18) FREEZING METHODS AND QUALITY LOSS AT FREEZING TEMPERATURES

Freezing is the use of storage temperatures below −18°C to accomplish the followings:

1. **Preservation**
   - Pathogen growth is halted below −4°C
   - Spoilage microorganisms don’t grow below −10°C
   - Chemical reaction rates are significantly reduced

2. **Processing aid**
   - Freezing changes the texture and viscosity for further processing, e.g. slicing meat products

3. **Product definition**
   - Freezing defines some food products, e.g. ice-cream and frozen deserts

FREEZING METHODS

There are many different types of freezer available for freezing and freezer operators are often uncertain about which type is best suited to their needs. Three factors may be initially considered when selecting a freezer; financial, functional and feasibility.

Financial considerations will take into account both the capital and running cost of the equipment and also projected losses such as product damage and dehydration. Expensive freezers should therefore justify their purchase by giving special benefits and if these benefits are not worthwhile, they need not be considered.

Functional considerations will take into account such things as whether the freezer is required for continuous or batch operation and also whether the freezer is physically able to freeze the product. For instance, a horizontal plate freezer would be inappropriate for freezing large whole tuna.

Feasibility will take into account whether it is possible to operate the freezer in the plant location. A liquid nitrogen freezer (LNF), for instance, may be suitable in every respect for freezing the product and the high costs of using this method of freezing may be justified. However, if the location of the plant is such that there can be no guaranteed supply of liquid nitrogen, the freezer should not be considered.

A). **Air Freezing**

Packaged or unpackaged nonfluid foods can be frozen in air at temperatures ranging from −18°C to −40°C.

1. **Sharp Freezing**
   - It consists of placing products in a very cold room, maintained at temperatures in the range of −15°C to −29°C. Although the air within the room will circulate by convection, usually little or no provision is made for forced connection. The relatively still air is a poor conductor of heat and foods placed in even these low temperatures are frozen comparatively slow, many hours or even days being required before the products are completely solidified.

   Fundamentally, sharp freezers are cold storage rooms especially constructed to operate at and maintain low temperatures. Freezing time is generally 3-72 hr or more depending on
the conditions and the size of product. Sharp freezing is uncommon in modern freezing operations.

This method is extremely slow and lacks efficient design characteristics. It may also jeopardize the quality of already frozen products stored in the room because flavors may be transferred from warm products yet to be frozen. The temperature of the products already in frozen storage may rise considerably as heat is transferred from the incoming unfrozen product. And dehydration due to slow freezing rate and temperature fluctuations may be excessive.

2. Air Blast Freezing
Vigorous circulation of cold air enables freezing to proceed at a moderately rapid rate. Products are placed on trays, either loose or in packages and the trays are placed on freezing coils in a low temperature room with cold air blowing over the product. In some installations of this system, the cold air that is in the low temperature room is circulated by means of large fans, whereas in other installations the air is blown through refrigerated coils located either inside the room or in an adjoining blower room.

Tunnel freezing is possibly the most commonly used freezing system. Tunnel freezing is substantially a system in which a long, slow moving mesh belt passes through a tunnel or enclosure containing very cold air in motion. The speed of the belt is variable according to the time necessary to freeze the product. Usually the cold air is introduced into the tunnel at the opposite end from the one where the product to be frozen enters, that is, the air flow is usually counter to the direction of the flow of the product. The temperature of the air is usually between –18° and –34°. The air velocity varies, however if rapid freezing is to be had, it is necessary to recirculate a rather large volume of the air in order to obtain a relatively small rise in the temperature of the air as it touches and leaves the product. Air has a very low specific heat and for that reason a large volume must be carefully distributed through the system.

Air velocities ranging all the way from 100 ft. per min. Up to 3500 ft. per min have been reported, and it is difficult to establish any speed as having more or less common usage. Possibly 2500 ft per min may be considered a practical and economical air velocity at –29° C.

Air blast freezing is economical and is capable of accommodating foods of a variety of sizes and shapes. It can however result in:

- Excessive dehydration of unpackaged foods if condition are not carefully controlled, and this in turn necessitates frequent defrosting of equipment, or
- Undesirable bulging of packaged foods which are not confined between rigid surfaces during freezing.

3. Fluidized-bed Freezing
Fluidized bed freezing is a modification of air-blast freezing. Solid food particles ranging in size from peas to strawberries can be fluidized by forming a bed of particles 1-5 in. Deep on a mesh belt (or mesh tray) and then forcing air upward through the bed at a rate sufficient to partially lift or suspend the particles in a manner somewhat reminiscent of a boiling liquid. If the air used for fluidization is appropriately cooled, freezing can be accomplished at a rapid rate. An air velocity of at least 375 lineal ft/min is necessary to
fluidize suitable particles, and an air temperature of about –34°C is common. Bed depth depends on the ease with which fluidization can be accomplished, and this in turn depends on size, shape, and the uniformity of particles. A depth of slightly more than 1 in. is suitable for easily fluidized particles, such as peas and whole kernel corn; a depth of 3-5 in. is used for partially fluidizable particles, such as green beans; and a depth of 8-10 in. can be used for nonfluidizable products, such as fish fillets. Although freezing time varies with conditions, some representative times for various products are listed in Table 1.

Table 1. Typical freezing times in a fluidized bed freezer (from Fennema, O., Karel, M., Lund, D., 1975)

<table>
<thead>
<tr>
<th>Product</th>
<th>Time to reduce temperature from 21°C to –18 °C, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peas</td>
<td>3-4</td>
</tr>
<tr>
<td>Lima beans</td>
<td>4-5</td>
</tr>
<tr>
<td>Diced carrots</td>
<td>6</td>
</tr>
<tr>
<td>Cut green beans</td>
<td>5-12</td>
</tr>
<tr>
<td>Strawberries</td>
<td>9-13</td>
</tr>
<tr>
<td>French fried potatoes</td>
<td>8-12</td>
</tr>
<tr>
<td>Fish fillets</td>
<td>30</td>
</tr>
</tbody>
</table>

Fluidized bed freezing has proved successful for many kinds and sizes of unpackaged food tissues, although the best results are obtained with products that are relatively small and uniform in size (e.g., peas, limas, cut green beans, strawberries, whole kernel corn, brussel sprouts).

The advantages of fluidized bed freezing as compared to conventional air-blast freezing are:

- More efficient heat transfer and more rapid rates of freezing
- Less product dehydration and less frequent defrosting of equipment
- Short freezing time is apparently responsible for the small loss of moisture.

A major disadvantage of fluidized bed freezing is that large or nonuniform products cannot be fluidized at reasonable air velocities.

4. Spiral Freezers

Spiral belt freezers use a product belt that can be bent laterally. The original spiral belt design uses a spiraling rail system to carry the belt, with a central drum that drives the belt through friction at the belt edge.

The latest spiral belt design uses a self-stacking, self-enclosing stainless steel belt for compactness, greater reliability and improved air flow. This design eliminates the traditional rail system and friction drive. The number of tiers in the belt stack can be varied to accommodate different capacities. Infeeds and outfeeds can be located to suit most line layouts. Depending on the upstream process and capacity required, this type of freezer is available in a range of models with different belt widths and may be completely factory assembled or partially assembled in modules for quick installation and future portability.

Spiral freezers are good systems for products requiring a long freezing time (generally 10 minutes to 2 hours) and for products that require careful handling. Typical products frozen
in spiral belt freezers include raw and cooked meat patties, fish fillets, chicken parts, pizza and a variety of packaged products.

B. Plate Freezing
Food products can be frozen by placing them in contact with a metal surface cooled either by cold brine or vaporizing refrigerants, such as refrigerant-12, 22 or ammonia. Packaged food products may rest on, slide against, or be pressed between cold metal plates. Plate freezers consist of a series of flat hollow refrigerated metal plates. The plates are mounted parallel to each other and may be either horizontal or vertical. The spaces between the plates are variable, the plates being opened out for loading and, prior to the freezing operation, closed so that the surface of the plates is in intimate contact with the packaged or unpackaged food. Clearly the frozen product is in the form of parallel sided blocks and, during the freezing process, heat flow is perpendicular to the faces of the plates. A moderate pressure (of the order of 10-30 kN m⁻²) is maintained between the plates and the package surfaces during freezing to promote good face to face contact.

Double contact plate freezers are commonly used for freezing foods in retail packages. This equipment, which may be batch, semi automatic, or automatic, consists of a stack of horizontal cold plates with intervening spaces to accommodate single layers of packaged product. The filled unit appears much like a multilayered sandwich containing cold plates and product in alternating layers. The plates are arranged so that they can be opened or closed in a vertical accordion-like manner, enabling product to be added or removed. When closed, the plates make firm contact with the two major surfaces of the packages, thereby facilitating heat transfer and assuring that the major surfaces of the packages do not bulge during freezing.

Contact plate freezing is an economical method that minimizes problems of product dehydration, defrosting of equipment and package bulging. Two notable disadvantages do however exist: (1). Packages must be uniform of thickness, (2). Freezing occurs at a moderately slow rate as compared to other modern methods. For example, a compact product in a well fitted package 1-1.5 in. thick, when cooled by plates ay –33°C, requires about 1-1.5 hr to freeze. Freezing times are extended considerably when the package contains a significant volume of void space.

C. Liquid Immersion Freezing
Liquid immersion freezing (usually referred to as direct immersion freezing) is accomplished when a food product, either packaged or unpackaged, is frozen by immersion in or by spraying with a freezant that remains liquid throughout the process. Aqueous solutions of the following substances have been used as freezants: propylene glycol, glycerol, sodium chloride, and mixtures of salt and sugar. This technique, although not common, is used commercially for canned citrus juice concentrate (cans of juice are passed continuously through a chamber containing liquid freezant); for poultry especially during the initial stages of freezing ( to impart a uniform, white color to the surface); and an occasionally for fish and shrimp.

The major advantages of liquid immersion freezing are that it results in rapid freezing (especially for foods which are unpackaged or are packaged in skin-tight films) and it is easily adapted to continuous operations. It is difficult, however, to find freezants with suitable properties.
D. Cryogenic Freezing
Cryogenic freezing refers to very rapid freezing achieved by exposing food items, unpackaged or thinly packaged, to an extremly cold freezant undergoing a change of state. The fact that heat removal is accomplished during a change of state by the freezant is used to distinguish cryogenic freezing from liquid-immersion freezing. The most common food grade cryogenic freezants are boiling nitrogen and boiling or subliming carbon dioxide.

The rate of freezing obtained with cryogenic methods is much greater than that obtained with air-blast or plate freezing but is only moderately greater than that obtained with fluidized bed or liquid immersion freezing.

Liquid nitrogen (LN) is used in many cryogenic freezers. The product is placed on a conveyor belt and moved into the insulated chamber, where it is cooled with moderately cold gaseous nitrogen moving counter current to the product. LN is propelled or dribbled on the product. Following the desired exposure time, the product pass to the place where it is allowed to equilibrate to the desired final temperature (-18°C to –30°C) before it is discharged. Final product temperature is usually no different than that obtained during conventional methods of freezing.

Advantages of LN freezing are as follows:

- Dehydration loss from the product is usually much less than 1%
- Oxygen is excluded during freezing
- Individually frozen pieces of product undergo minimal freezing damage
- The equipment is simple, suitable for continuous flow operations, adaptable to various production rates and product sizes, of relatively low initial cost, and capable of high production rates in a minimal space.

The only disadvantage of LN freezing is high operating cost, and this is attributable nearly entirely to the cost of LN.

SOME COMPARISİONS ABOUT THE ADVANTAGES AND DİSİADVANTAGES OF FREEZERS

AIR BLAST (use air for heat transfer, provides the largest range of designs)

BATCH
Advantages
Easy and economical to build
Can accommodate a wide range of products

Disadvantages
Labor intensive
Occupies a large floor space
Poor heat transfer may occur resulting in poor product quality
Excessive dehydration in unpacked products
Product damage due to sticking
Labor intensive and costly to clean
IN-LINE

Advantages
- Economical operation
- Space efficient
- Superior quality due to continuous processing flow and controlled heat transfer
- Reduced dehydration
- Easy to clean

Disadvantages
- Not as flexible as batch freezer
- Higher capital investment

CONTACT (heat transfer occur through conduction)

BATCH/IN LINE

Advantages
- Highly efficient heat transfer
- Compact size
- Low operating cost
- Relatively low capital investment
- Minimizes package distortion
- Retains product shape
- Improved bulk product handling

Disadvantages
- Inflexible: used primarily for foods in packages
- Limited package geometry

CRYOGENIC

BATCH/IN LINE

Advantages
- Low dehydration
- Can be simpler to operate because no refrigeration is required
- Lower capital cost
- Efficient freezing and high product quality
- Economical for low to medium capacity production and test runs

Disadvantages
- High operating cost of expandable refrigerant
- Dependence of refrigerant delivery
- Should be monitored regularly
- Potential operational hazard
- Uneconomical for large scale production

QUALITY LOSS AT FREEZING TEMPERATURES
Freezing is a quick and convenient way to preserve fruits and vegetables. Frozen fruits and vegetables of high quality and maximum nutritional value can be produced if the directions below are followed. These directions are based on:
• The chemical and physical reactions which take place during the freezing process,
• Scientific knowledge of the effect of freezing on the tissues of fruits and vegetables,
• Food microbiology.

The chief function of freezing is to preserve food while maintaining its high quality. This is accomplished by reducing the product temperature, thereby slowing the quality deterioration processes: the oxidation of fat, the growth of microorganisms, enzymatic reactions and the loss of surface moisture (dehydration).

Chemical changes during freezing
Fresh fruits and vegetables, when harvested, continue to undergo chemical changes, which can cause spoilage and deterioration of the product. This is why these products should be frozen as soon after harvest as possible and at their peak degree of ripeness.

Fresh produce contains chemical compounds called enzymes, which cause the loss of color, loss of nutrients, flavor changes, and color changes in frozen fruits and vegetables. These enzymes must be inactivated to prevent such reactions from taking place.

The blanching process inactivates enzymes in vegetables. Blanching is the exposure of the vegetables to boiling water or steam for a brief period of time. The vegetable must then be rapidly cooled in ice water to prevent it from cooking. Contrary to statements in some publications on home freezing, in most cases blanching is absolutely essential for producing quality frozen vegetables. Blanching also helps to destroy microorganisms on the surface of the vegetable and to make some vegetables, such as broccoli and spinach, more compact.

The major problem associated with enzymes in fruits is the development of brown colors and loss of vitamin C. Because fruits are usually served raw, they are not blanched like vegetables. Instead, enzymes in frozen fruit are controlled by using chemical compounds, which interfere with deteriorative chemical reactions. The most common control chemical is ascorbic acid (vitamin C). Ascorbic acid may be used in its pure form or in commercial mixtures with sugars.

Some directions for freezing fruits also include temporary measures to control enzyme-activated browning. Such temporary measures include soaking the fruit in dilute vinegar solutions or coating the fruit with sugar and lemon juice. However, these latter methods do not prevent browning as effectively as treatment with ascorbic acid.

Another group of chemical changes that can take place in frozen products is the development of rancid oxidative flavors through contact of the frozen product with air. Using a wrapping material, which does not permit air to pass into the product, can control this problem. 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.

Textural changes during freezing
County extension offices frequently receive questions about whether certain fruits, vegetables, or mixtures of either may be successfully frozen. Such questions can be answered by knowing the effect of freezing on various plant tissues.
Water makes up over 90 percent of the weight of most fruits and vegetables. This water and other chemical substances are held within the fairly rigid cell walls, which give support structure, and texture to the fruit or vegetable. Freezing fruits and vegetables actually consists of freezing the water contained in the plant cells.

When the water freezes, it expands and the ice crystals cause the cell walls to rupture. Consequently, the texture of the produce, when thawed, will be much softer than it was when raw. This textural difference is especially noticeable in products, which are usually consumed raw. For example, when a frozen tomato is thawed, it becomes mushy and watery. This explains why celery, lettuce, and tomatoes are not usually frozen (Table 1) and is the reason for the suggestion that frozen fruits, usually consumed raw, be served before they have completely thawed. In the partially thawed state, the effect of freezing on the fruit tissue is less noticeable.

Textural changes due to freezing are not as apparent in products which are cooked before eating because cooking also softens cell walls. These changes are also less noticeable in high starch vegetables, such as peas, corn, and lima beans.

**Rate of freezing**

Freezing produce as quickly as possible can control the extent of cell wall rupture. In rapid freezing, a large number of small ice crystals are formed. These small ice crystals produce less cell wall rupture than slow freezing which produces only a few large ice crystals. This is why some home freezer manuals recommend that the temperature of the freezer be set at the coldest setting several hours before foods will be placed in the freezer. Some freezer manuals tell the location of the coldest shelves in the freezer and suggest placing unfrozen products on these shelves.

All freezer manuals give guidelines for the maximum number of cubic feet of unfrozen product, which can be frozen at one time. This is usually 2 to 3 pounds of vegetable to each cubic foot of freezer space per 24 hours. Overloading the freezer with unfrozen products will result in a long, slow freeze and a poor quality product.

**Changes caused by fluctuating temperatures**

To maintain top quality, frozen fruits and vegetables should be stored at 0° F or lower. This temperature is attainable in separate freezer units and in some combination refrigerator-freezers. A freezer thermometer can help you determine the actual temperature of your freezer. If your freezer has number temperature settings, such as from 1 to 9, check the manual to see what settings are recommended for different uses.

Storing frozen foods at temperatures higher than 0° F increases the rate at which deteriorative reactions can take place and can shorten the shelf life of frozen foods. Do not attempt to save energy in your home by raising the temperature of frozen food storage above 0° F.

Fluctuating temperatures in the freezer can cause the migration of water vapor from the product to the surface of the container. This defect is sometimes found in commercially frozen foods, which have been improperly handled.
Moisture loss
Dehydration is of particular interest because it is less obvious, harder to quantify and often has a large economic impact. It is the result of the inevitable loss of water vapor that occurs when a product is exposed to air or another gaseous medium. Frost accumulating on the coil surfaces provides a gross indicator of the rate of dehydration moisture loss.

Fast cooling and freezing greatly reduce dehydration for two reasons. First, the temperature of the product is reduced quickly, which minimizes the evaporation rate (the rate at which water moves from the product into the air). Second, fast freezing minimizes the length of time the product is evaporating water at a higher rate. To achieve fast cooling and freezing, cold air is not enough. It needs to be distributed efficiently over the product surface by an effective airflow design.

Freezer burn
Moisture loss, or ice crystals evaporating from the surface area of a product, produces freezer burn—a grainy, brownish spot where the tissues become dry and tough in frozen storage. This surface freeze-dried area is very likely to develop off flavors. Packaging in heavyweight, moisture proof wrap will prevent freezer burn.

Microbial growth in the freezer
The freezing process does not actually destroy the microorganisms, which may be present on fruits and vegetables. While blanching destroys some microorganisms and there is a gradual decline in the number of these microorganisms during freezer storage, sufficient populations are still present to multiply in numbers and cause spoilage of the product when it thaws. For this reason it is necessary to carefully inspect any frozen products which have accidentally thawed by the freezer going off or the freezer door being left open.

Nutrient value of frozen foods
Freezing, when properly done, is the method of food preservation, which may potentially preserve the greatest quantity of nutrients. To maintain top nutritional quality in frozen fruits and vegetables, it is essential to follow directions contained in this leaflet for pretreatment of the vegetables, to store the frozen product at 0° F and to use it within suggested storage times.
REFERENCES
Air products Web Page, www.airproducts.com
Asymptote Food Freezing Company Web Page, www.asymptote.co.uk