FOOD FREEZING

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Contents

Summary

The spectacular growth of the frozen food industry has been largely due to favorable economics of process, convenience of preparation, and the high quality of processed products. The range of frozen products includes fruits, vegetables, juices, meats, dairy products, and bakery goods. Modern freezing systems cause minimal changes in the quality attributes of products during processing. The ice crystallization process is carefully controlled to obtain desired quality characteristics. During frozen storage, the environmental conditions are maintained at subfreezing levels with minimum fluctuations in temperature to minimize undesirable alterations in quality. Designing a freezing process involves calculations of the total heat being removed to accomplish freezing, and the time needed to lower the temperature to the required frozen storage conditions. A variety of different systems are used in commercial freezing, including air blast freezing, fluidized bed freezing, cryogenic freezing, and plate freezing. These systems are selected based on the requirements of the product being frozen. New developments in the freezing industry are expected, with improved knowledge of food properties and other changes in foods associated with the freezing process.

1. History and Origin

One of the earliest known attempts to invent the freezing process is attributed to Sir Francis Bacon, a well-known English philosopher. In March 1626, he bought a hen, dressed it, and stuffed it with snow. Unfortunately, he caught a chill while experimenting and died of bronchitis a few days later. Bacon's use of snow as a cooling medium would not provide a sufficient temperature gradient to freeze food. In 1861, Enoch Piper of Camden, Maine, patented a method to freeze whole fish using a mixture of salt and ice to obtain a medium with sub-freezing temperature. He spread the mixture over racks of fish to freeze the product and was able to hold the frozen fish in insulated storage rooms cooled with chilled brine. These, and similar methods, soon became common practice in fishing ports of the Great Lakes, New England, and New York state, where ice was plentiful. In 1924, Clarence Birdseye developed a simple freezing system by putting foods packaged in rectangular containers in contact with metal belts chilled from -40 to -45°C with calcium chloride solution. Later, he employed pressure to improve the contact between the food and the metal plates and used vaporizing ammonia to cool the plates. His process and its auxiliaries gave birth to the modern frozen food industry.

The frozen food industry had a humble beginning in the early part of the twentieth century, limited to freezing fruits, vegetables, meats, and fish. Today, the range of frozen foods includes: bakery goods, ice cream, desserts, consumer and catered packaged products, and juices.

Frozen foods are valued for their superior sensory and nutritional quality when compared with foods preserved by other methods. The quality attributes of a frozen food can be maintained with a properly designed freezing process, and a carefully monitored handling and storage practice. Furthermore, frozen foods are convenient to cook in the home (or institutional kitchen) prior to consumption. Consumer demand for foods easy and quick to prepare has increased over the last several decades in a number of industrialized countries. Frozen foods have largely benefited from this demand, as evidenced by the strong growth in sales. From 1970 to 1990, the total value of all U.S. frozen foods increased from $8 to $55 billion. In 1990, the total volume of U.S. frozen foods was 12.9 million tons compared with 6 million tons for Europe.

2. Food Quality and the Freezing Process

2.1. Handling Prior to Freezing

Prior to freezing, the time elapsed in initial preparation of a food commodity is a critical factor influencing the quality of the frozen product. Once a fruit or vegetable is harvested or an animal slaughtered, the intrinsic biochemical reactions do not cease. Instead, varieties of reactions continue to alter the food's quality, often in a deteriorative mode. Therefore, the handling of foods prior to freezing, and environmental conditions such as temperature and humidity, require careful control. With vegetables, intrinsic enzymes must be inactivated prior to freezing. Otherwise, enzymatic reactions occurring at frozen storage temperatures may degrade such attributes as color, flavor, texture, and nutritional value (see *Kinetics of Chemical Reactions in Foods*, *Engineering Properties of Foods*).

Vegetables are blanched prior to freezing to inactivate their inherent enzymes. Typically, the activity of three enzymes—peroxidase, catalase, and lipoxygenase—is monitored to determine the effectiveness of a blanching treatment. In an industrial blanching process, vegetables are either submerged in hot water or exposed to steam. The blanching process is designed with the following criteria in mind:

- All food particulates should be uniformly exposed to the heating medium.
- Blanching time for all food particulates should be uniform.
- Food particulates should not be physically damaged during blanching.
- Any leaching of product components should be minimized.
- The blanching process should conserve energy and water.

Developments in the design of blanching equipment have addressed some of these criteria. Hot water blanchers sometimes have tubular systems, where water heated with steam injection is used to heat and convey food particulates. In a rotary, screw blancher system, hot water and food particulates are brought into contact in a static drum with a central screw that turns and improves the contact between the food and hot water. An integrated blancher and cooler design involves heating and cooling sections within the same unit. The product enters the blancher on a conveyor belt and is preheated, followed by blanching in a steam environment, and the cooling zones. Some researchers believe this system has improved energy efficiency and reduced water consumption. Although there has been considerable interest in the use of microwaves for blanching, problems exist in achieving uniform heating when water distribution within a particulate is non-uniform. Moreover, the operational costs of a microwave system for industrial-scale blanching are significantly higher than with conventional units using water or steam.

Typical blanching conditions are shown in Table 1. After blanching, the product is cooled by immersion in chilled water. Blanched vegetables are either packaged in retail-size packages or frozen without packaging. For meats and poultry products, pre-treatment processes such as ageing, chilling, trimming, cutting, cleaning, sorting, and grading influence the final frozen quality.

Product	**Blanching Time (s)**	**Heating Medium**
Asparagus	210-300	Steam
Broccoli	210	Steam
Carrots	120-180	Water at 99°C
Cauliflower	240-300	Steam
Corn on the cob	360-660	Steam
Corn	180	Steam

Peas	48 - 60	Water at 99°C
Spinach	120-180	Steam

Table 1. Typical blanching conditions for vegetables.

2.2. Freezing Conditions

In modern freezers, the time of exposure and temperature of the freezing medium are carefully controlled. Ice crystallization during freezing, where water present in a food crystallizes into ice, is the most fundamental step in the freezing process. The crystallization process is comprised of the nucleation stage and the crystal growth stage. In the first stage, nucleation establishes sites in a food where ice crystals may later grow. Nucleation sites are typically the non-aqueous entities. In heterogeneous nucleation, the type common in the freezing of foods, water molecules aggregate around the nucleate. Other factors, such as supercooling, physical disturbance, and change in viscosity with temperature, also affect the rate of nucleation.

After the nuclei are formed, crystals begin to grow, often at a rapid rate. Among the factors affecting crystal growth are the rate of heat removal, temperature of the cooling medium, diffusion, and change in viscosity with temperature (see *Crystallization*).

The number of nuclei formed during the nucleation stage and the ultimate size of the crystal formed during crystal growth may affect the final quality of some frozen foods, such as ice cream and berry fruits. In a slow freezing process, ice crystals grow into large sizes in the extra-cellular spaces, causing damage to the plant or animal tissue being frozen. The deleterious effects of freezing on product quality are partially due to ice crystal growth at the expense of water extracted from the interior of the cells. When small ice crystals form in the intra- and extra-cellular spaces, damage to quality is minimized. For example, in the formation of small ice crystals, the drip loss during thawing associated with the expulsion of juices from frozen products such as meats is minimized.

2.3. During Frozen Storage

Physical and chemical changes continue to occur in frozen foods during storage. They include lipid oxidation (see *Kinetics of Chemical Reactions in Foods*), insolubilization (or gelation of proteins), loss of vitamins, and degradation of chlorophyll. These changes can profoundly affect the sensory characteristics of foods (see *Sensory Evaluation*). In frozen storage, microbial growth is arrested, and even psychrophilic microbes generally cease to grow below -10°C.

Localized surface dehydration, also called "freezer burn", is a serious physical change that leads to localized surface dehydration and discoloration. This phenomenon is most common in meats, fish, and poultry products, and is caused by small changes in local vapor pressure occurring due to fluctuations in storage temperature. Proper packaging and the use of low and uniform storage temperatures can help alleviate this problem.

Three color changes can be observed in frozen foods during storage: (1) fading of natural color constituents due to changes in chlorophylls (e.g., green vegetables); (2) loss of color from product to surrounding medium (e.g., diffusion of pigments from red cherries stored in sugar syrups); and (3) change in color (e.g., darkening of bone in frozen chicken upon cooking, and browning of sliced peaches due to polyphenoloxidase reacting with air in headspace). These types of changes in color are indicative of quality deterioration during frozen storage. Future research is necessary to minimize these adverse changes.

Flavor changes due to rancidity in frozen meats, poultry, and fish cause major deterioration. For example, fatty fish is prone to oxidative rancidity and must be stored at temperatures below -25°C to avoid undesirable changes. Similarly, blanching of vegetables is necessary to avoid off-flavor problems during frozen storage.

Other textural defects that may occur during improper storage conditions include loss of juiciness in meats, dryness of fish muscle that makes it crumbly, loss of fluidity in egg yolk, and aggregation of starches in sauces.

Although freezing is one of the best preservation methods for maintaining the nutrient content of foods during storage, the pre-freezing steps of washing and blanching may be responsible for loss of water-soluble nutrients. Loss of nutrients during thawing is slight, except when associated with drip loss in improperly frozen fruits, meats, fish, and poultry products.

Damage to the frozen food frequently occurs when a product is thawed prior to consumption. The consumer often conducts the thawing process, unaware of its implications on product quality. During thawing, physical and chemical changes and microbial growth may significantly alter a products quality attributes.

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Biographical Sketch

Dr. R. Paul Singh is a Professor of Food Engineering, Department of Biological and Agricultural Engineering and Department of Food Science and Technology, University of California at Davis. At the University of California, Professor Singh teaches courses to students majoring in Food Science and Engineering on topics related to heat and mass transfer in foods. His research is concerned with developing a quantitative understanding of food processes. He uses mathematical models with computer-aided simulations to seek improvements in process efficiency. He is a fellow of the Institute of Food Technologists, American Society of Agricultural Engineers, and the International Academy of Food Science and Technology. He is author and co-author of 13 books and over 200 refereed papers on food engineering topics. His textbook, *Introduction to Food Engineering*, 3rd edition (co-authored with Dr. Dennis R. Heldman), is used worldwide in teaching food engineering principles and applications.