annular space between the inner and outer tubes and the liquid food passes through the inner tube. Scrapers prevent product buildup on the inner tube wall and promote agitation of the product. Units are manufactured with capacities of 100 to 300,000 lb per hr.

Freezers for Unpackaged or Lightly Packaged Foods. Direct immersion freezers such as the Ottesen brine freezer, Harden F. Taylor brine spray system, and the Zarotschenzeff fog freezer were developed primarily for fisheries application. With the introduction of packaged foods, these freezing methods were discontinued. Direct immersion freezing is used for freezing some fishery products at sea aboard the vessel and, more recently, for freezing poultry.

In freezing poultry, the packaged product is propelled through a chilled bath of propylene glycol contained in an insulated rectangular tank. The refrigerant is directed into the tank in jets so as to move the packaged product from one end to the other. A spoked unloader and drain trough help drain excess glycol from the product, which is finally washed with water.

Liquid nitrogen freezing is a new method that holds promise for the future. In this process, either packaged or unpackaged food is conveyed through an insulated cabinet containing a pool of liquid nitrogen which evaporates at −320 F. Direct heat exchange results in rapid subcooling of the product, from 180 to −5 F in less than 5 min.

The advantage of the liquid nitrogen method of freezing is the extremely high production that can be attained from a relatively small unit. However, the cost of liquid nitrogen is still quite high, and freezing costs could be as high as 8 cents per pound of product. Also, little technical information is available on the effect of this very rapid method of freezing on the quality of the frozen product. Severe crystallization and rupture may occur with some foods because of the very rapid freezing experienced.

Freezing by Indirect Contact

Indirect freezing may be defined as freezing by engaging the product with a metal surface cooled by ammonia. Refrigerants 12 or 22, or cold brine. Many different types of indirect freezers were developed but these methods were subsequently discarded in favor of the more efficient contact-plate freezer.

Contact-Plate Freezing is one of the most popular methods of freezing packaged food in the United States. An early contact freezer, developed by Birdseye and Hall, consisted of a series of horizontal refrigerated hollow plates actuated by means of hydraulic pressure so that they could open to receive the product. Ammonia or brine circulating through hollow passages in the plates provided the necessary refrigeration effect.

In recent years the use and manufacture of pressure-type multi-plate freezers has expanded considerably to meet the demand for a flat, well-formed frozen package that will stack compactly in the retail cabinet. The freezers in use today may be classified as batch, semi-automatic, or automatic. Description of representative types of this equipment follows:

Batch-Type Contact Freezers. The batch freezer in commercial use today is very similar to that first developed by Birdseye and Hall. A number of different sizes are available varying from 6 to 20 freezing stations and a loading capacity of 200 to 2500 lb of 1-in. thick packages. The plates are located within an insulated cabinet, and refrigeration is accomplished usually by flooding the internal of the plates with ammonia, Refrigerants 12 or 22, or cold brine. Two-stage refrigeration compression systems are used to achieve plate temperatures as low as −50 F.

The superimposed plates are actuated by means of a double-acting hydraulic ram. The packaged food in sizes varying from 1 to 3 in. thick is placed on metal trays and inserted between the plates. Spacers are placed between the plates to prevent crushing of those packages not solidly packed.

The freezing rate of products in a contact plate freezer varies with the size of the package, the type of product, and the packaging material used. Meat, poultry, fish, and similar solidly packed products require about 1 hr when packed in 1-in. thick cartons, 3 hr in 2-in. thick cartons, and 4 hr in 2½-in. thick cartons. Products of the same size that are not solidly packed require more time to freeze because of the insulating effect of the air space within the package.

Refrigeration requirements vary with the product being frozen and the size of the freezer. As a rule of thumb, manufacturers estimate that about 1½ tons of refrigeration, at 0 psi suction pressure, are required for a plate load of 800 pounds of product.

The advantages of the batch freezer are rapid product freezing, low maintenance cost, and low freezing costs. The principal disadvantage is the labor required to load and unload the packages.

Semi-automatic Contact Freezers. The semi-automatic freezer is similar to the batch freezer, except that it provides for operator-controlled loading and unloading of the packages. One system consists of a series of refrigerated plates mounted loosely in an elevator cage, which is located in an insulated room. Standard machines handle products from ⅝ in. to 2-in. thick.

In a typical installation, fish sticks are frozen at −50 F plate temperature at the rate of 34 packages per minute. The freezer holds a total of 1680 eight-ounce cartons in 20 stations. In operation, the packages approach the unit in single file on a continuous conveyor. When 14 cartons accumulate, the machine operator presses a button and a horizontal bar pushes the packages off the conveyor into the waiting slot between the two freezer plates. As a row of warm packages enters, previously frozen packages are advanced one row and emptied out the back of the freezer onto a conveyor belt leading to a caser. When 6 rows of packages are loaded, a counting device inactivates the feeder and lifts the freezer plates to the next station, at the same time closing the plates on the products just loaded. The loading cycle is then repeated in the same sequence mentioned above until all the plates are full. At that time the elevator cage automatically drops and the 2 top plates are opened for product loading and emptying of the frozen food.

This type of freezer will generally handle only one size product at a time. The food must be well packaged and should not exude any moisture or drip, which would result in sticking of the package to the plates. Adjustable spaces between the plates enable proper contact between plates and product. Defrosting can be accomplished periodically by a special heat gas arrangement.

Automatic Plate Freezers. One commercial type of automatic freezer is similar in operation to that described above, except that the loading and unloading are controlled automatically by a series of microswitches and electrical relays. The plates are located within an insulated cabinet, and the frozen products are removed and the products loaded from a conveyor by a hydraulically operated ram. The plates rise after being loaded until the freezer is filled, after which time the plates are lowered and the sequence of operation repeated. A 17-station freezer of this design will hold 208 cartons (4 in. by 5 in.) and will complete one loading and unloading cycle in 45 min. The loading time can be varied to meet product freezing requirements.

In another continuous plate freezer, packaged fruits, vegetables, meat, fish, and other foods are fed directly from the wrapping machine by a belt conveyor through an opening in the walls of the refrigerated enclosure onto eight roller-type loading stations at the front of the freezer. Electronic devices control the loading of each station so that after loading one station the conveyor moves up to the next station until all are filled. During loading a movable frame causes the lower freezing plate to move forward and down, thereby opening the station to receive a full row of packages. The forward and back action of the lower plate forces the packages to move to the back of the freezer, where one row is ejected and the packages carried away on a conveyor to a caser. This particular freezer is available in one to eight stations with a capacity of about 2000 to 14,000 pounds of product in 1-in. thick packages.

AIR-BLAST FREEZING

Air-blast freezers are widely used to produce a great variety of quick-frozen foods of excellent quality. These freezers differ markedly from sharp freezers in that they are usually designed in the form of tunnels and take full advantage of the heat-transfer efficiency of rapidly circulating air. Very cold air in rapid motion may be obtained by directing an air blast through refrigerated coils; and, if more rapid freezing is desired, the cold air blast may be confined in an insulated tunnel.

The blast freezer has the advantage of being able to handle a great number of different products. It is particularly useful in freezing loose or bulky items varying in size, but precautions must be taken to prevent excessive dehydration from occurring. Solidly packaged consumer-size products may become distorted in size and are best frozen in a plate freezer. Blast freezing is costly because of the extra energy required for fan operation. Also, maintenance costs of these freezers can be quite high. In addition, considerable defrosting of the equipment is needed, particularly when freezing unpackaged foods.

Commercially, the tunnel freezer is a commonly used method. Every packer using this system has his own ideas and improvements incorporated into the freezer, but basically a tunnel freezer consists of a long slow-moving mesh belt passing through an insulated tunnel or enclosure containing very cold air in continuous rapid motion. The speed of the belt is variable to the time required to freeze the product. Other tunnel freezers make use of wire mesh trays which are loaded onto racks. The tray racks are pushed into the freezing tunnel and are pushed out when the product is solidly frozen. In most cases, the air blast is introduced into the tunnel at the end opposite to the entrance of product to be frozen so that the cold air is in counterflow to the direction of the product. Temperatures of the air blast range from 0 to −30 F, although lower temperatures are sometimes used. Air velocities of 100–3500 fpm have been reported.

Another example of air blast freezing is a multi-level continuous tray freezer used for freezing loose or packaged products. The insulated freezer shell contains either solid or mesh trays connected by pivots to two chain conveyors that wind back and forth over several levels in the path of circulating cold air. In operation a timer allows a fixed quantity of cartons or loose products to pass on a loading belt located directly in front of the freezer trays. The products are then swept onto the top tier of freezing trays, carried along eight levels and discharged at the bottom onto a conveyor that carries them to the storage area.

W. J. Finnegan designed an air-blast freezer in 1938 that is described as a multi-stage tubular freezer. This system was designed to reduce the moisture loss usually associated with the regular air blast and tunnel freezers by maintaining a small temperature difference between the refrigerant and the contacting air with the product being frozen. It also maintained a relatively high humidity in the recirculated air used in freezing. This freezer is made up of two vertical banks of liquid ammonia-flooded recirculating tubes that are designed with extended fin surfaces. The tubes are enclosed in an insulated cabinet to form the freezing tunnel with the tubes running along either side and a space left between them to allow the passage of trucks with trays to carry the product to be frozen. The tunnel is divided into 6 sections, the first for precooling, the next 4 for freezing, and the last section for tempering. Air with a velocity of from 1000–1200 fpm circulates in the 4 freezing sections with the air being directed in a reverse direction in each of the 4 sections. The feeding and discharge sections have no forced air circulation, so they act as an air lock.

Loaded trucks are pushed manually into the precooling section and from there are carried through the freezer by a chain conveyor, with the speed of the conveyor regulated to the proper freezing time for specific products. Each truck has an air-tight metal wall on one end, which completes the closing off of each stage as the truck passes through the tunnel. Each truck is also equipped with adjustable air baffles on each side of the trays, so arranged as to force air up and down through the product on the trays. As the truck passes into the next section, this up and down movement of air is automatically reversed because the horizontal direction of the air blast has been reversed.

Considerable promotion behind the marketing of vegetables and fruits in loose frozen form has resulted in modification of the belt-type blast tunnel to accomplish the chilling and freezing in three stages rather than in one. In a recently developed three-stage unit, blanched peas and corn are subjected to 0 F and glazed on the first belt, then transferred to the second belt where they are first subjected to a −10 F air blast and then to −20 F circulating air. The product leaves the freezer at −15 F.

The *Continuous Fast Freezer* is a recent development. This is a vertical freezer in which trays of product are moved upwards through an air blast. A time clock controls the movement of the trays and is set for a predetermined freezing cycle to meet the needs of the product depending on whether it is loose frozen or packaged.

For loose frozen products such as peas, beans, cut corn and others, trays filled with the product are fed in at the bottom of the freezing column, stepping each tray upward at a predetermined rate and discharging the tray of frozen product at the top by automatically dumping the product from the tray and returning the empty tray to the starting position. Completely automatic, the controls are interconnected so that no operation can start until the previous operation has been completed. The product to be frozen feeds onto the trays on the lower conveyor directly from the cooling flume carrying the product from the final inspection belt. Each tray is leveled off to a depth about 1½ in. by a leveling plow before the tray is fed into the freezer. At the top of the freezer, the frozen product passes from the dump hopper through a breaker to break up large clusters of the product and then feeds by gravity or conveyor to the packaging machine.

The operation is similar when packaged foods are frozen except that the packages are placed on the trays by hand and removed in the same manner on leaving the conveyor belt.

The *Continuous Shelf Freezer* is a recent development in air-blast freezing and one that is automatic. This freezer is often referred to as the FES-Patterson machine. Shelves of packages are pushed through the machine by hydraulic rams. Cold air is circulated over the packages and each package has 3 sides exposed to the cold air.

Another recently developed machine is the *Spiral Belt*