Related Commercial Resources

CHAPTER 16

INDUSTRIAL FOOD-FREEZING SYSTEMS

FREEZING is a method of food preservation that slows the physical changes and chemical and microbiological activity that cause deterioration in foods. Reducing temperature slows molecular and microbial activity in food, thus extending useful storage life. Although every product has an individual ideal storage temperature, most frozen food products are stored at 0 to –30°F. Chapter 11 lists frozen storage temperatures for specific products.

Freezing reduces the temperature of a product from ambient to storage level and changes most of the water in the product to ice. Figure 1 shows the three phases of freezing: (1) cooling, which removes sensible heat, reducing the temperature of the product to the freezing point; (2) removal of the product's latent heat of fusion, changing the water to ice crystals; and (3) continued cooling below the freezing point, which removes more sensible heat, reducing the temperature of the product to the desired or optimum frozen storage temperature. Values for specific heats, freezing points, and latent heats of fusion for various products are given in Chapter 9.

The longest part of the freezing process is removing the latent heat of fusion as water turns to ice. Many food products are sensitive to freezing rate, which affects yield (dehydration), quality, nutritional value, and sensory properties. The freezing method and system selected can thus have substantial economic impact.

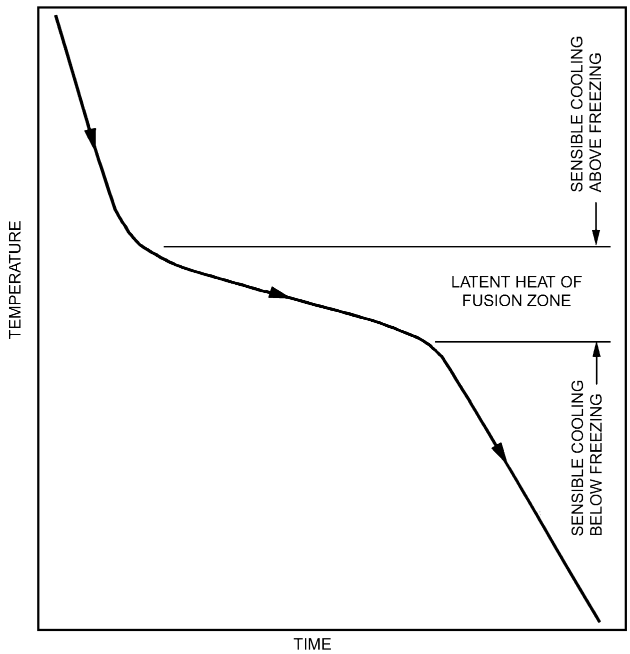

Fig. 1 Typical Freezing Curve

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

When selecting freezing methods and systems for specific products, consider special handling requirements, capacity, freezing times, quality, yield, appearance, first cost, operating costs, automation, space availability, and upstream/downstream processes.

This chapter covers general freezing methods and systems. Additional information on freezing specific products is covered in Chapters 14, 17 to 20, and 25 to 29. Related information can be obtained in Chapters 9 and 10, which cover thermal properties of foods as well as their cooling and freezing times. Information on refrigeration system practices is given in Chapters 1 to 3.

FREEZING METHODS

Freezing systems can be grouped by their basic method of extracting heat from food products:

Blast freezing (convection). Cold air is circulated over the product at high velocity. The air removes heat from the product and releases it to an air/refrigerant heat exchanger before being recirculated.

Contact freezing (conduction). Food, packaged or unpackaged, is placed on or between cold metal surfaces. Heat is extracted by direct conduction through the surfaces, which are directly cooled by a circulating refrigerated medium.

Cryogenic freezing (convection and/or conduction). Food is exposed to an environment below –76°F by spraying liquid nitrogen or liquid carbon dioxide into the freezing chamber.

Cryomechanical freezing (convection and/or conduction). Food is first exposed to cryogenic freezing and then finish-frozen through mechanical refrigeration.

Special freezing methods, such as liquid immersion (e.g., brines for packaged products), are covered under the specific product chapters.

BLAST FREEZERS

Blast freezers use air as the heat transfer medium and depend on contact between the product and the air. Sophistication in airflow control and conveying techniques varies from crude blast-freezing chambers to carefully controlled impingement freezers.

The earliest blast freezers consisted of cold storage rooms with extra fans and a surplus of refrigeration. Improved airflow control and mechanization of conveying techniques have made heat transfer more efficient and product flow less labor-intensive.

Although **batch freezing** is still widely used, more sophisticated freezers integrate freezing into a continuous production line. This **process-line freezing** has become essential for large-volume, high-quality, cost-effective operations. A wide range of blast freezer systems are available, including

Batch
- Cold storage rooms
- Stationary blast cells
- Push-through trolleys

Continuous/Process-Line
- Straight belts (two-stage, multipass)
- Fluidized beds
- Fluidized belts
- Spiral belts
- Carton (carrier)

Cold Storage Rooms

Although a cold storage room is not considered a freezing system, it is sometimes used for this purpose. Because a storage room is not designed to be a freezer, it should only be used for freezing in exceptional cases. Freezing is generally so slow that the quality of most products suffers. The quality of the already frozen products stored in the room is jeopardized because the excess refrigeration load may raise the temperature of the frozen products considerably. Also, flavors from warm products may be transferred.

Stationary Blast Cell Freezing Tunnels

The stationary blast cell (Figure 2) is the simplest freezer that can be expected to produce satisfactory results for most products. It is an insulated enclosure equipped with refrigeration coils and axial or centrifugal fans that circulate air over the products in a controlled way. Products are usually placed on trays, which are then placed into racks so that an air space is left between adjacent layers of trays. The racks are moved in and out of the tunnel manually using a pallet mover. It is important that the racks be placed so that air bypass is minimized. The stationary blast cell is a universal freezer, because almost all products can be frozen in a blast cell. Vegetables and other products (e.g., bakery items, meat patties, fish fillets, prepared foods) may be frozen either in cartons or unpacked and spread in a layer on trays. However, product losses from spillage, damage, and dehydration can be greater, and product quality can be reduced. In some instances, this type of freezer is also used to reduce to 0°F or below the temperature of palletized, cased products that have previously been frozen through the latent heat of fusion zone by other means. The flexibility of a blast cell makes it suitable for small quantities of varied products; however, labor requirement is relatively high and product movement is slow.

Push-Through Trolley Freezers

The push-through trolley freezer (Figure 3), in which the racks are fitted with wheels, incorporates a moderate degree of mechanization. Racks are usually moved on rails by a pushing mechanism, which can be hydraulically or electrically powered. This type of freezer is similar to the stationary blast cell, except that labor costs and product handling time are decreased. This system is widely used to **crust-freeze** (quick-chill) wrapped packages of raw poultry and for irregularly shaped products. Another version uses a chain drive to move the trolleys through the freezer.

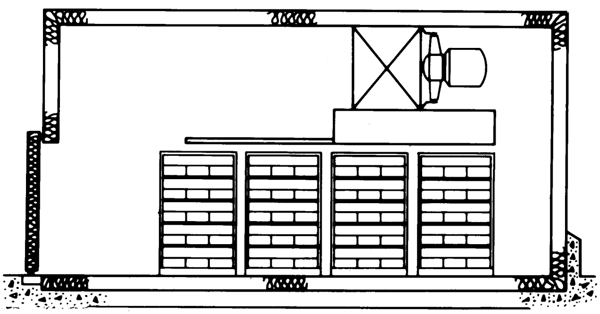

Fig. 2 Stationary Blast Cell

Straight Belt Freezers

The first mechanized blast freezers consisted of a wire mesh belt conveyor in a blast room, which satisfied the need for continuous product flow. A disadvantage to these early systems was the poorly controlled airflow and resulting inefficient heat transfer. Current versions use controlled vertical airflow, which forces cold air up through the product layer, thereby creating good contact with the product particles. Straight belt freezers are generally used with fruits, vegetables, French fried potatoes, cooked meat toppings (e.g., diced chicken), and cooked shrimp.

The principal design is the **two-stage belt freezer** (Figure 4), which consists of two mesh conveyor belts in series. The first belt initially precools or crust-freezes an outer layer or crust to condition the product before transferring it to the second belt for freezing to 0°F or below. Transfer between belts helps to redistribute the product on the belt and prevents product adhesion to the belt. To ensure uniform cold air contact and effective freezing, products should be distributed uniformly over the entire belt. Two-stage freezers are generally operated at 15 to 25°F refrigerant temperatures in the precool section and –25 to –40°F in the freezing section. Capacities range from 1 to 50 tons of product per hour, with freezing times from 3 to 50 min.

When products to be frozen are hot (e.g., French fries from the fryer at 180 to 200°F), another cooling section is added ahead of the normal precool section. This section supplies either refrigerated air at approximately 50°F or filtered ambient air to cool the product and congeal the fat. Refrigerated air is preferred because filtered ambient air has greater temperature variations and may contaminate the product.

Multipass Straight Belt Freezers

For larger products with longer freezing times (up to 60 min) and higher capacity requirements (0.5 to 6 ton/h), a single straight belt freezer would require a very large floor space. Required floor space can be reduced by stacking belts above each other to form either (1) a single-feed/single-discharge multipass system (usually three passes) or (2) multiple single-pass systems (multiple infeeds and discharges) stacked one on top of the other. The multipass (triple-pass) arrangement (Figure 5) provides another benefit in that the product, after being surface frozen on the first (top) belt,

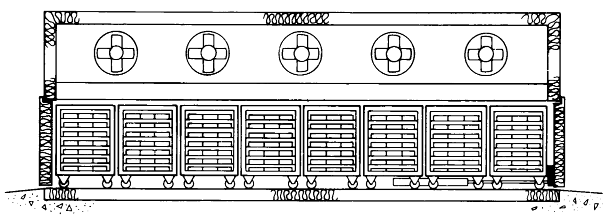

Fig. 3 Push-Through Trolley Freezer

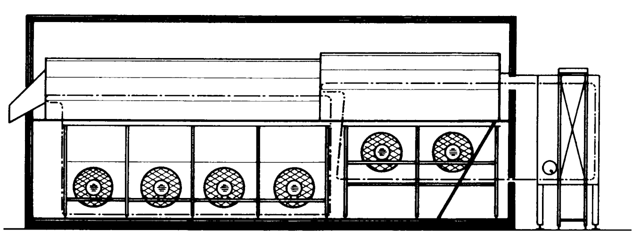

Fig. 4 Two-Stage Belt Freezer

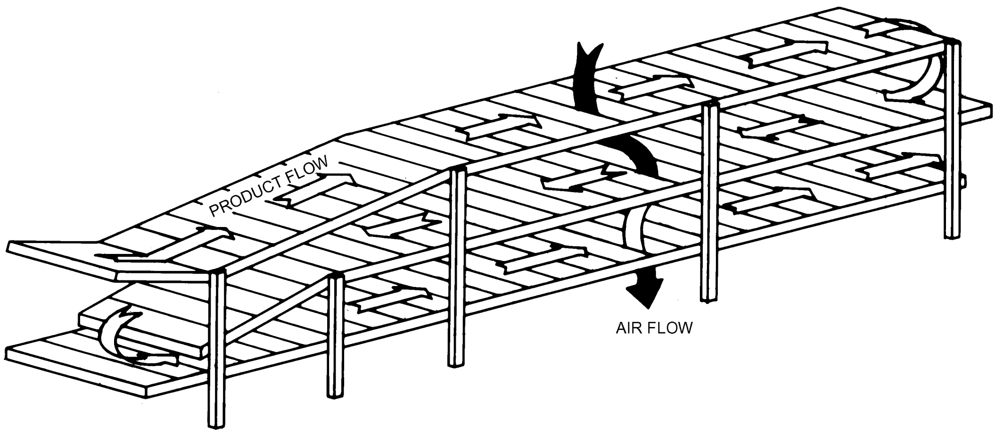

Fig. 5 Multipass, Straight Belt Freezer

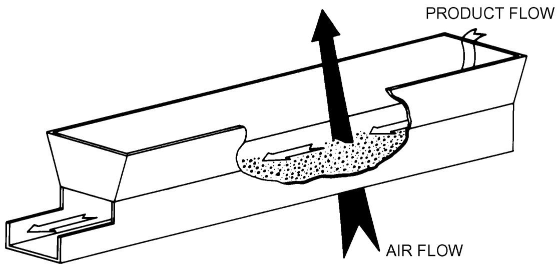

Fig. 6 Fluidized Bed Freezer

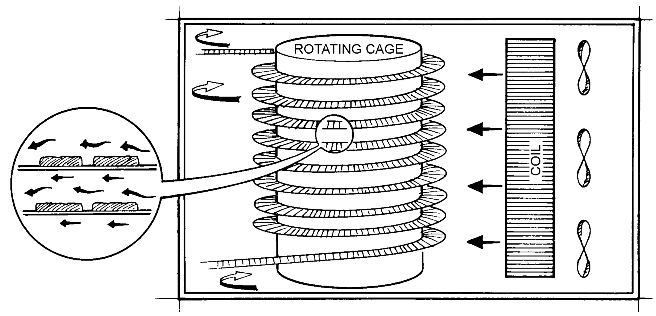

Fig. 7 Horizontal Airflow Spiral Freezer

may be stacked more deeply on the lower belts. Thus, the total belt area required is reduced, as is the overall size of the freezer. However, this system has a potential for product damage and product jams at the belt transfers.

Fluidized Bed Freezers

This freezer uses air both as the medium of heat transfer and for transport; the product flows through the freezer on a cushion of upward-flowing cold air (Figure 6). This design is well suited for small, uniform-sized particulate products such as peas, diced vegetables, and small fruit.

The high degree of fluidization improves the heat transfer rate and allows good use of floor space. The technique is limited to well-dewatered products of uniform size that can be readily fluidized and transported through the freezing zone. Because the principle depends on rapid crust-freezing of the product, the operating refrigerant temperature must be –40°F or lower, giving air temperatures of –20°F or lower. Fluidized bed freezers are normally manufactured as packaged, factory-assembled units with capacity ranges of 1 to 10 ton/h. Particulate products generally have a freezing time of 3 to 15 min.

Fluidized Belt Freezers

A hybrid of the two-stage belt freezer and the fluidized bed freezer, the fluidized belt freezer has a fluidizing section in the first belt stage. An increased air resistance is designed under the first belt to provide fluidizing conditions for wet incoming product, but the belt is there to help transport heavier, less uniform products that do not fluidize fully. Once crust-frozen, the product can be loaded deeper for greater efficiency on the second belt. Two-stage fluidized belt freezers operate at –30 to –35°F refrigerant temperature and in capacity ranges from 1 to 50 ton/h. A good order-of-magnitude estimate of total refrigeration load for individually quick-frozen (IQF) freezers is 40 tons of refrigeration per ton of product per hour. Small freezers require about 10 to 15% more capacity per ton of product per hour.

Spiral Belt Freezers

This freezer is generally used for products with long freezing times (generally 10 min to 3 h), and for products that require gentle handling during freezing. An endless conveyor belt that can be bent laterally is wrapped cylindrically, one tier below the last; this configuration requires minimal floor space for a relatively long belt. The original spiral belt principle uses a spiraling rail system to carry the belt, although more recent designs use a proprietary self-stacking belt requiring less overhead clearance. The number of tiers in the spiral can be varied to accommodate different capacities. In addition, two or more spiral towers can be used in series for products with long freezing times. Spiral freezers are available in a range of belt widths and are manufactured as packaged, modular, and field-erected models to accommodate various upstream processes and capacity requirements.

Airflow varies from open, unbaffled spiral conveyors to flow through extensive baffling and high-pressure fans. Horizontal airflow is applied to spiral freezers (Figure 7) by axial fans mounted along one side. The fans blow air horizontally across the spiral conveyor with minimal baffling limited to two portions of the spiral circumference. The rotation of the cage and belt produces a rotisserie effect, with product moving past the high-velocity cold air near the discharge, aiding in uniform freezing.

Several proprietary designs are available to control airflow. One design (Figure 8) has a mezzanine floor that separates the freezer into two pressure zones. Baffles around the outside and inside of the belt form an air duct so that air flows up or down around the product as the conveyor moves the product. The controlled airflow reduces freezing time for some products.

Another design (Figure 9) splits the airflow so that the coldest air contacts the product both as it enters and as it leaves the freezer. The coldest air introduced on the incoming, warm product may increase surface heat transfer and freeze the surface more rapidly, which may reduce product dehydration.

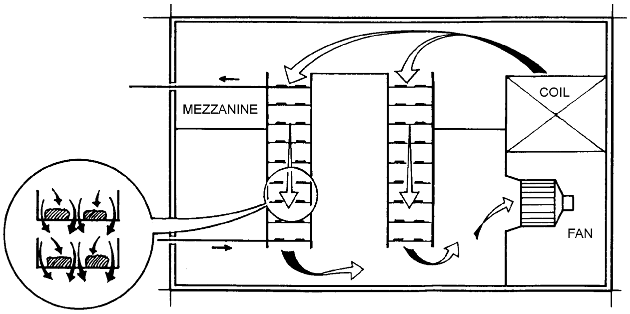

Fig. 8 Vertical Airflow Spiral Freezer

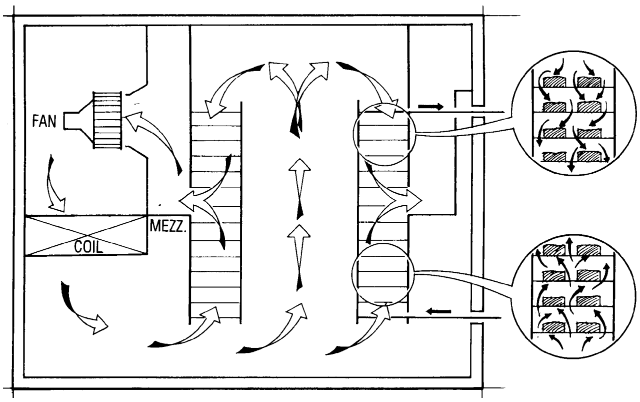

Fig. 9 Split Airflow Spiral Freezer

Typical products frozen in spiral belt freezers include raw and cooked meat patties, fish fillets, chicken portions, pizza, and a variety of packaged products. Spiral freezers are available in a wide range of capacities, from 0.5 to 10 ton/h. They dominate today's frozen food industry and account for the majority of unpackaged nonparticulate frozen food production, as well as many packaged products.

Impingement Freezers

In this design (Figure 10), cold air flows perpendicular to the product's largest surfaces at a relatively high velocity. Air nozzles with corresponding return ducts are mounted above and below the conveyors. The airflow constantly interrupts the boundary layer that surrounds the product, enhancing the surface heat transfer rate. The technique may therefore reduce freezing time of products with large surface-to-mass ratios (thin hamburger patties, for example). Impingement freezers are designed with single-pass or multipass straight belts. Freezing times are 1 to 10 min. Cost-effective application is limited to thin food products (less than 1 in. thick).

Carton Freezers

The carton (or carrier) freezer (Figure 11) is a very-high-capacity freezer (5 to 20 ton/h) for medium to large cartons of products such as red meat, poultry, and ice cream. These units are also used as chillers for meat products and block cheese.

In the top section of the freezer, a row of loaded product carriers is pushed toward the rear of the freezer, while on the lower section they are returned to the front. Elevating mechanisms are located at both ends. A carrier is similar to a bookcase with shelves. When it is indexed in the loading/discharge end of the freezer, the already-frozen product is pushed off each shelf one row at a time onto a discharge conveyor. When the carrier is indexed up, this shelf aligns with the loading station, where new products are continuously pushed onto the carrier before it is moved once again to the rear of the freezer. Refrigerated air is circulated over the cartons by forced

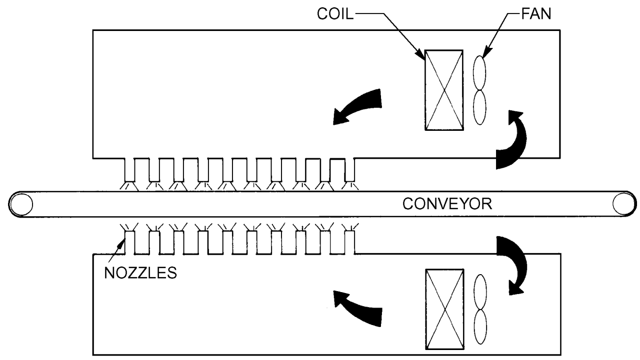

Fig. 10 Impingement Freezer

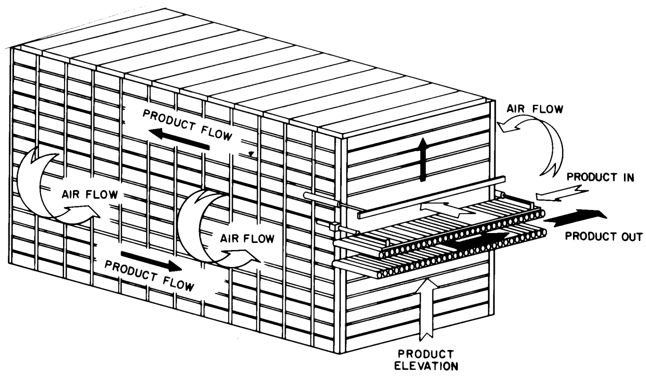

Fig. 11 Carton (Carrier) Freezer

convection. Generally, the air and product are arranged in cross flow, but some designs have air flowing either with or counter to the product (i.e., along the length of the freezer).

Computerized systems are now available to control shelf loading, unloading, and movement to freeze and/or cool products with different retention times in the same unit simultaneously. This increased flexibility is particularly useful and cost-effective where different sizes and cuts are prevalent (e.g., red meat and poultry products).

CONTACT FREEZERS

A contact freezer's primary means of heat transfer is conduction; the product or package is placed in direct contact with a refrigerated surface. Contact freezers can be categorized as follows:

Batch
- Manual horizontal plate
- Manual vertical plate

Process-Line
- Automatic plate
- Contact belt (solid stainless steel)
- Specialized design

The most common type of contact freezer is the **contact plate freezer**, in which the product is pressed between metal plates. Refrigerant is circulated inside channels in the plates, which ensures efficient heat transfer and results in short freezing times, provided that the product is a good conductor of heat, as in the case of fish fillets, chopped spinach, or meat offal. However, packages or cavities should be well filled, and if metal trays are used, they should not be distorted.

Manual and Automatic Plate Freezers

Contact plate freezers (Figure 12) are available in horizontal or vertical arrangements with manual loading/unloading. Horizontal plate freezers are also available in an automatic loading/unloading version, which generally accommodates higher capacities and con-

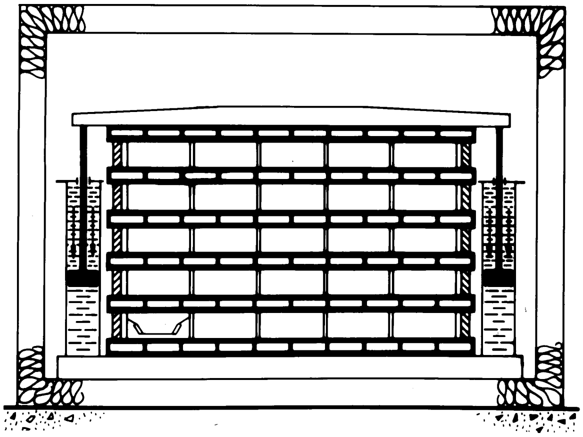

Fig. 12 Plate Freezer

tinuous operation. The advantage of good heat transfer in contact plate freezers is gradually reduced with increasing product thickness. For this reason, thickness is often limited to 2 to 3 in. Contact plate freezers operate efficiently because they require no fans, they are very compact, and there is no extra heat transfer between the refrigerant and a heat transfer medium. An advantage with packaged products is that pressure from the plates minimizes any bulging that may occur. Thus, packages are even and square within close tolerances. Automatic plate freezers accommodate up to 200 packages per minute, with freezing times from 10 to 150 min. When greater capacities are required, freezers are placed in series with associated conveyor systems to handle loading and unloading packages.

Specialized Contact Freezers

A combination of air and contact freezing is used for wet fish fillets and similar soft, wet products with relatively large, flat surfaces. The continuous, solid stainless steel belt is typically 4 to 6 ft wide and may be 100 ft long. Product is loaded onto the belt at one end of the freezer and then travels in a fixed position through the freezing zone to the discharge end. Freezing is usually accomplished both by conduction through the belt to a cooling medium below the belt and by convection through controlled airflow above the belt, or by convection only through high-velocity air above and below the belt. This freezer design produces attractive product, but a drawback is the physical size of the freezer. Capacities for typical products are generally limited to 1 to 2.5 ton/h, with a freezing time of less than 30 min.

Another specialized contact freezer conveys food products on a continuous plastic film over a low-temperature (–40°F) refrigerated plate. Contact with the film freezes approximately the bottom 0.04 in. of products in about 1 min. This equipment is used to eliminate product deformation or wire mesh belt markings on products that are flat, wet and sticky, soft, or in need of hand shaping before entering an air blast freezer. Another benefit of contact prefreezing is that it reduces dehydration losses in the subsequent freezing step. Examples of products suitable for contact prefreezing are marinated, boneless chicken breasts and thin fish fillets.

CRYOGENIC FREEZERS

Cryogenic (or gas) freezing is often an alternative for (1) small-scale production, (2) new products, (3) overload situations, or (4) seasonal products. Cryogenic freezers use liquid nitrogen or liquid carbon dioxide (CO_2) as the refrigeration medium, and the freezers may be batch cabinets, straight belt freezers, spiral conveyors, or liquid immersion freezers.

Liquid Nitrogen Freezers

The most common type of liquid nitrogen freezer is a straight-through, single-belt, process-line tunnel. Liquid nitrogen at –320°F is introduced at the outfeed end of the freezer directly onto the product; as the liquid nitrogen vaporizes, those cold vapors are circulated toward the infeed end, where they are used for precooling and initial freezing of the product. The “warmed” vapors (typically –50°F) are then discharged to the atmosphere. The low temperature of the liquid and vaporous nitrogen provides rapid freezing, which can improve quality and reduce dehydration for some products. However, the freezing cost is high because of the cryogen’s cost, and the surface of high-water-content products may crack if precautions are not taken.

Consumption of liquid nitrogen is in the range of 0.9 to 2.0 lb of nitrogen per pound of product, depending on the water content and temperature of the product. Although this translates into relatively high operating costs, the small initial investment makes liquid nitrogen freezers cost-effective for some applications.

Carbon Dioxide Freezers

A similar cryogenic freezing method places boiling (subliming) CO_2 in direct contact with foods frozen in a straight belt or spiral freezer. Carbon dioxide boils at approximately –110°F, and the system operates like a liquid nitrogen freezing system, consuming cryogenic liquid as it freezes product. Applications for CO_2 freezing include producing individual quick-frozen (IQF) diced poultry, pizza toppings, and seafood.

CRYOMECHANICAL FREEZERS

Although the technique is not new, cryomechanical freezing (combination of cryogenic and blast freezing) applications are increasing. High-value, sticky products, such as IQF shrimp, and wet, delicate products, such as IQF strawberries and IQF cane berries, are common applications for these systems.

A typical cryomechanical freezer has an initial immersion step in which the product flows through a bath of liquid nitrogen to set the product surface. This rapid surface freezing reduces dehydration and improves the handling characteristics of the product, thus minimizing sticking and clumping. The cryogenically crust-frozen product is then transferred directly into a mechanical freezer, where the remainder of the heat is removed and the product temperature is reduced to 0°F or lower. The cryogenic step is sometimes retrofitted to existing mechanical freezers to increase their capacity. The mechanical freezing step makes operating costs lower than for cryogenic-only freezing.

OTHER FREEZER SELECTION CRITERIA

Reliability

Because of the harsh operating conditions, the freezing system is probably the most vulnerable equipment in a process line. A process line usually incorporates only one freezer, which makes reliability a major concern.

To achieve normal equipment life expectancy, freezing systems must be designed and constructed with adequate safety factors for electrical/mechanical components and with materials that can withstand harsh environments and rugged usage.

Hygiene

Cleanability and sanitary design are as important as reliability. Freezing systems should (1) have a minimum number of locations where the product can hang up, (2) be constructed of noncorrosive, safe materials, and (3) be equipped with manual and/or automatic sanitation systems for washdown and cleanup. If the equipment is not or cannot be properly cleaned and sanitized, product contamination can result. These features are particularly important for chilled, partially cooked, and fully cooked products that may not be fully reheated or properly prepared before consumption.

Quality

The quality of processed food products is affected by physical changes and by rates of microbiological activity and chemical reactions, each of which is influenced by the rate of temperature change. See Chapter 12 for more information on food microbiology. The freezing process physically changes the food product; the rate of physical change or freezing time determines the size of ice crystals produced.

At a slow freezing rate, initially formed ice crystals can grow to a relatively large size; fast freezing forces more crystals to be seeded with a smaller average size. However, different-sized ice crystals are formed because the product's surface freezes faster than its inner parts. Large ice crystals may damage cell walls of the product, usually increasing loss of juices during thawing. For some products, this can greatly affect the texture and flavor of the remaining product tissue.

The influence of freezing time is more apparent in some products than in others. For strawberries, a shorter freezing time can significantly reduce drip loss. Drip loss is 20% for strawberries frozen in 12 h but only 8% for strawberries frozen in 15 min. Cryogenic systems perform the same freezing function in 8 min or less, reducing drip loss to less than 5%.

A well-applied mechanical, cryogenic, or cryomechanical freezer can crust-freeze products rapidly, minimizing loss of natural juices, aromatics, and flavor essences and maintaining higher, more marketable product quality. Also, lower storage temperature and fewer, less severe temperature fluctuations tend to help preserve quality. However, long-term storage can diminish any benefits of more rapid freezing.

Economics

Ironically, freezing equipment is considered both the most expensive and the least expensive link in the modern processing chain. Although the freezer frequently represents the single largest investment in a line, its operating costs are usually only 3 to 5% of the total. Packaging costs may vary widely but generally are several times greater than total freezing cost.

One essential factor to consider when choosing freezing equipment is the loss in product mass that occurs during freezing. The cost of this loss may be about the same as the operating cost of the freezer for inexpensive products such as peas; the loss is even more significant for expensive products such as seafood.

Loss of product mass during freezing may be caused by mechanical losses, downgrading, and dehydration (shrink). **Mechanical losses** occur from products dropping to the floor or sticking to conveyor belts, and are specific to each processing plant. A modern freezer should produce minimal losses in this category. **Downgrading losses** refer to product damage, breakage, and other occurrences that render the product unsalable at the top-quality price. For most products, a modern freezing system should incur minimal losses from damage and breakage.

Dehydration losses occur in any freezing system. Evaporation of water vapor from unpackaged products during freezing becomes evident as frost builds up on evaporator surfaces. Frost is also caused by excessive infiltration of warm, moist air into the freezer. Still air inside a diffusiontight carton often creates larger dehydration losses than individual quick freezing of unpackaged products. Heat transfer is poor because no circulation of air occurs within the package. The resulting evaporation of moisture can be significant; however, the frost stays inside the carton.

Unpackaged food products cannot be chilled or frozen without losing at least some moisture. The most important factor affecting food dehydration is the time it takes for the product to freeze: the faster the freezing (within practical and cost limitations), the less dehydration shrinkage and the higher the quality. Most mechanical in-line freezers have speeds comparable to that of cryogenics: 12 to 15 min for hamburger patties in a mechanical spiral freezer, for instance, compared to 8 to 10 min in a cryogenic freezer.

Table 1 Moisture-Carrying Capacity of Air (Saturated)

Temperature, °F	Ratio of Water to Dry Air, by Weight
0	0.0008
–10	0.00046
–20	0.00026
–30	0.00015
–40	0.00008
–50	0.00004

Source: Adapted from Table 2, Chapter 6, of the 2005 *ASHRAE Handbook—Fundamentals.*

Most common mechanical freezing methods for unpackaged foods use air as the heat transfer medium; the amount of moisture air absorbs depends on temperature and pressure, as shown in Table 1. For more specific values, see Table 2 in Chapter 6 of the 2005 *ASHRAE Handbook—Fundamentals*.

From Table 1, 0°F air can, if it becomes saturated, absorb 10 times the amount of moisture from product that –40°F air would.

In air, moisture flows away from high-vapor-pressure or high-temperature areas (e.g., food products) toward areas of lower pressure or temperature (e.g., air). Higher air temperatures increase the likelihood of product moisture loss, but only during the initial freezing, before the outer crust freezes or is sealed with ice.

Many manufacturers use high evaporator temperatures to reduce energy costs; when coupled with high air volumes and an air temperature close to the refrigerant temperature, this method has the added benefit of reducing food dehydration. Lower evaporator temperatures tend to remove more moisture from air, which in turn leads to greater moisture being robbed from the product. Using the smallest achievable air temperature rise is helpful; for mechanical systems, try to keep the temperature difference between coil air and refrigerant to 10 to 12°F.

Increasing air quantities also helps reduce shrinkage. Airflow around the product should be evenly distributed, to allow good heat transfer.

Drip loss varies according to initial product quality, amount of surface or product moisture available, and time to freeze. Quicker freezing times reduce drip loss by sealing the surface.

The rate of moisture diffusion, and how readily a product releases moisture to air, also affects shrinkage. Different products have different moisture diffusion rates, which can be difficult to estimate or measure.

A poorly designed freezing system for unpackaged products operates with dehydration losses of easily 3 to 4%, but well-designed mechanical or cryogenic freezing systems can be built to operate with losses near 0.5%. Liquid nitrogen tunnels normally operate with a dehydration loss of about 0.4 to 1.25%, which occurs when the nitrogen gas is circulated over the product at the infeed end of the freezer. Infeed circulation is sometimes needed to temper the product and to use the nitrogen's heat capacity most efficiently. Nitrogen immersion freezers have lower dehydration losses but use more liquid nitrogen. A CO_2 freezer using jet impingement operates with a dehydration loss of about 0.5 to 1.25%.

In general, the faster the product surface temperature is reduced, the lower the dehydration rate. Although air relative humidity affects dehydration during frozen storage, it has little effect on dehydration rates during freezing.

REFRIGERATION SYSTEMS

Most mechanical food freezers use ammonia as the refrigerant and are equipped with either liquid overfeed or gravity-flooded evaporators. The choice of evaporator system depends on freezer size and configuration, space limitations, freezer location, existing plant systems (where applicable), relative cost, and end user preference. For systems with three or more evaporators, a liquid overfeed system is usually less costly to install and operate.

Evaporators may be defrosted with water, hot gas, or a combination of both. Defrost systems can be manual, manual start/automatic run, or fully automatic. Coil defrost can take place at a shift change or be sequential, so that the freezer remains in continuous operation for long periods. Selection of a defrost system depends on plant and product requirements, water supply and disposal situation, sanitation regulations, and end user preference.

With a liquid overfeed system, carefully consider refrigeration line sizing and potential static head penalties if the liquid overfeed recirculator is remote from the freezer. Locating the liquid recirculation equipment adjacent to and below the evaporators provides for the most efficient and productive operation of the freezing equipment. In particular, vertical risers in wet suction lines can result in liquid logging (retention), leading to excessive pressure drops. See Chapter 1 for design considerations.

A design evaporator temperature for the freezer should be selected to achieve the lowest overall capital and operating cost possible for the freezer and the other high- and low-side refrigeration components, while remaining consistent with product requirements and other plant operating conditions.

If there is significant air infiltration into the freezer, then special air-cooling coil designs using large fin spacing (or staggered fin space) may be necessary to avoid excessive deterioration of performance by frosting.

In a mechanical system, using a –50°F evaporator temperature instead of –40°F increases the utility bill by about 15%. A system with lower evaporator temperature may have slightly higher first cost, but will cause significantly less shrinkage. For temperatures below –40°F, a CO_2/NH_3 cascade refrigeration system should be considered, and may be less expensive than a two-stage NH_3 system.

Operation

Modern conveyor freezers are equipped with programmable logic controls (PLCs) and/or computer control systems that can monitor and control key elements of freezer operation to maximize productivity, product quality, and safety. Items to be monitored and controlled include belt speeds, air and refrigerant temperatures, air and refrigerant pressures, evaporator defrost cycles, belt washers and dryers, amperage for electric motors, safety and alarm functions, and other variables specific to the products being frozen.

The presence of electronic controls alone does not guarantee freezer performance; human operators are still needed. The number and specialty of operators required depends on the size of the plant and the quantity of freezers. A small plant may have a combination operator covering belt production and refrigeration. In larger plants, a freezer operator may oversee production while a specialist attends to the refrigeration cycle. Long-term success requires well-trained, knowledgeable operators who make the proper adjustments as changes occur in the process.

Maintenance

Freezing systems operate in a harsh environment in which some of the components are hidden from view by the enclosure and product. Many freezers operate 5000 to 7000 h per year. The best freezers are ruggedly constructed and well designed for easy maintenance. Nevertheless, a well-run maintenance program is essential to productivity and safety.

Freezer manufacturers supply operation and maintenance manuals with key instructions, information on components, parts lists, and suggestions regarding maintenance and safety inspections and tasks on a planned-frequency basis. Manufacturers also provide training programs for maintenance technicians.

It is important for plants to have a sufficient number of properly trained maintenance technicians to maintain all systems. Duties include prescribed inspections, routine maintenance tasks, troubleshooting, and required maintenance during nonproduction periods. Depending on plant size, technicians may be individual mechanics, electricians, and refrigeration specialists or combinations of the three.

It is suggested that plants hire contract services when they are not able to cover any or all maintenance and operation functions adequately with their own personnel.

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