Cold Facts

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Food Freezing Equipment: Quality, Safety and Efficiency

The Cold Hard Facts About Cryogenic Food Freezing

Submitted by Air Products

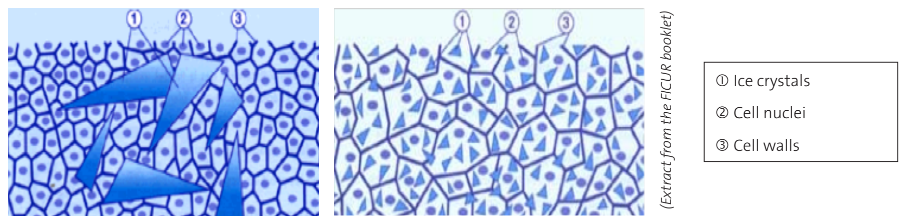
Frozen foods are desirable to consumers because they offer numerous benefits including convenience, good value for the money, extended storage and portion control, to name just a few. In order to continue serving the interests of consumers who demand high-quality products, food manufacturers need to have a better understanding of the fundamentals of the freezing process and its effect on food.

Freezing protects the quality of food, and the quality of freezing method used impacts the organoleptic properties of food after thawing. Organoleptic properties are characteristics experienced through the senses, such as appearance, texture, taste and smell.

Abundant research has shown that the key to high-quality frozen food is freezing rate: the faster the freezing rate, the higher the quality of food product. This article explains how rapid freezing with cryogenic-based systems minimizes organoleptic deterioration, particularly in sensitive foods like seafood, fruit, vegetables and meat.

The Freezing Process

Frozen food, while microbiologically stable, remains susceptible to physical and biochemical reactions that may compromise its oganoleptic qualities. This can be attributed to the proportion of frozen water found in various frozen foods.



A-Slow freezing B-Fast freezing

Figure 1: Illustration of crystal formation according to freezing kinetics

For example, in meat, at a stabilized temperature of -20° C (-4° F), the percentage of non-frozen water is still over 10% of the total water content of the product. This liquid portion has specific characteristics. It is progressively enriched with various dissolved substances as more and more of the water forms ice crystals. This is referred to as the freeze-concentrated phase, during which a large number of changes occur as frozen products age. Essentially, this phase allows the regrouping of enzymes and their substrates within a restricted volume of liquid which can accelerate certain reactions despite the retardant effect of low temperatures.

The kinetics of the decrease in temperature during the freezing process—and therefore the freezing method used—will influence the characteristics (number and size) and growth of ice crystals:

- The nucleation rate is the number of nuclei formed per unit of time. This parameter increases with faster cooling rates. For example, each degree of sub-cooling multiplies the nucleation rate by 10.
- The growth rate of crystals is linked to the capacity to remove heat where the ice crystals are forming (related to the characteristics of the product and temperature of the medium).
- The size of crystals depends on the two previous factors. The formation of a large number of nuclei, as well as a rapid growth rate, encourages the formation of small crystals.

In many cases, deterioration caused by ice can be explained by the rigidity and the size of crystals within the cellular structure of the food. This results in mechanical pressure that can damage the cellular structure of products such as meat, fruit, and vegetables. Figure 1 shows the size and distribution of crystals depending on the freezing kinetics.

As illustrated in Figure 1, during slow freezing methods, ice crystals are formed much faster from water outside food cells than inside the cells. These large ice crystals generate mechanical pressure and sharp edges that damage all cellular components. This results in higher drip loss and dehydration during thawing.

Conversely, during fast freezing methods, ice crystals are formed uniformly inside and outside of food cells, leading to the formation of smaller

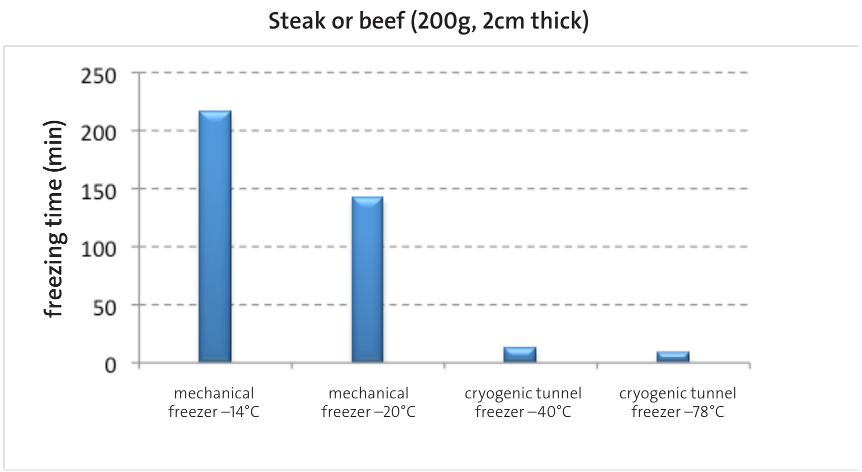


Figure 2: Typical freezing time based on freezing technique

ice crystals with much less damage to a product's cellular structure. This results in a higher quality food product due to reduced drip loss and dehydration.

Freezing Methods

Two common freezing methods used at the industrial level are mechanical freezing and cryogenic freezing.

Mechanical freezing is the term used to describe traditional vapor compression cycle freezers—much like a home freezer—which normally operate at a temperature between -20° C and -50° C (-4° F and -58° F). Mechanical freezers function by circulating a refrigerant—usually ammonia or a chemical refrigerant—around the system, which withdraws heat from the food product. This heat is then transferred to a condenser and dissipated into air or water. The refrigerant itself, now a high-pressure, hot liquid, is directed into an evaporator. As it passes through an expansion valve, it is cooled and then vaporizes into a gaseous state. Now a low-pressure, low-temperature gas again, it can be reintroduced into the system.

Cryogenic freezing is achieved using a very low-temperature gas—typically nitrogen or carbon dioxide (CO2)—which is circulated directly around the food. Cryogenic freezing systems normally operate under -70°C (-94°F). Due to the extremely cold temperatures of cryogenic gases, foods can be frozen within minutes rather than the hours required with mechanical freezing systems.

The temperature differences between mechanical and cryogenic freezing systems result in very different freezing kinetics between the two technologies. Figure 2 shows the typical freezing time—the time required for the temperature at the center of the product to drop from -1°C to -7°C—depending on the method of freezing used.

Due to the considerable temperature difference between freezing methods, cryogenic freezing has a significantly shorter freezing time than mechanical freezing. Cooling kinetics are largely responsible for the differences in levels of deterioration seen in the finished product when we compare the impact of freezing technology with the quality of food.

Impact of Freezing Method on Food Quality

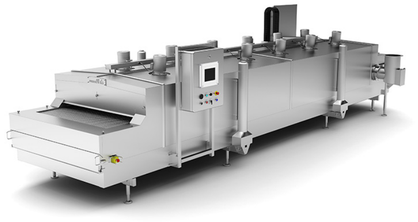
All freezing methods cause some degree of moisture loss during the freezing process itself (evaporative weight loss) and/or during thawing (drip loss).

Evaporative weight loss reduces the weight, and therefore the value, of the product, especially in meat, poultry and seafood. At the same time, surface dehydration impacts product texture, color and cooking time. The evaporative weight loss reduces the thermal conductivity of the surface layer and therefore prolongs cooking time. This is particularly important in applications where cooking time is limited, such as burgers for fast food outlets. In most applications, the best way to cut evaporative loss is to reduce temperature as quickly as possible. Rapid temperature reduction lowers the vapor pressure of free water at the surface of the food and so reduces dehydration.

Drip loss occurs during thawing if a food product suffers from cellular damage, caused by the growth of large ice crystals during a slow freezing process. This loss of moisture affects the color, flavor and nutritional quality of the thawed products as nutrients and pigments are contained in the lost moisture. Structural damage can also cause textural degradation, or a reduction in firmness, particularly in vegetables and fruits. This was demonstrated in Agnelli and Macscheroni's 2002 study, which showed the effects of freezing damage when they measured the texture of frozen strawberries using a compression test. They showed that the strawberries maintained their firmness to a greater degree when rapidly frozen using cryogenic freezing.

The color of thawed food is affected by freezing in two ways. The first, as explained above, is pigment loss due to drip loss. Secondly, as ice crystals grow during freezing, there is a concentration of the solutes in the remaining unfrozen fraction. This increase in concentration speeds up processes such as oxidation and enzymatic browning. The longer the product remains at a temperature close to the freezing plateau (i.e., the slower the freezing process), the greater these effects will be.

Agnelli and Macscheroni's research also demonstrated the importance of the rate of freezing and the benefits of a faster freezing rate, including reduced drip loss and pigment drainage, and minimized meat browning as the color of cryogenically frozen burgers is more like the original meat color than those frozen using mechanical methods.



Cryogenic Freezing Equipment

Cryogenic freezing equipment can look very much like mechanical freezing equipment. Configurations including cabinet freezers, straight tunnel freezers, multi-pass tunnel freezers and spiral freezers are all very common in both mechanical and cryogenic systems. On the other hand, cryogenic equipment can also be very different from anything that can be done mechanically. Because the "refrigerant" can be applied directly to the food in cryogenic systems, unique equipment configurations are popular.

Immersion freezing with liquid nitrogen (LIN) brings the food item into direct contact with a bath of LIN, subjecting the food to temperatures below -185° C (-301°F) for a matter of seconds. The benefits of a quick freeze are even more pronounced in this style of freezer. Immersion freezers are extraordinarily effective for IQF (individually quick frozen) products because creating a very cold surface crust helps prevent pieces from adhering to one another.

Flighted deck freezers using CO2 are also effective for IQF products. The conveyor in a flighted deck freezer is a series of low angle rises and short falls designed to keep products from freezing together. When liquid CO2 is sprayed into the freezer, CO2 snow is formed. This snow sublimates relatively slowly and is mixed in with the food product as the food tumbles over the flights. The intimate contact between the cryogen and the food results in a very rapid freeze.

Conclusion

Various studies on changes in the state of food products have shown that the quality of freezing and storage methods have great impact on the organoleptic properties of the products after thawing. Freezing rate is the key parameter for ensuring high-quality frozen food. Because the extremely cold temperatures of cryogenic gases like LIN and CO2 enable the most rapid freezing rate, cryogenic freezing minimizes organoleptic deterioration—such as loss of texture and dehydration—in sensitive food products like seafood, fruits, vegetables and meat.

Cryogenic freezing systems provide numerous benefits across a range of foods, resulting in higher quality products. In addition, many food manufacturers find the low capital outlay, flexibility, and ease of use and cleanability of these systems to be very appealing.

Air Products is a leader in cryogenic technology applications with more than 40 years of experience serving the food industry. With production-scale food laboratories in the US, Europe and Asia, the company can test a customer's product on commercial-scale equipment to determine the feasibility of using cryogenic cooling and freezing for their specific food product. For more information, call (800) 654-4567, or visit their website at **www.airproducts.com/food.**

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