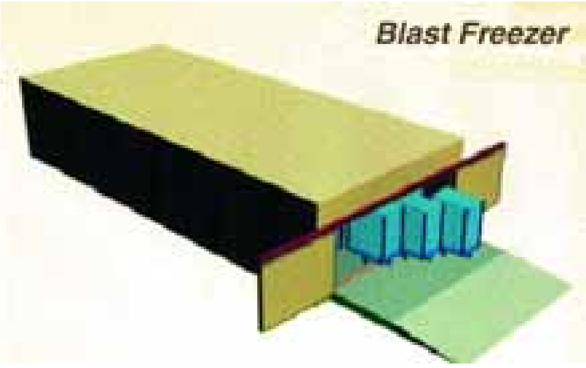
1.2.4 Freezing capacity

Freezing equipment selection is based on the requirements for freezing a certain quantity of food per hour. For any type of freezer, freezing capacity (expressed in tonnes per hour) is defined as the ratio of the quantity of the product that can be loaded into the freezer to the holding time of the product in that particular freezer. The first parameter, the amount of food product loaded into the freezer, is affected by both the dimensions of the product and the mechanical constraints of the freezer. The denominator (holding time) has an important role in freezing systems and is based on the calculation of the amount of heat removed from the product per hour, which varies depending on the type of product frozen (Persson and Lohndal, 1993).

1.2.5 Freezing systems

There is a variety of freezing systems available for freezing, and for most products, more than one type of freezer can be used. Therefore, in selecting a freezing system initially, a cost-benefit analysis should be conducted based on three important factors: economics, functionality, and feasibility. Financial considerations mainly involve capital investment and the production cost of selected equipment. Product losses during freezing operation should be included in cost estimation since generating higher cost freezers may have other benefits in terms of reducing product losses. Functional factors are mostly based on the suitability of the selected freezer for particular products. The mode of process, either in-line or batch, should be considered based on the fact that computerized systems are becoming more important for ease of handling and lowering production costs. Mechanical constraints for the freezer should also be considered since some types of freezers are not physically suitable for freezing certain products. Lastly,

Figure 6. **Air blast freezer.**

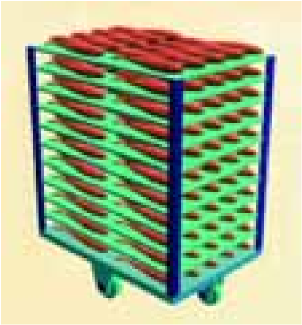


the feasibility of the process should be considered in terms of plant location or location of the processing area, as well as cleanability and hygienic design, and desired product quality (Johnston *et al.,* 1994).

These factors and initial considerations can help eliminate several choices in freezer selection, but the relative importance of factors may change depending on the process. For developing countries where the freezing application is relatively new, the cost factor becomes more important than other factors due to the decreased production rates and need for lower capital investment costs.

1.2.6 Freezing Equipment

Figure 7. **Trolley in a tunnel freezer.**



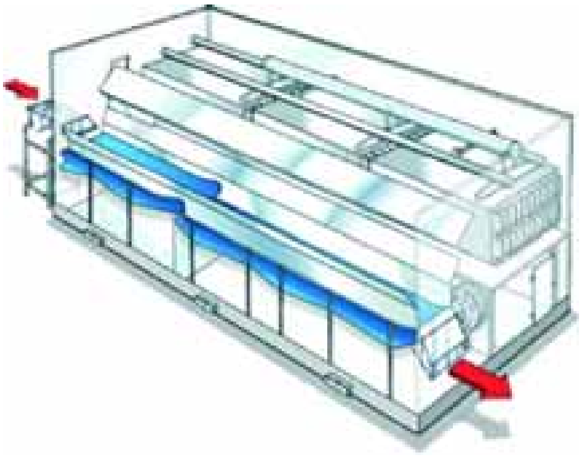
The industrial equipment for freezing can be categorized in many ways, namely as equipment used for batch or in-line operation, heat transfer systems (air, contact, cryogenic), and product stability. The rate of heat transfer from the freezing medium to the product is important in defining the freezing time of the product. Therefore, the equipment selected for freezing process characterizes the rate of freezing.

Air-blast freezers

The air blast freezer is one the oldest and commonly used freezing equipment due to its temperature stability and versatility for several product types. In general, air is used as the freezing medium in the freezing design, either as still air or forced air. Freezing is accomplished by placing the food in freezing rooms called sharp freezers. Still, air freezing is the cheapest way of freezing and has the added advantage of a constant temperature during frozen storage, which allows usage for unprocessed bulk products like beef quarters and fish. However, it is the slowest method of freezing due to the low surface heat transfer coefficient of circulating air inside the room. Freezing time in sharp freezers is largely dependent on the temperature of the freezing chamber and the type, initial temperature, and size of product (Desrosier and Desrosier 1977). An improved version of the still air freezer is the forced air freezer, which consists of air circulation by convection inside the freezing room. However, even modification of the sharp freezer with extra refrigeration capacity and fans for increased air circulation does not help control the air flow over the products during slow freezing. A typical design for air blast freezers is shown in Figure 6.

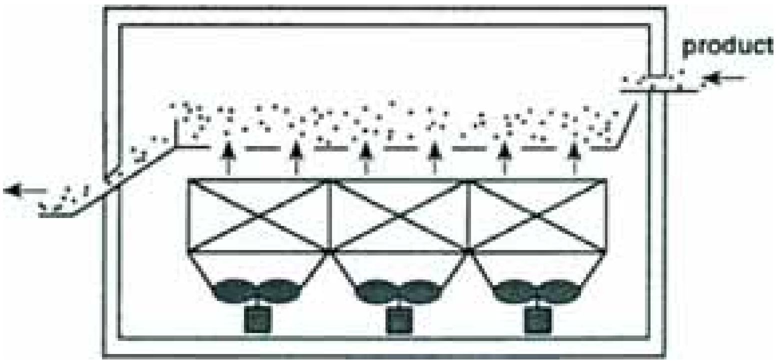
Figure 8. **The cross-section view of a spiral belt freezer.**
(Courtesy of Frigoscandia Equipment Ltd., UK)

Figure 9a. **Cross-sectional view of a fluidized bed freezer.**
(Courtesy of Frigoscandia Equipment Ltd., UK)



There are a considerable number of designs and arrangements for air blast freezers, primarily grouped in two categories depending on the mode of process, as either in-line or batch. Continuous freezers are the most suitable systems for mass production of packaged products with similar freezing times, in which the product is carried through on trucks or on conveyors. The system works on a semi-batch principle when trucks are used, since they remain stationary during the process except when a new truck enters one end of the tunnel, thus moving the others along to release a finished one at the exit. The batch freezers are more flexible since a variety of products can be frozen at the same time on individual trolleys. Over-loading may be a problem for these types of freezers, thus the process requires closer supervision than continuous systems.

Figure 9b. **Simple working principle of a fluidized bed freezer.**
(Saravacos, G.D., Kostaropoulos, A.E., 2002)



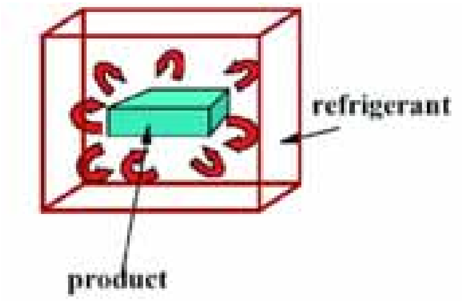
Tunnel freezers

In tunnel freezers, the products on trays are placed in racks or trolleys and frozen with cold air circulation inside the tunnel. In order to allow air circulation, optimum space is provided between layers of trolley, which can be moved continuously in and out of the freezer manually or by forklift trucks. This freezing system is suitable for all types of products, although there are some mechanical constraints including the requirement of high manpower for handling, cleaning, and transportation of trays (Mallett, 1993). A trolley for a tunnel freezer is shown in Figure 7.

Belt freezers

Belt freezers were first designed to provide continuous product flow with the help of a wire mesh conveyor inside the blast rooms. A poor heat transfer mechanism and the mechanical problems were solved in modern belt freezers by providing a vertical airflow to force air through the product layer. Airflow has good contact with the product only when the entire product is evenly distributed over the conveyor belt. In order to decrease required floor space, the belts can be arranged in a multi-tier belt freezer or a spiral belt freezer. Spiral belt freezers consist of a belt that can be bent laterally around a rotating drum to maximize belt surface area in a given floor space. This type of design has the advantage of eliminating product damage in transfer points, especially for products that require gentle handling (Mallett, 1993). Both packed and unpacked products with long freezing times (10 min to 3 hr) can be frozen in spiral belt freezers due to the flexibility of the equipment (ASHRAE, 1994). A typical spiral belt freezer is shown in Figure 8.

Figure 10. **Direct contact freezer.**



Fluidized bed freezers

The fluidized bed freezer, a fairly recent modified type of air-blast freezer for particular product types, consists of a bed with a perforated bottom through which cold air is blown vertically upwards (Rahman, 1999). The system relies on forced cold air from beneath the conveyor belt, causing the products to suspend or float in the cold air stream (George, 1993). The use of high air velocity is very effective for freezing unpacked foods, especially when they can be completely surrounded by flowing air, as in the case of fluidized bed freezers.

Figure 11. **Simple illustration of a typical immersion freezer (Fellows, 2000).**

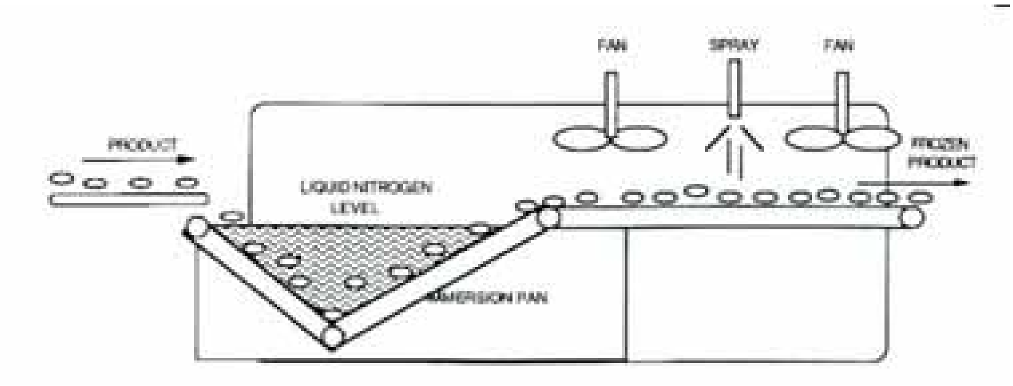
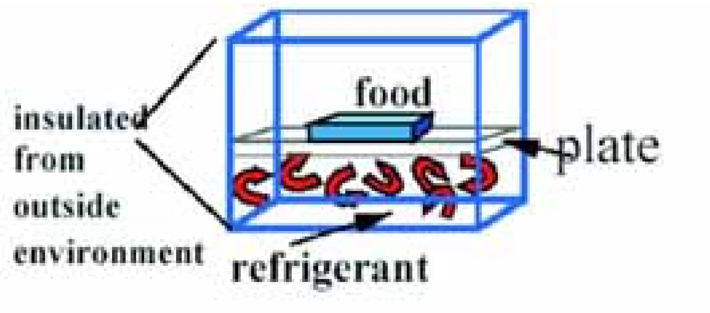
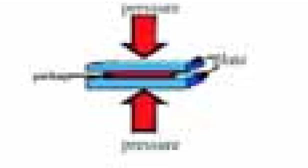


Figure 12. **Indirect contact freezer.**



The use of fluidization has several advantages compared with other methods of freezing since the product is individually quick frozen (IQF), which is convenient for particles with a tendency to stick together (Persson and Lohndal, 1993). The idea of individually quick frozen foods (IQF) started with the first technological developments aimed at

Figure 13a. **Pressure application in a plate freezer.**



quick freezing. The need for an effective means of freezing small particles with the potential for lumping during the process is the objective of IQF freezing. Small vegetables, prawns, shrimp, french-fried potatoes, diced meat, and fruits are some of the products now frozen with this technology. A typical fluidized-bed freezer is shown in Figures 9a and 9b.

Figure 13b. **Plate freezer with a two-stage compressor and sea water condenser (Courtesy of DSI Samifi Freezers S.r.I.)**

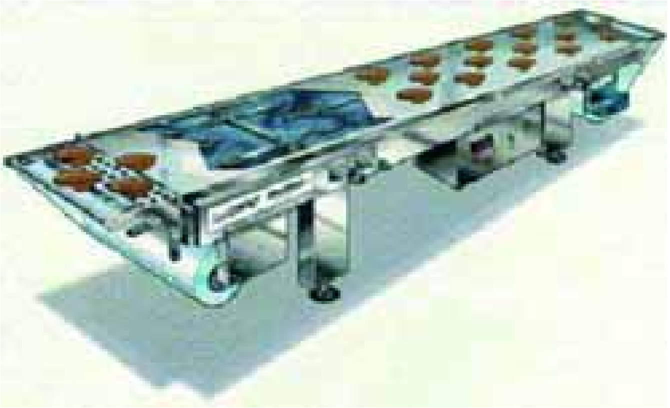
Contact freezers

Contact freezing is the one of the most efficient ways of freezing in terms of heat transfer mechanism. In the process of freezing, the product can be in direct or indirect contact with the freezing medium. For direct contact freezers, the product being frozen is fully surrounded by the freezing medium, the refrigerant, maximizing the heat transfer efficiency. A schematic illustration is given in Figure10. For indirect contact freezers, the product is indirectly exposed to the freezing medium while in contact with the belt or plate, which is in contact with the freezing medium (Mallett, 1993).

Immersion freezers

The immersion freezer consists of a tank with a cooled freezing media, such as glycol, glycerol, sodium chloride, calcium chloride, and mixtures of salt and sugar. The product is immersed in this solution or sprayed while being conveyed through the freezer, resulting in fast temperature reduction through direct heat exchange (Hung and Kim, 1996). Direct immersion of a product into a liquid refrigerant is the most rapid way of freezing since liquids have better heat conducting properties than air. The solute used in the freezing system should be safe without taste, odour, colour, or flavour, and for successful freezing, products should be greater in density than the solution. Immersion freezing systems have been commonly used for shell freezing of large particles due to the reducing ability of product dehydration when the outer layer is frozen quickly. A commonly seen problem in these freezing systems is the dilution of solution with the product, which can change the concentration and process parameters. Thus, in order to avoid product contact with the liquid refrigerant, flexible membranes can be used (George, 1993). A simple illustration of the immersion freezer is shown in Figure 11.

Figure 14. **Contact belt freezer.**
(Courtesy of Frigoscandia Equipment Ltd., UK)



Indirect contact freezers

In this type of freezer, materials being frozen are separated from the refrigerant by a conducting material, usually a steel plate. The mechanism of indirect contact freezer is shown in Figure 12. Indirect contact freezers generally provide an efficient medium for heat transfer, although the system has some limitations, especially when used for packaged foods due to resistance of package to heat transfer. Additionally, corrosive effects may occur due to interaction of metal packages with heat transfer surfaces.

Plate freezers

The most common type of contact freezer is the plate freezer. In this case, the product is pressed between hallow metal plates, either horizontally or vertically, with a refrigerant circulating inside the plates. Pressure is applied for good contact as schematically shown in Figure13a.

This type of freezing system is only limited to regular-shaped materials or blocks like beef patties or block-shaped packaged products. A typical plate freezer is shown in Figure 13b.

Contact belt freezers

This type of freezer is designed with single-band or double-band for freezing of thin product layers as shown in Figure 14. The design can be either straight forward or drum. Typical products frozen in belt freezers are, fruit pulps, egg yolk, sauces and soups (Persson and Lohndall, 1993).

Cryogenic freezers

Cryogenic freezing is a relatively new method of freezing in which the food is exposed to an atmosphere below -60 °C through direct contact with liquefied gases such as nitrogen or carbon dioxide (Hung and Kim, 1996). This type of system differs from other freezing systems since it is not connected to a refrigeration plant; the refrigerants used are liquefied in large industrial installations and shipped to the food-freezing factory in pressure vessels. Thus, the small size and mobility of cryogenic freezers allow for flexibility in design and efficiency of the freezing application. Low initial investment and rather high operating costs are typical for cryogenic freezers (Persson and Lohndal, 1993).

Liquid Nitrogen freezers

Liquid nitrogen, with a boiling temperature of -196 °C at atmospheric pressure, is a by-product of oxygen manufacture. The refrigerant is sprayed into the freezer and evaporates both on leaving the spray nozzles and on contact with the products. The system is designed in a way that the refrigerant passes in counter current to the movement of the products on the belt giving high transfer efficiency. The refrigerant consumption is in the range of 1.2-kg refrigerant per kg of the product. Typical food products used in this system are, fish fillets, seafood, fruits, berries (Persson and Lohndal, 1993).

Liquid carbon dioxide freezers

Liquid carbon dioxide exists as either a solid or gas when stored at atmospheric pressure. When the gas is released to the atmosphere at -70 °C, half of the gas becomes dry-ice snow and the other half stays in the form of vapor. This unusual property of liquid carbon dioxide is used in a variety of freezing systems, one of which is a pre-freezing treatment before the product is exposed to nitrogen spray (George, 1993).

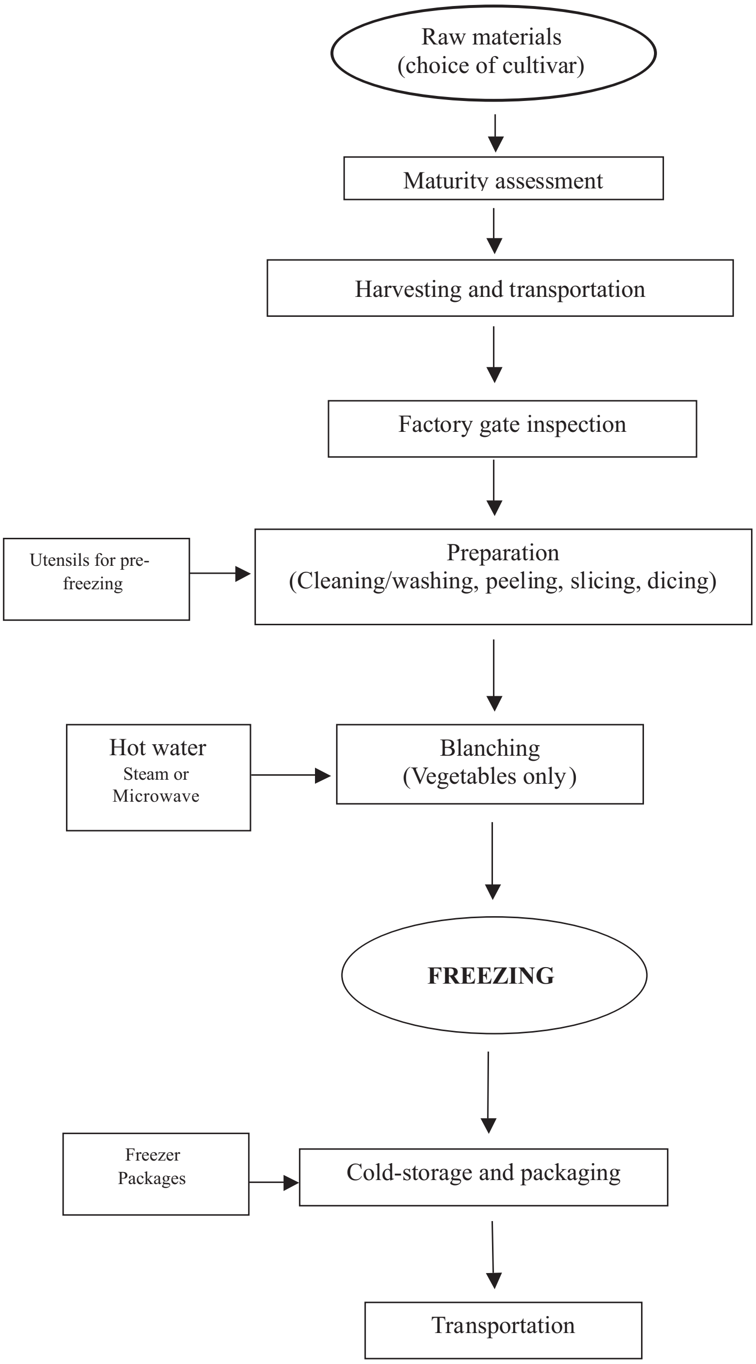
1.2.7 Packaging

Proper packaging of frozen food is important to protect the product from contamination and damage while in transit from the manufacturer to the consumer, as well as to preserve food value, flavour, colour, and texture. There are several factors considered in designing a suitable package for a frozen food. The package should be attractive to the consumer, protected from external contamination, and effective in terms of processing, handling, and cost (Rahman, 1999). Proper selection is based on the type of package and material. There are typically three types of packaging used for frozen foods: primary, secondary, and tertiary. The primary package is in direct contact with the food and the food is kept inside the package up to the time of use. Secondary packaging is a form of multiple packaging used to handle packages together for sale. Tertiary packaging is used for bulk transportation of products (Harrison and Croucher, 1993).

Packaging materials should be moisture-vapor-proof to prevent evaporation, thus retaining the highest quality in frozen foods. Oxygen should also be completely evacuated from the package using a vacuum or gas-flush system to prevent migration of moisture and oxygen (ASHRAE, 1994; Sebranek, 1996). Glass and rigid plastic are examples of moisture-vapor-proof packaging materials. Many packaging materials, however, are not moisture-vapor-proof, but are sufficiently moisture-vapor-resistant to retain satisfactory quality in foods. Most bags, wrapping materials, and waxed cartons used in freezing packaging are moisture-vapor-resistant. In general, the containers should be leakage free while easy to seal. Durability of the material is another important factor to consider, since the packaging material must not become brittle at low temperatures and crack (MSU, 1999).

A range of different packaging materials, mainly grouped as rigid and non-rigid containers, can be used for primary packaging. Glass, plastic, tin, and heavily waxed cardboard materials are in the rigid container group and usually used for packaging of liquid food products. Glass containers are mostly used for fruits and vegetables if they are not water-packed. Plastics are the derivatives of the oil-cracking industry (Brydson,

Figure 15. **A general flow chart of frozen fruits and vegetables (Mallett, 1993).**



1982). Non-rigid containers include bags and sheets made of moisture-vapor-resistant heavy aluminum foil, polyethylene or laminated papers. Bags are the most commonly used packaging materials for frozen fruits and vegetables due to their flexibility during processing and handling (Harrison and Croucher, 1993). They can be used with or without outer cardboard cartons to protect against tearing.

Shape and size of the container are also important factors in freezing products. Serving size may vary depending on the type of product and selection should be based on the amount of food determined for one meal. For shape of the container, freezer space must be considered since rigid containers with flat tops and bottoms stack well in the freezer, while round containers waste freezer space.

1.2.8 Frozen storage and distribution

The quality of the final product depends on the history of the raw material. Using the lowest possible temperature is essential for frozen storage, transport, and distribution in achieving a high-quality product, since deteriorative processes are mainly temperature dependent. The lower the product temperature is, the slower the speed of reaction is leading to loss of quality. The temperatures of supply chains in freezing applications from the factory to the retail cabinet should be carefully monitored. The temperature regime covering the freezing process, the cold-store temperatures (-18 °C), distribution temperatures (-15 °C), and retail display (-12 °C) are given as legal standards (Harrison and Croucher, 1993).

1.3 Freezing fruits and vegetables in small and medium scale operations and its potential applications in warm climates

The preservation of fruits and vegetables by freezing is one of the most important methods for retaining high quality in agricultural products over long-term storage. In particular, the freshness qualities of raw fruits and vegetables can be retained for long periods, extending well beyond the normal season of most horticultural crops (Arthey, 1993). The potential application of freezing preservation of fruits and vegetables, including tropical products, has been increasing recently in parallel with developments in developing countries. Freezing of fruits and vegetables in small and medium scale operations is detailed in the following sections and a general flowchart is shown in Figure 15.

1.3.1 Freezing fruits

The effect of freezing, frozen storage, and thawing on fruit quality has been investigated over several decades. Today frozen fruits constitute a large and important food group (Skrede, 1996). The quality demanded in frozen fruit products is mostly based on the intended use of the product. If the fruit is to be eaten without any further processing after thawing, texture characteristics are more important when compared to use as a raw material in other industries. In general, conventional methods of freezing tend to destroy the turgidity of living cells in fruit tissue. Different from vegetables, fruits do not have a fibrous structure that can resist this destructive effect. Additionally, fruits to be frozen are harvested in a fully ripe state and are soft in texture. On the contrary, a great number of vegetables are frozen in an immature state (Boyle *et al.,* 1977). Fruits have delicate flavours that are easily damaged or changed by heat, indicating they are best eaten when raw and decrease in quality with processing. In the same way, attractive colour is important for frozen fruits. Chemical treatments or additives are often used to inactivate the deteriorative enzymes in fruits. Therefore, proper processing is essential for all steps involved, from harvesting to packaging and distribution. A freezing guide for freezing fruits is shown in table 5.

Production and harvesting

The characteristics of raw materials are of primary importance in determining the quality of the frozen product. These characteristics include several factors such as genetic makeup, climate of the growing area, type of fertilization, and maturity of harvest (Boyle *et al.,* 1977).

The ability to withstand rough handling, resistance to virus diseases, molds, uniformity in ripening, and yield are some of the important characteristics of fruits in terms of economical aspects considered in production. The use of mechanical harvesting generally causes bruising of fruits and results in a wide range of maturity levels for fruits. In contrast, hand-picking provides gentler handling and maturity sorting of fruits. However in most cases, it is non-economical compared to mechanical harvesting due to high labor cost (Boyle *et al.,* 1977).

As a rule, harvesting of fruits at an optimum level for commercial use is difficult. Simple tests like pressure tests are applied to determine when a fruit has reached optimum maturity for harvest. Colour is also one of the characteristics used in determining maturity since increased maturation causes a darker colour in fruits. A combination of colour and pressure tests is a better way to assess maturity level for harvesting (Skrede, 1996).

Controlled atmosphere storage is a common method of storage for some fruits prior to freezing. In principle, a controlled atmosphere high in carbon dioxide and low in oxygen content slows down the rate of respiration, which may extend shelf life of any respiring fruit during storage. Due to the fact that these fruits do not ripen appreciably after picking, most fruits are picked as near to eating-ripe maturity as possible.

Pre-process handling and operations

Freezing preservation of fruits can only help retain the inherent quality present initially in a product since the process does not improve the quality characteristics of raw materials. Therefore, quality level of the raw materials prior to freezing is the major consideration for successful freezing. Washing and cutting generally results in losses when applied after thawing. Thus, fruits should be prepared prior to the freezing process in terms of peeling, slicing or cutting. Freezing preservation does not require specific unit operations for cleaning, rinsing, sorting, peeling, and cutting of fruits (Spiess, 1984).

Fruits that require peeling before consumption should be peeled prior to freezing. Peeling is done by scalding the fruit in hot water, steam or hot lye solutions (Boyle and Wolford, 1968). The effect of peeling on the quality of frozen products has been studied for several fruits, including kiwi (Robertson, 1985), banana (Cano *et al.,* 1990), and mango (Cano and Marín, 1992). The rate of freezing can be increased by decreasing the size of products frozen, especially for large fruits. An increase in the freezing rate results in smaller ice crystals, which decreases cellular damage in fruit tissue. Banana, tomato, mango, and kiwi are some examples of large fruits commonly cut into smaller cubes or slices prior to freezing (Skrede, 1996).

The objective of blanching is to inactivate the enzymes causing detrimental changes in colour, odour, flavour, and nutritive value, but heat treatment causes loss of such characteristics in fruits (Gutschmidt, 1968). Therefore, only a few types of fruits are blanched for inactivation of enzymes prior to freezing. The loss of water-soluble minerals and vitamins during blanching should also be minimized by keeping blanching time and temperature at an optimum combination (Spiess, 1984).

Effect of ingredients

Addition of sugars is an extremely important pretreatment for fruits prior to freezing since the treatment has the effect of excluding oxygen from the fruit, which helps to retain colour and appearance. Sugars when dissolved in solutions act by withdrawing water from cells by osmosis, resulting in very concentrated solutions inside the cells.

The high concentration of solutes depresses the freezing point and therefore reduces the freezing within the cells, which inhibits excessive structural damage (Munoz-Delgado, 1978). Sugar syrups in the range of 30-60 percent sugar content are commonly used to cover the fruit completely, acting as a barrier to oxygen transmission and browning. Several experiments have shown the protective effect of sugar on flavour, odour, colour, and nutritive value during freezing, especially for frozen berries (Gutschmidt, 1968).

Packaging

Fruits exposed to oxygen are susceptible to oxidative degradation, resulting in browning and reduced storage life of products (Munoz-Delgado, 1978; Tomassicchio *et al.,* 1986). Therefore, packaging of frozen fruits is based on excluding air from the fruit tissue. Replacement of oxygen with sugar solution or inert gas, consuming the oxygen by glucose-oxidase and/or the use of vacuum and oxygen-impermeable films are some of the methods currently employed for packaging frozen fruits. Plastic bags, plastic pots, paper bags, and cans are some of the most commonly used packaging materials (with or without oxygen removal) selected, based on penetration properties and thickness (Gradziel, 1988).

There are several types of fruit packs suitable for freezing: syrup pack, sugar pack, unsweetened pack, and tray pack and sugar replacement pack. The type of pack is usually selected according to the intended use for the fruit. Syrup-packed fruits are generally used for cooking purposes, while dry-packed and tray-packed fruits are good for serving raw in salads and garnishes.

Syrup pack

The proportion of sugar to water used in a syrup pack depends on the sweetness of the fruit and the taste preference of the consumer. For most fruits, 40 percent sugar syrup is recommended. Lighter syrups are lower in calories and mostly desirable for mild-flavoured fruits to prevent masking the flavour, while heavier syrups may be used for very sour fruits (Kendall, 2002).

Syrup is prepared by dissolving the sugar in warm water and cooling the solution down before usage. Just enough cooled syrup is used to cover the prepared fruit after it has been settled by jarring the container. In order to keep the fruit under the syrup, a small piece of crumpled waxed paper or other water resistant wrapping material is placed on top; the fruit is pressed down into the syrup before closing, then sealed and frozen (Beck, 1996).

Table 5. **Fruit freezing guide**

(Kendall, Colorado State University, Cooperative Extension, 2002)

Fruit	Preparation	Type of Pack
Apples	Wash, peel, and slice into antidarkening solution -- 3 tablespoons lemon juice per quart of water	Pack in 30-40% syrup, adding 1/2 teaspoon crystalline ascorbic acid per quart of syrup. Pack dry or with up to 1/2 cup sugar per quart of apple slices.
Apricots	Wash, halve, and pit. Peel and slice if desired. If apricots are not peeled, heat in boiling water for 1/2 minute to keep skins from toughening during freezing. Cool in cold water, drain.	Pack in 40% syrup, adding 3/4 teaspoon crystalline ascorbic acid per quart of syrup.
Avocados	Peel soft, ripe avocados. Cut in half, remove pit, mash pulp.	Add 1/8 teaspoon crystalline ascorbic acid to each quart of puree. Package in recipe-size amounts.
Berries	Select firm, fully ripe berries. Sort, wash, and drain.	Use 30% syrup pack, dry unsweetened pack, dry sugar pack, (3/4 cup sugar per quart of berries), or tray pack.
Cherries (sour or sweet)	Select well-colored, tree-ripened cherries. Stem, sort, and wash thoroughly. Drain and pit.	Pack in 30-40% syrup. Add 1/2 teaspoon ascorbic acid per quart of syrup. For pies and other cooked products, pack in dry sugar using 3/4-cup sugar per quart of fruit.
Citrus fruits, (sections or slices)	Select firm fruit, free of soft spots. Wash and peel.	Pack in 40% syrup or in fruit juice. Add 1/2 teaspoon ascorbic acid per quart of syrup or juice.
Grapes	Select firm, ripe grapes. Wash and remove stems. Leave seedless grapes whole. Cut grapes with seeds in half and remove seeds.	Pack in 20% syrup or pack without sugar. Use dry pack for halved grapes and tray pack for whole grapes.
Melons (cantaloupe, watermelon)	Select firm-fleshed, well-colored, ripe melons. Wash rinds well. Slice or cut into chunks.	Pack in 30% syrup or pack dry using no sugar. Pulp also may be crushed (except watermelon), adding 1 tablespoon sugar per quart. Freeze in recipe-size containers.

Pectin can be used to reduce sugar content in syrups when freezing berries, cherries, and peaches. Pectin syrups are prepared by dissolving 1 box of powdered pectin with 1 cup of water. The solution is stirred and boiled for 1 minute; 1/2 cup of sugar is added and dissolved; the solution is then cooled down with the addition of cold water. Previously prepared fruit is put into a 4 to 6 quart bowl and enough pectin syrup is added to cover the fruit with a thin film. The pack is sealed and promptly frozen (Brady, 2002).

Sugar packs

In preparing a sugar pack, sugar is first sprinkled over the fruit. Then the container is agitated gently until the juice is drawn out and the sugar is dissolved. This type of pack is generally used for soft sliced fruits such as peaches, strawberries, plums, and cherries, by using sufficient syrup to cover the fruit. Some whole fruits may also be coated with sugar prior to freezing (Beck, 1996).

Unsweetened packs

Unsweetened packs can be prepared in several ways, either dry-packed, covered with water containing ascorbic acid, or packed in unsweetened juice. When water or juice is used in syrup and sugar packs, fruit is submerged by using a small piece of crumpled water-resistant material. Generally, unsweetened packs yield a lower quality product when compared with sugar packs, with the exception, some fruits such as raspberries, blueberries, scalded apples, gooseberries, currants, and cranberries maintain good quality without sugar (Beck, 1996).

Tray packs

Unsweetened packs are generally prepared by using tray packs in which a single layer of prepared fruit is spread on shallow trays, frozen, and packaged in freezer bags promptly. The fruit sections remain loose without clumping together, which offers the advantage of using frozen fruit piece by piece.

Sugar replacement packs

Artificial sweeteners can be used instead of sugar in the form of sugar substitutes. The sweet taste of sugar can be replaced by using these kinds of sweeteners, however the beneficial effects of sugar like colour protection and thick syrup can not be replaced. Fruits frozen with sugar substitutes will freeze harder and thaw more slowly than fruits preserved with sugar (Beck, 1996).

1.3.2 Freezing vegetables

Freezing is often considered the simplest and most natural way of preservation for vegetables (Cano, 1996). Frozen vegetables and potatoes form a significant proportion of the market in terms of frozen food consumption (Mallett, 1993). The quality of frozen vegetables depends on the quality of fresh products, since freezing does not improve product quality. Pre-process handling, from the time vegetables are picked until ready to eat, is one of the major concerns in quality retention.

Crop cultivar, production, and maturity

The choice of the right cultivar and maturity before crop is harvested are the two most important factors affecting raw material quality. Raw material characteristics are usually related to the vegetable cultivar, crop production, crop maturity, harvesting practices, crop storage, transport, and factory reception.

The choice of crop cultivars is mostly based on their suitability for frozen preservation in terms of factory yield and product quality. Some of the characteristics used as selection criteria are as follows (Cano, 1996):

- Suitability for mechanical harvesting
- Uniform maturity
- Exceptional flavour and uniform colour and desirable texture
- Resistance to diseases
- High yield

Although cultivar selection is a major factor affecting the quality of the final product, many practices in the field and factors during growth of crop can also have a significant effect on quality. Those practices include site selection for growth, nutrition of crop, and use of agricultural chemicals to control pests or diseases. The maturity assessment for harvesting is one of the most difficult parts of the production. In addition to conventional methods, new instruments and tests have been developed to predict the maturity of crops that help determining the optimum harvest time, although the maturity assessment differs according to crop variety (Hui *et al.,* 2004).

Harvesting

At optimum maturity, physiological changes in several vegetables take place very rapidly. Thus, the determination of optimum harvesting time is critical (Arthey, 1993). Some vegetables such as green peas and sweet corn only have a short period during which they are of prime quality. If harvesting is delayed beyond this point, quality deteriorates and the crop may quickly become unacceptable (Lee, 1989). Most of the vegetables are subjected to bruising during harvesting.

Pre-process handling

Table 6. **Vegetable freezing guide (Archuleta, 2003)**

Vegetable	Preparation	Blanch/Freeze
Asparagus	Wash and sort by size. Snap off tough ends. Cut stalks into 5-cm lengths.	Water blanch: 2 min Steam blanch: 3 min
Beans	Wash and trim the ends. Cut if desired.	Water blanch: Whole: 3 min. Cut: 2 min. Steam blanch: Whole: 4 min. Cut: 3 min.
Beets	Wash and remove the tops leaving 2.5 cm of stem and root.	Cook until tender: 25-30 min Cool promptly, peel, trim. Cut into slices or cubes and pack.
Broccoli	Wash and cut into pieces.	Water blanch: 3 min. Steam blanch: 3 min.
Cabbage	Wash and cut into wedges.	Water blanch: 3 min. Steam blanch: 4 min.
Carrots	Wash, peel and trim. Cut if desired.	Water blanch: 5 min.
Cauliflower	Discard leaves; steam and wash. Break into flowerets.	Water blanch: Whole: 5 min. Steam blanch: Whole: 7 min
Corn	Remove husks and silks. Trim ends and wash.	Water blanch: Whole: 5 min. Steam blanch: Whole: 7 min
Greens	Select young tender greens. Wash and trim the leaves.	Water blanch: 2 min. Steam blanch: 3 min.
Herbs	Wash.	No heat treatment is needed.
Mushrooms	Wipe and damp with paper towel. Trim hard tip of stems. Sort and cut large mushrooms.	May be frozen without heat treatment.
Peas	Shell garden peas.	Water blanch: 1-1/2 min. Steam blanch: 1-1/2 min.
Peppers	Wash, remove stems and seeds.	Freeze whole or cut as desired. No heat treatment is needed.
Potatoes	Peel, cut or grate as desired.	Water blanch: Whole: 5 min. Pieces: 2-3 min.

Vegetables at peak flavour and texture are used for freezing. Postharvest delays in handling vegetables are known to produce deterioration in flavour, texture, colour, and nutrients (Lee, 1989). Therefore, the delays between harvest and processing should be reduced to retain fresh quality prior to freezing. Cooling vegetables by cold water, air blasting, or ice will often reduce the rate of post-harvest losses sufficiently, providing extra hours of high quality retention for transporting raw material to considerable distances from the field to the processing plant (Deitrich *et al.,* 1977).

Blanching

Blanching is the exposure of the vegetables to boiling water or steam for a brief period of time to inactivate enzymes. Practically every vegetable (except herbs and green peppers) needs to be blanched and promptly cooled prior to freezing, since heating slows or stops the enzyme action, which causes vegetables to grow and mature. After maturation, however, enzymes can cause loss in quality, flavour, colour, texture, and nutrients. If vegetables are not heated sufficiently, the enzymes will continue to be active during frozen storage and may cause the vegetables to toughen or develop off-flavours and colours. Blanching also causes wilting or softening of vegetables, making them easier to pack. It destroys some bacteria and helps remove any surface dirt (Desrosier and Tressler, 1977).

Blanching in hot water at 70 to 105 °C has been associated with the destruction of enzyme activity. Blanching is usually carried out between 75 and 95 °C for 1 to 10 minutes, depending on the size of individual vegetable pieces (Holdsworth, 1983). Blanched vegetables should be promptly cooled down to control and minimize the degradation of soluble and heat-labile nutrients (Deitrich *et al.,* 1977).

The enzymes used as indicators of effectiveness of the blanching treatment are peroxidase, catalase, and more recently lipoxygenase. Peroxidase inactivation is commonly used in vegetable processing, since peroxidase is easily detected and is the most heat stable of these enzymes (Arthey, 1993).

Vegetables can be blanched in hot water, steam, and in the microwave. Hot water blanching is the most common way of processing vegetables. Blanching times recommended for various vegetables are given in Table 6, which indicates that the operation time can vary depending on the intended product use. For water blanching, vegetables are put in a basket and then placed in a kettle of boiling water covered with a lid. Timing begins immediately (Archuleta, 2003). Steam blanching takes longer than the water method, but helps retain water-soluble nutrients such as water-soluble vitamins.

Chapter 2

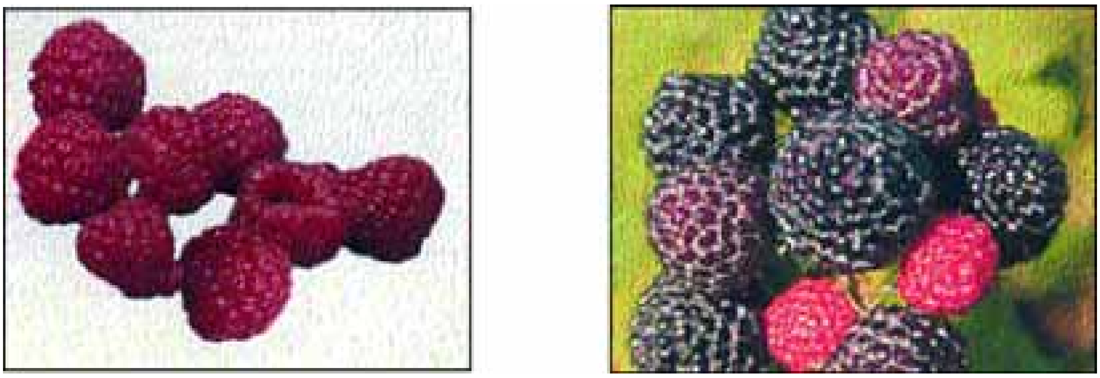
Formulation and processing of selected frozen food prototypes

General unit operations commonly applied to all fruits and vegetables are given in the previous section, however specific preparations are required for each kind. Therefore, food prototypes based on fruits and vegetables are used to demonstrate the freezing application on specific food products.

2.1 Selecting a formulation for mixed fruits

One of the most common commercially frozen fruit products is mixed frozen berries as is shown in Figure 16. The mixtures typically contain combinations of raspberries, blackberries, blueberries, and strawberries. There is a wide range of mixtures available in the market for frozen berry combinations. Raspberries and blackberries for example, which are known to freeze well and retain their wholeness and shape, dependent on the structure of the fruit, are strongly associated with their cultivar. The processing requirements for different varieties of berries do not change significantly. Therefore, a mixture of raspberries and blackberries is chosen in this case as a fruit formulation to simplify the freezing process.

Figure 16. **Raspberries and blackberries.**



Procedure for processing mixed berries

- Full-flavoured, ripe berries of like size preferably with tender skins are selected.
- Berries are sorted, washed, and drained.
- Berries are packed into containers and covered with cold 40 percent sugar syrup, with proper headspace.
- Polyethylene freezer bags are sealed and frozen.

2.2 Selecting a formulation for mixed vegetables

Frozen mixed vegetables constitute a large portion of the frozen vegetable market and are now available in an ever-increasing variety of mixtures as is shown in Figure 17. The mixtures include three or more types of vegetables, properly prepared and blanched. The USDA standards for frozen mixed vegetables describe this item as a mixture containing three or more of the basic vegetables—beans, carrots, corn, and peas. When three vegetables are used, none of the vegetables should be more than 40 percent of the total weight; the individual percent decreases with increased number of vegetable types (Hui *et al.,*2001).

Figure 17. **Mixed vegetables.**

In a mixed frozen vegetable product, vegetables of different sizes are present in the mixture. Therefore, during pre-freeze treatments, especially blanching, care must be taken to be sure all vegetables are blanched properly.

Procedure for processing mixed vegetables

- A mixture of four vegetables in which none of the vegetables is less than 8 percent by weight nor more than 35 percent by weight of all the frozen mixed vegetables are selected.
- The vegetables are sorted, washed and peeled.
- They are cut into uniform size and blanched in hot water for 5 minutes, and immediately cooled after blanching.
- Packed and frozen.

Figure 18. **Flow diagram of freezing process for fruit-based product.**

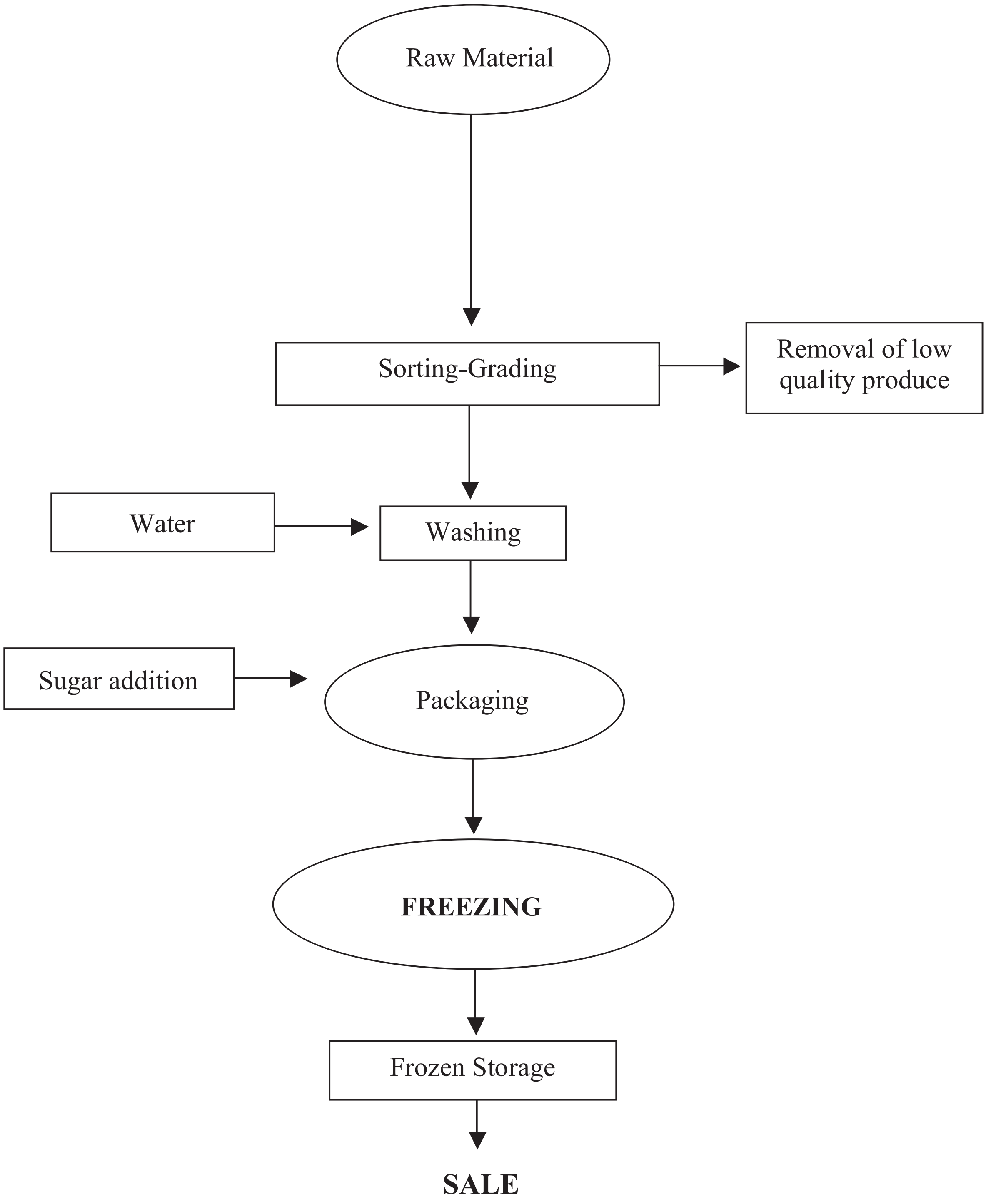
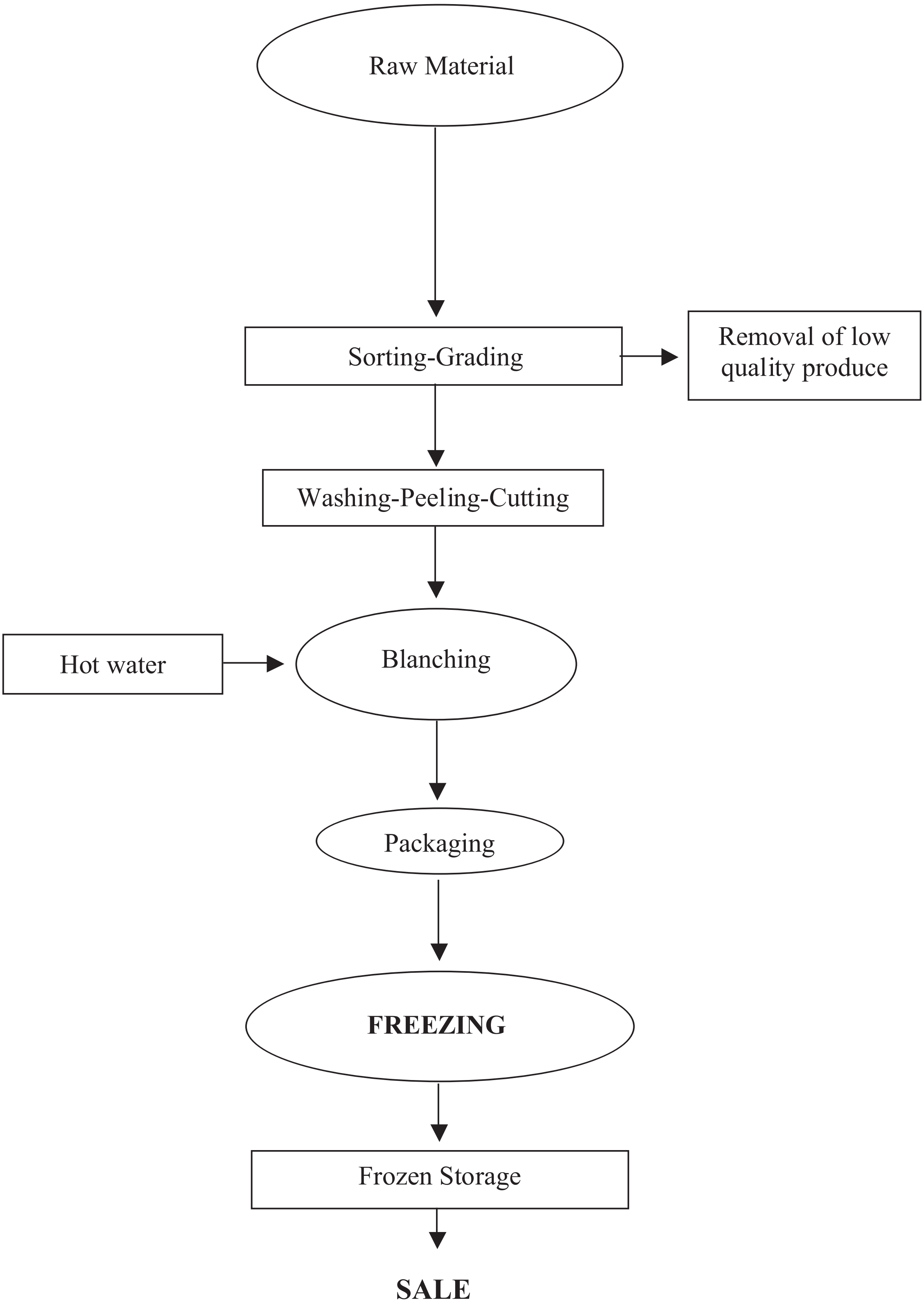


Figure 19. **Flow diagram of freezing process of vegetable-based product.**



2.3 Recommendations for the processing site

Initial selection of the processing site should be based on significant considerations. The design of the general processing plant has great importance in assuring quality of the final product and the effectiveness of the process (Mayes and Telling, 1993). Some recommendations related to the location, and the general plant layout, are summarized in the following section (Herron, 1968). Also Figures 18 and 19 show a general flow diagram recommendable for freezing of fruits and vegetables respectively.

2.3.1 Location

- Areas free from objectionable odours, smoke, flies, ash, and dust or other sources of contamination shall be considered in choosing the location for the food processing plant.
- Frozen food preparation plants shall be completely separate from areas used as living or sleeping quarters by solid partitions with no connecting openings.

2.3.2 General plant layout

- Product preparation and processing (including freezing) departments shall be of sufficient size to permit the installation of all necessary equipment with proper space for plant operations.
- The proper flow of the product shall be arranged in the plant, without backtracking, from the time raw materials are received until the frozen, packaged article is shipped from the plant.
- Raw material storage rooms and areas where pre-freezing operations (e.g., washing and peeling of fruits and vegetables, and preparation of meats) are carried out shall be separated from rooms or areas where frozen food is formulated, processed, and packaged.
- Doors connecting various rooms or openings to the outside shall be tight-fitted, solid, and kept in a closed position by self-closing devices.
- Facilities for efficient quick-freezing of the product shall be provided and conveniently located near the food processing and packaging departments. Proper freezer storage shall be provided with convenient access to the quick freezing facilities.
- A separate room for storing inedible materials such as fruit and vegetable peels, pending removal from the plant, shall be provided in a location convenient to the various preparation and processing areas. This waste storage room shall be of sufficient size to permit proper storage.

- The discharge from the exhaust system, if used, shall be located far away from fresh air inlets into the plant. Packaging and labeling material shall be stored in a separately enclosed space convenient to the packaging department.

Employees shall not be permitted to eat in food processing or packaging areas. Well located, properly ventilated dressing rooms and toilet rooms of ample size with self-closing doors shall be provided for employees (Herron, 1968).

Chapter 3

Raw materials and required equipment

The formulations given as examples are selected based on the proper illustration of the freezing process without complicated operations. Therefore, simple formulations with a reduced number of ingredients are used as food products. In the same manner, required equipment is chosen based on a reduced production rate in order to simplify the calculations.

3.1 Ingredients for the proposed formulations

The main ingredients in prototype fruit-based and vegetable-based formulations are as follows:

- Fruit-based formulation
  Raspberry, blackberry, sugar syrup (40 percent)
- Vegetable-based formulation
  Carrot, green beans, cauliflower, and onions

3.2 Freezing equipment

As mentioned earlier in the section on freezing equipment, production rate is an important consideration in selection of proper equipment for the freezing operation. To simplify the process parameters of the selected prototype formulations, a lower production rate is used. 1 000 kg of frozen product (fruits or vegetables) per month was found suitable in a small-scale operation where usage of a domestic freezer is generally more convenient than an industrial freezer. Several types of domestic freezers are available on the market but the selection was based on economical considerations. Chest freezers are relatively more economical than other types of domestic freezers in terms of energy usage for small-scale operations. Considering the production rate per month and capacity, an optimum domestic freezer, the Zanussi ZCF146 chest freezer with internal volume of 414 lt, was chosen to handle freezing of the fruits and vegetables. This is shown in Figure 20.

Figure 20. **Zanussi ZCF146 chest freezer with internal volume of 414 lt.**

3.3 Processing equipment

The equipment required in pre-freezing operations and packaging include proper kitchen utensils for washing and cutting, hot water kettles for blanching, and proper devices for packaging. In general, the highest investment cost in the freezing process is the freezer operation. The utensils are only a small percentage of the initial investment.

3.4 Frozen Storage

Following the freezing operation, frozen products are maintained in frozen storage, which is also an important step in the quality retention of frozen food products. During frozen storage, the amount of ice in the system generally remains constant for any given temperature, where the number of ice crystals decreases due to increase in average crystal size (Blanshard and Franks, 1987). Fluctuations in storage temperature and temperature gradient within the product cause moisture migration, relocating the water within the product and undesirable recristalization which may afect texture and general quality. Therefore, it is important to maintain and monitor the efficiency of frozen storage for retention of high quality within the frozen products.

Cold stores are generally maintained at –30 °C and the cost of the facility is mostly based on the size of the storage room. The main cost of a storage facility is due to the construction of the building, preparation of the site, and provision of the services. However, public cold stores also provide service for small-scale operations and are relatively less costly than private ones (Johnston *et al.,* 1994).

Chapter 4

Recommendations for final product quality

The quality of frozen products and consumer acceptance can be enhanced by optimizing process conditions such as rate of freezing, quality of raw materials, and storage conditions details (see previous chapters for more detail). However, important factors can be grouped in a less confusing way based on conclusions drawn from the aspects related to quality deterioration. These groups are sensory quality, including the physical and chemical aspects of quality deterioration, microbiological quality, and nutritive quality of frozen products.

4.1 Sensory quality

The main components of the overall sensation of flavor are taste and aroma (Salunkhe, 1991). The receptors on the tongue are responsible of perceiving flavors, while aroma generally contributes to total flavor. The analysis used to determine the effects of freezing process, frozen storage, and thawing on product flavor is largely based on the changes produced in chemical compounds. Sensory quality of frozen products is commonly determined based on texture, which includes both the properties perceived by sensation in mouth and appearance (Skrede, 1996). Therefore, a good understanding of the physical aspects of freezing will help improve the product's quality retention during the freezing process.

4.1.1 Physical aspects of freezing

Moisture migration is the principal physical change occurring in frozen foods, affecting the physical, chemical, and biochemical properties, including texture and palatability of the food (Pham and Mawson, 1997).

Texture

Most fruits and vegetables are over 90 percent water of total weight. The water and dissolved solutes inside the rigid plant cell walls give support to the plant structure, and texture to the fruit or vegetable tissue. In the process of freezing, when water in the cells freezes, an expansion occurs and ice crystals cause the cell walls to rupture. Consequently, the texture of the produce is generally much softer after thawing when compared to non-frozen produce. This textural difference is especially noticeable in products normally consumed raw, as in the case of fruits. It is usually recommended that frozen fruits be served before they are completely thawed, since in the partially thawed state the effect of freezing on the fruit tissue is less noticeable. On the other hand, due to the fact cooking also softens cell walls, textural changes caused by freezing are not significantly noticeable in products cooked before eating, as in the case of most vegetables (Schafer and Munson, 1990).

Freezer burn

One of the most common forms of quality degradation due to moisture migration in frozen foods is freezer burn, a condition defined as the glassy appearance in some frozen products produced by ice crystals evaporating on the surface area of a product (Kaess, 1961). The grainy, brownish spots occurring on the product cause the tissue to become dry and tough and to develop off-flavors. This quality defect can be prevented by using heavyweight, moisture proof packaging during the freezing process (Pham and Mawson, 1997).

4.1.2 Chemical aspects of freezing

Chemical changes that can cause spoilage and deterioration of fresh fruits and vegetables will continue after harvesting. This is the main reason for eliminating any delays during pre-freezing operations. As mentioned earlier, several enzymes that cause the loss of color, loss of nutrients, flavor changes, and color changes in frozen fruits and vegetables, should be inactivated by means of thermal treatments prior to freezing. In most cases, blanching is essential for producing quality frozen vegetables, since it also helps destroy microorganisms on the surface of the produce. However, in processing fruits, heat treatment may cause more degradation in quality. In this case, enzymes in frozen fruits can be controlled by using chemical compounds, which interfere with deteriorative chemical reactions. Ascorbic acid is an example that may be used in its pure form or in commercial mixtures with sugars for inhibition of enzymes in fruits.

Development of rancid oxidative flavors through contact of the frozen product with air is another group of chemical changes that can take place in frozen products. This problem can be controlled by excluding oxygen through proper packaging as mentioned earlier. It is also advisable to remove as much air as possible from the freezer bag or container to reduce the amount of air in contact with the product (Schafer and Munson, 1990).

4.2 Hygienic and sanitary quality: legal standards

Despite a general increase in microbiological outbreaks in processed foods, frozen foods have demonstrated a good food safety record. The confidence in frozen foods largely depends on the microbiological quality of the raw materials prior to usage, the efficiency of processing, and finally the efficiency of consumers in following specified product instructions (Mayes and Telling, 1993).

Microbiological aspects of freezing

Microorganisms differ significantly in their sensitivity to freezing, thus the main concern about the microbiological aspects of freezing is the growth of organisms during thawing rather than during freezing (Archer *et al.,* 1995). In general, the freezing process does not significantly destroy the microorganisms that may be present in fruits and vegetables. The blanching process prior to freezing destroys some microorganisms and there is a gradual decline in the number of microorganisms during freezer storage. However, a sufficient number of survivors are still present that can multiply and cause spoilage of the product during thawing. Fluctuation in storage temperature is one of the main reasons for microbial deterioration of frozen products during storage. Thus, a careful inspection of frozen products is essential to ensure proper freezing storage with constant temperatures (Schafer and Munson, 1990).

Legal standards

Several agencies exist that establish regulatory standards for frozen fruits and vegetables based on import-export regulations of countries around the world. Some of the general regulations for consideration in the freezing of fruits and vegetables are summarized by the Canadian Food Inspection Agency Liaison (Preparedness and Policy Coordination).

Frozen fruit products

a. Shall be prepared from fresh or previously frozen fruit that is preserved by freezing.
b. Shall be packed
    (i) with or without a sweetening ingredient in dry form, or
    (ii) in a packing medium consisting of
        (A) water, with or without a sweetening ingredient, or
        (B) one or more fruit juices, concentrated fruit juices, reconstituted fruit juices, fruit purees or fruit nectars, with or without a sweetening ingredient.

c. May contain citric acid or ascorbic acid, in accordance with good manufacturing practice.
d. May contain any other substance, the addition of which to frozen fruit is in accordance with good manufacturing practice, and is generally recognized as safe.

Frozen vegetable products

a. Shall be prepared from fresh vegetables, or as a mixture of frozen vegetables, that are preserved by freezing.
b. May contain salt.
c. May contain any other substance, the addition of which to frozen vegetables is in accordance with good manufacturing practice, and is generally recognized as safe.

4.3 Nutritional quality: energy contribution

For any type of food preservation method, the retention of nutritional components is a concern, but freezing is probably the least destructive when properly done (Sebranek, 1996). To maintain top nutritional quality in frozen fruits and vegetables, it is essential to follow directions contained in this manual, for each and every step of the freezing process (Schafer and Munson, 1990).

- Fruits—Most frozen fruits will maintain a high quality for 8 to 12 months. Unsweetened fruits will lose quality faster than those packed in sugar or sugar syrups.
- Vegetables—Most vegetables will maintain a high quality for 12 to 18 months at -18 °C or lower.

Fruits and vegetables are important sources of vitamin C, folate, and minerals, with colored fruits and vegetables also a source of carotenoids. The freezing process itself has no effect on nutrients, but during blanching (prior to freezing) water-soluble nutrients may be leached-out during the process (Bender, 1981).

4.4 Marketing the product

Marketing of the product clearly is of great importance considering the increasing competition in the food industry. The ever-increasing number of brands and the technological improvements in the frozen food division require that improved marketing strategies be followed. The presentation of the product, which includes labeling, is one of the most appealing characteristics of a product in terms of consumer selection.

Suitable package for the product

A good quality freezer container should be used to maintain the quality of frozen fruits and vegetables. Many moisture- and vapor-resistant wraps, such as heavyweight aluminum foil, plastic coated freezer paper, and other plastic films are effective at excluding oxygen. These wraps are not as convenient for fruits and vegetables as plastic bags or rigid freezer containers, therefore polyethylene plastic bag containers can be used for frozen product formulations. Plastic film bags made especially for freezing are readily available. They can be sealed with twist and tie tops. Collapsible cardboard freezer boxes are frequently used as an outer covering for plastic bags to protect them against tearing, and for easy stacking in the freezer (Schafer and Munson, 1990).

Labeling

Most regulatory agencies, depending on the location of production, require that some specific information be included on the label of the frozen food package. Several basic requirements are recommended for labeling of frozen products:

- The common or usual name of the ingredients
- The form (or style) of vegetables or fruits, such as whole, slices, or halves. If the form is visible through the package, it need not be stated.
- For some vegetables and fruits, the variety or color
- Liquid in which a vegetable is packaged must be listed near the name of the product.
- The total contents (net weight) must be stated in grams for containers holding 1 kilogram or less.

Other information required on the label, although not on the front panel:

- Ingredients, such as spices, flavoring, coloring, or special sweetener, if used
- Any special type of treatment
- The packer’s or distributor’s name and place of business
- Nutritional information
- Expiration date
- Storage requirements
- Heating instructions
- Labels may also give the quality or grade, count, size, and maturity of the vegetables, cooking directions, and recipes or serving ideas. If the label lists the number of servings per container, the law requires that the size of the serving be given in common measures, such as ounces or cups.

For specified vegetable mixture formulation, some of the items a package contains:

Nutrition Facts
Serving Size ¾ cup (85 g)
Serving Per Container 5
Amount per serving

Calories 25	Calories from fat 0
	% Daily Value*
Total Fat 0 g	0 %
Saturated fat 0 g	0 %
Sodium 20 mg	1 %
Total Carbohydrate 5 g	2 %
Dietary Fiber 2 g	8 %
Sugars 2 g	
Protein 2 g	

Vitamin A 60 %	Vitamin C 25 %
Calcium 2 %	Iron 2 %

* Percent Daily Values are based on a 2 000-calorie diet. Your daily values may be higher or lower depending on your calorie needs.

	Calories:	2 000	2 500
Total fat	Less then	65 g	80 g
Saturated fat	Less then	20 g	25 g
Cholesterol	Less then	300 mg	300 mg
Sodium	Less then	2 400 mg	2 400 mg
Total Carbohydrate		300 g	375 g
Dietary fiber		25 g	30 g

Cooking Instructions
STIR FRY: Heat oiled wok or frying pan to 380 °F. Cook for 5-7 minutes, while stirring, until vegetables are done to taste.

MICROWAVE: Pour contents of bag into a microwaveable dish. Add 2 table spoons of water; cover and cook for an additional 4 minutes on high power. Stir and cook for additional 4-5 minutes.

Chapter 5

Cost analysis and product price

An accurate cost analysis of a freezing application can only be done on a case by case basis. Tables 7 and 8 show some useful data for freezing cost analysis and many factors have to be considered that depend on local conditions and economics (Johnston et al., 1994). However:

- initial cost of freezer;
- lost interest in cash outlay of freezer;
- maintenance and repair;
- electricity needed to reach and maintain freezing temperatures;
- packaging materials;
- water and fuel to prepare food for freezing;
- added ingredients, such as sugar or anti-darkening agents.

A small-scale operation usually means higher cost per kilogram of product frozen. Thus, capital cost related to the production capacity decreases as the freezer size increases. The initial cost of a freezer varies with size, type, special features, and age. New freezers require little repair the first year or so. However, in the long-run, the U.S. Department of Agriculture (USDA) recommends an expected repair cost for new freezers of 2 percent of the purchase price per year. For used freezers, this rate may be higher (Johnston *et al.,* 1994).

The cost of water and fuel used in washing, blanching, and chilling foods varies with area charges for these commodities and individual practices. Also, the cost of added ingredients also varies with type and quantity added. Added ingredients to consider include sweeteners such as sugar and honey and anti-darkening agents such as citric acid and ascorbic acid.

Costs should generally be calculated as the cost per unit weight (kilogram or metric ton) of the frozen product. This gives the real cost of the process and also takes into account the plant utilization factor, which is extremely important. One UK processor divides the freezing costs into proportions as stated below:

Table 7. **Comparison of freezing times for small fruits and vegetables (Johnston *et al.*, 1994)**

Method	**Approximate freezing times**
Package freezing (10 oz containers):	
Air blast	3 to 5 hr
Plate	1/2 to 2 hr
Bulk freezing -- air blast:	
Belt	20 to 30 min
Fluidized belt or tray	5 to 10 min
Cryogenic freezing	1/2 to 1 min

5.1 Cost analysis

The Total cost of a freezing plant is generally divided into two main areas: *investment cost* and *production cost*. These costs can be further broken down into individual costs as shown below:

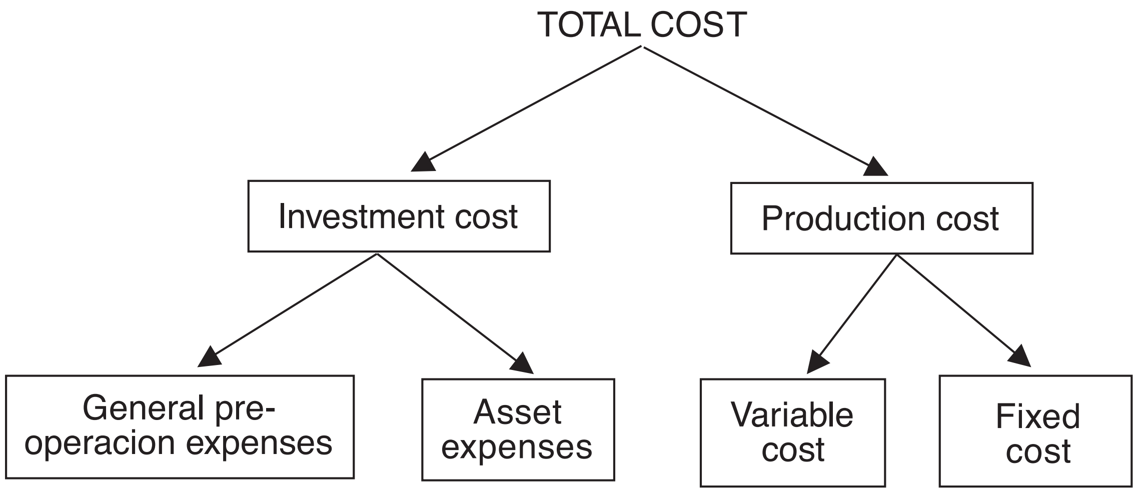


Table 8. **Freezing cost proportions (Johnston *et al.*, 1994)**

Preparation labor costs	48%
Packaging	10%
Freezing	10%
Overheads	32%

- Sample cost analysis and price determination for frozen mixed vegetables with 1 000 kg/month production rate is estimated on the basis of simplified determinations.

5.1.1 Investment cost

A capital investment is required for any industrial process, and determination of the necessary investment is an important part of the plant design project.The investment cost of a processing plant generally includes the cost of general *pre-operation expenses*, such as the establishment of the company, necessary licenses, training, tests or previous studies, and *asset expenses* like buildings, land, machines, materials, tools, and installation costs.

- *Pre-operation expenses*: The cost of pre-operation expenses varies depending on the application. Considering the main items included, a simple assumption of US$ 250 can be estimated for pre-operation expenses (including licenses, training of workers, local cost …).
- *Asset expenses*: Estimation of asset cost is given in Table 9 for frozen mixed vegetables.

5.1.2 Production cost

All expenses directly connected with the manufacturing operation, or the physical equipment of a process plant itself, are included in production costs. These expenses are subdivided into *variable cost* and *fixed cost*.

Table 9. **Estimation of asset cost for frozen vegetables**

Asset cost

Assets	**Quantity**	**Unit Cost ($US)**	**Total Cost ($US)**
Semi-industrial Kitchen	1	250.00	250.00
Digital Scale	1	100.00	100.00
Domestic Freezer	1	600.00	600.00
Storage Room	1	300.00	300.00
Utensils	-	150.00	150.00
			TOTAL US$ 1 400.00

Pre-operation cost	**US$**	**250.00**
Asset cost	**US$**	**1,400.00**
Invest cost	**US$**	**1,650.00**

Variable cost

Variable cost is a direct production cost including expenses directly associated with the manufacturing operation. This type of cost involves the following expenditures:

- raw materials;
- operating labour;
- power and utilities (steam, electricity, fuel, refrigeration, water, etc);
- maintenance and repair;
- operating supplies;
- laboratory charges.

Fixed cost

Fixed costs remain almost constant from year to year and do not vary with the production rate. Expenses included in this cost item:

- depreciation;
- taxes and insurance;
- administrative cost.

Variable cost: example

1. Calculation of labour cost: Considering US$ 300 (per month) per labour for a freezing process in which 2 workers are employed, a labour cost of US$ 600 can be estimated.

2. Cost of energy for a freezing process is calculated based on several factors, of which energy efficiency of the freezing systems is one of the most important. Based on the energy consumption of the equipment per hour, energy tariffs and hours of operation, a simple operating cost in terms of energy can be calculated:

   Production rate: 1 000 kg of frozen vegetables per month (2 000 packages);
   Freezer capacity: 40 kg of frozen product in 20 hours;
   Working capacity: 500 hrs of operation per month;
   Average electricity cost: US$ 0.10/kW,
   Power: 1.5 kW for 500 hrs = 750 kWh/month;
   750 kWh at US$ 0.10/kW = US$ 75/month.

3. Calculation of cost of raw materials and supplies required for 100 kg of product.

Raw materials and supplies (100 kg vegetables)

Raw Material	**Quantity**	**Unit Cost US$**	**Total Cost US$**
Carrot (kg)	25	1.25	31.25
Green Beans (kg)	25	2.50	65.50
Onion (kg)	25	1.25	31.25
Cauliflower (kg)	25	2.00	50.00
Water (l)	500	0.01	5.00
Packaging Material	200	0.05	10.00
		TOTAL US$	193.00

4. Calculation of cost of raw materials and supplies required for 1 000 kg of product.

Raw materials and supplies:	US$ 193 x 10 =	US$	1 930.00
Labour cost:		US$	600.00
Energy cost:		US$	75.00
Total variable cost:		**US$**	**2 605.00**

Fixed cost: example

1. Calculation of depreciation cost:

Annual depreciation = Total price of equipment / 8
Monthly depreciation = Annual depreciation / 12

Total asset cost = US$ 1 400.00
Annual depreciation US$ 1 400 / 8 = US$ 175
Monthly depreciation US$ 175 / 12 = US$ 14.58

2. Calculation of administrative cost:

Monthly administrative cost

Description	**Monthly cost (US$)**
Repair and Maintenance	75,00
Cleaning and Disinfecting	50,00
Utilities	50,00
Production Chief	200,00
Other	50,00
TOTAL	**425,00**

Depreciation cost:	US$	14.58
Administrative cost:	US$	425.00
Total fixed costs:	**US$**	**439.58**

Total variable costs:	US$	2 605.00
Total fixed costs:	US$	439.58
Total production cost:	**US$**	**3 044.58**

5.2 Product price determination

To determine the sales price of the product, *unit price* of the product has to be calculated. Sales price of a product mostly depends on the following items:

- unit production cost;
- competence price;
- demand for product;
- capacity of market;
- adjustment of payments;
- time for recovery of investment cost.

Calculation of *Unit sales price* is based on *Total production costs*. Production rate of 1 000 kg/month and 500 g of vegetables per product package is considered in calculations.

Unit cost (per package) = US$ 3 044.58 / 2 000 = US$ 1.52

- Unit sales price is estimated as US$ 3.20 depending on market.

5.3 Equilibrium production rate

Equilibrium value is defined as the minimum unit quantity of product to be sold in order to cover production cost. Equilibrium production rate is calculated according to the following formula:

Minimum unit = Fixed cost / (Unit product price – Variable unit cost)

- Variable unit cost: Total variable cost / 2 000

  Variable Unit Cost (per package) = US$ 1.30

- Minimum Unit = US$ 439.58/(US$ 3.20 - US$ 1.30)
  Minimum Unit: 232 packages

In order to cover production cost, 232 product packages out of 2 000 must be sold on a monthly basis.

References

AFFI, 2003. American Frozen Food Institute, (http://www.affi.com/factstat-trends.asp) Sources: NPD, Group, Inc., The Food Institute, Frozen Food Age, IRI, National Restaurant Association, Technomic, Inc, and USA Today.

Archer, G.P., Kennedy, C. J. and Wilson, A. J. 1995. Towards predictive microbiology in frozen food systems-a framework for understanding microbial population dynamics in frozen structures and in freeze-thaw cycles. International Journal of Food Science and Technology. 30, pp. 711.

Archuleta, M. 2003. Freezing Vegetables Guide E-320. New Mexico State University, college of Agricultural Home Economics Extension Service.

Arthey, D. 1993. Freezing of vegetables and fruits. In: Mallett, C.P. ed., Frozen Food Technology Chapman and Hall, London, UK.

ASHRAE Handbook. 1994. Refrigeration systems and Applications, American society of Heating, Refrigerating, and Air-conditioning Engineers, Atlanta, GA, USA.

Barbosa-Canovas, G.V. and Ibarz, A. 2002. Unit Operations in Food Engineering. CRC Press, Boca Raton, FL, USA.

Blanshard, J. M.V. and Franks, F. 1987. Ice crystallization and its control in frozen-food systems. Food Structure and behavior, Academic Press, London, UK, pp. 51-65.

Brady, P.L. 2002. Freezing fruit. UA Cooperative Extension Service, University of Arkansas, USA.

Beck, P. 1996. Freezing fruits. NDSU Extension Service, North Dakota State University of Agriculture and Applied Science.

Bender, A.E. 1981. Food manufacture and nutrition. Nutrition and the Food Industry, Naringforskning Suppl. 19, pp. 24.

Boyle, F.P. and Wolford ER. 1968. The preparation for freezing and freezing of fruits, the Freezing Preservation of Foods, Vol 3, 4th ed., AVI Wesport, CT, USA.

Boyle, F.P., Feinberg, B., Ponting, J.D. and Wolford, E.R. 1977. Freezing fruits. In: Desrosier, N.W., Tressler, D.K. editors, Fundamentals of Food Freezing. Avi Publishing Inc. Wesrport, USA. pp. 135-215.

Brydson, J.A. 1982. Plastic Materials. 4th ed., Butterworths, London, UK.

Canadian Food Inspection Anency Liaison, 2004. Preparedness and Policy Coordination, Food and Drug Regulations, C.R.C., c 870 (http://www.inspection.gc.ca/english/reg/rege.shtml).

Cano, M.P. and Marin, M.A. 1992. Pigment composition and color of frozen and canned kiwi fruit slices. Journal of Agricultural Food Chemistry. 40, pp. 2141.

Cano, M.P. 1996. Vegetables, Freezing Effects on Quality, Marcel Deccer, NY.

Cano, P., Marin, M.A. and Fuster, C. 1990. Freezing of banana slices, Influence of maturity level and thermal treatment prior to freezing. Journal of Food Science. 55, 4, pp. 1070.

Chen, C. 1985. Thermodynamic analysis of freezing and thawing of foods enthalpy and apparent specific heat. Journal of Food Science. 50.

Clealand, D.J. and Clealand, A.C. 1987a. Prediction of freezing and thawing times for multi-dimensional shapes by simple formulae. Part:1 Regular shapes. International Journal of Refrigeration. p. 10, pp. 156-164.

Clealand, D.J. and Clealand A.C. 1987b. Prediction of freezing and thawing times for multi-dimensional shapes by simple formulae. Part: 2 Irregular shapes. International Journal of Refrigeration. 10, pp. 234-240.

Delgado, A.E. and Sun, D.W. 2000. Heat and mass transfer for predicting freezing processes, a review. Journal of Food Engineering. 47, pp. 157-174.

Desrosier, N.W. and Desrosier, J.V. 1977. Principles of Food Freezing, the Technology of Food Freezing, 4th ed., AVI Publishing Co. Inc.Wesposrt CT, USA.

Desrosier, N.W. and Tressler, D.K. 1977. Fundamentals of Food Freezing, AVI Publishing Co. Inc. Wesposrt CT.

Dietrich, W.C., Olson R. L., Nutting, M.D., Neumann, H.J., and Boggs, M. M. 1959. time-temperature tolerance of frozen food. XVIII. Effect of blanching conditions on color stability of frozen beans, Food Technology, 13:258.

DSI Samifi Freezers S.r.I, Melzo, Italy. (http://www.dsi-as.com).

Enochian, R.V. and Woolrich, W.R. 1977. The rise of Frozen Foods, Principles of Food Freezing, the Technology of Food Freezing, 4th ed., AVI Publishing Co. Inc. Westport CT, USA.

Fellows, P. J. 2000. Food processing Technology, principles and practice. CRC Press, Boca Raton, FL

Fennema, O. 1977. Loss of vitamins in fresh and frozen foods. Food technology, 12:32-38.

Fennema, O. R. 1973. low temperature Preservation of foods and living matter. Fennema, O. R., Powrie, W. D., Marth, E. H., Eds, Plenum, New York, Ch. 3.

Franks, F. 1985. Biophysics and biochemistry at low temperatures, Cambridge University Press, Cambridge, UK. pp. 21.

Frigoscandia equipment LTD, UK. (http://www.fmcfoodtech.com/FMC).

George, R.M. 1993. Freezing process used in food industry. Trends in Food Science and Technology. 4, pp. 134.

Gutschmidt, J. 1968. Principles of freezing and low temperature storage, with particular reference to fruits and vegetables, Low Temperature Biology of Foodstuff, Recent Advances on Food Science, Vol 4, Pergamon Press, London.

Gradziel, P.H. 1988. The effects of frozen storage time, temperate and packing on the quality of the tomato cultivars. Diss Abstr Int B48:9.

Harris, R.S. and Kramer, E. 1975. Nutrition Evaluation of food Processing, 2nd ed. Avi Publishing Co. Westport, USA.

Harrison, P. and Croucher, M. 1993. Packaging of Frozen Foods, Frozen Food Technology (Mallett CP ed.) Chapman and Hall, London, UK.

Herron, J.T. 1968. Certification of foregoing Rules and Regulations pertaining to Frozen Food Processing Plants, Hot Springs, Arkansas, on the 23rd day of April.

Holdsworth, S.D. 1983. The Preservation of Fruits and Vegetable Food Products, Macmillan Press, London, UK.

Hui, Y.H., Ghanzala, S., Graham, D.E., Murrell, K.D. and Nip, W.K. 2004. Handbook of Vegetable Preservation and Processing. Marcel Dekker, Inc.

Hung, Y.C. and Kim, N.K. 1996. Fundamental aspects of freeze-cracking. Food Technol 50:59.

Information Resources Inc., 2003. American Frozen Food Institute.

International Institute of Refrigeration. 1986. Recommendations of the Processing and Handling of Frozen Foods, Paris.

Johnston, W.A., Nicholson, F.J., Roger, A. and Stroud, G.D. 1994. Freezing and refrigerated storage in fisheries. FAO, Fisheries technical paper-340.

Kaess, G. 1961. Freezer burn as a limiting factor in the storage of animal tissue. Food Technology. 15, pp. 122-128.

Kendall, P. 2002. Freezing vegetables. Colorado State University Cooperative Extension.

Lee, C.Y. 1989. Green peas, Quality and Preservation of Vegetables, (N.A. Michael Eskin, ed.), CRC Press, Boca Raton, FL, USA. pp. 159.

Levy, F. 1979. Enthalpy and specific heat of meat and fish in the freezing range. J Food

Technol, 14:549.

Mallett, C.P. 1993. Frozen Food Technology. Chapman and Hall, London, UK.

Mayes, T. and Telling, G. 1993. Product Safety from Factory to Consumer, Frozen Food Technology (Mallett CP ed.) Chapman and Hall, London, UK.

Michigan State University Extension. 1999. Containers for freezing. Preserving Food Safety (http://www.msue.msu.edu/msue/imp/mod01/01600506.html).

Munoz-Delgado, J.A. 1978. Effects of freezing, storage and distribution on quality and nutritive attributes of foods, in particular of fruit and vegetables. Food Quality and Nutrition, Applied Science Publishers Ltd. London, UK.

Nagaoka, J., Takigi, S. and Hotani, S. 1955. Experiments on the freezing of fish in air-blast freezer, Proc. 9th Int Congr Refrig, Paris, France.

Persson, P.O. and Lohndal, G. 1993. Freezing Technology, Frozen Food Technology (Mallett CP ed.), Chapman and Hall, London, UK.

Pham, Q, T. and Mawson, R. F. 1977. Moisture migration and Ice Recrystallization in Frozen Foods. In: Quality in Frozen Foods, Erickson, M. C., Hung, Y., Eds. Chapmann and Hall, New York

Plank, R. 1980. El Empleo del Frío en la Industria de la Alimentación, Barcelona: Reverte.

Quick Frozen Foods International, 2000. Global Frozen Food Almanac, 33, No.2.

Rahman, M.S. 1999. Handbook of Food Preservation, Marcel Dekker, NY, USA.

Ramaswamy, H.S. and Tung, M.A. 1984. A review on predicting freezing times of foods. Journal of Food Process Engineering. 7, pp. 169-203.

Riedel, V.L. 1949. Chemical Engineering Technology. 21, pp. 340.

Robertson, G.L. 1985. Changes in the chlorophyll and pheophytin concentrations of kiwifruit during processing and storage. Food Chemistry, p. 17, p. 25.

Sahagian, M.E. and Goff, H.D. 1996. Effect of freezing rate on thermal, mechanical and physical aging properties oft the glassy state in frozen sucrose solutions. Thermochimica Acta. pp. 246-271.

Salunkhe, D.K., Bolin, H.R and Reddy, N.R. 1991. Sensory and objective quality evaluation. Storage, Processing. And Nutritional Quality of Fruits and Vegetables, Vol 1, 2nd ed. CRC Press, Boca Raton, FL, USA.

Saravacos, G. D., Kostaropoulos, A. E. 2002. Handbook of Food Processing Equipment, Kluwer academic.

Schafer, W. and Munson, S.T. 1990. Freezing of fruits and vegetables. Extension Service of University of Minnesota (www.extension.umn.edu/distribution/nutrition/DJ0555.html).

Skrede, G. 1996. Fruits, Freezing effects on Food Quality (Jeremiah LE ed.), Marcel Dekker, NY, USA.

Sebranek, J.G. 1996. Poultry and poultry products, Freezing Effects on Food Quality, Marcel Dekker, NY, USA.

Spiess, W.E.L. 1984. Changes in ingredients during production and storage of deep frozen food-a review of the pertinent literature. ZFL 8:625.

Stoecker, W.F. and Jones, J.W. 1982. Refrigeration and Air Conditioning, NY, USA. McGraw Hill.

Succar, J. and Hakayawa, K. 1983. Empirical formulae for predicting thermal physical properties of foods at freezing and defrosting temperatures, Lebensm Wiss Technol, pp. 16.

Tomasicchio, M., Andreotti, R. and Giorgi, A. 1986. Osmotic dehydration of fruits. II.Pineapples, strawberries and plums, Ind Conserve 61:2.

United States – Energy Information Administration, Monthly Energy Review, July 2003.

This manual provides basic and essential information on freezing technology to preserve fruits and vegetables in small-scale operations. Practical examples demonstrating the application of the technology are given to provide a better understanding of the processes. Freezing is the most widely used method of food preservation permitting retention of quality of the products during long periods of storage. Compared to other conventional methods used in the storage of fruits and vegetables, freezing is the most satisfactory method in terms of quality, process and overall cost. Currently, the frozen food market is one the largest sectors in the food industry. Industrialized countries dominate the trade in frozen food commodities, but developing countries can also develop their own frozen food industries. Introduction of adequate freezing technology, based on a better understanding of the technical and practical processes, is essential to meet the growing consumer demand for frozen foods in developing countries.

ISBN 92-5-105295-6 ISSN 1010-1365

9 789251 052952

TC/M/Y5979E/1/04.05/2200