CHAPTER 19

FISHERY PRODUCTS

THE major types of fish and shellfish harvested from North American waters and used for food include the following:

- Groundfish (haddock, cod, whiting, flounder, and ocean perch), lobster, clams, scallops, snow crab, shrimp, capelin, herring, and sardines from New England and Atlantic Canada
- Oysters, clams, scallops, striped bass, and blue crab from the Middle and South Atlantic
- Shrimp, oysters, red snapper, clams, and mullet from the Gulf Coast
- Lake herring, chubs, carp, buffalofish, catfish, yellow perch, and yellow pike from the Mississippi Valley and Great Lakes
- Alaska pollock, Pacific pollock, tuna, halibut, salmon, Pacific cod, various species of flatfish, king and snow crab (*Chinoecetes opelio*; about 200,000,000 lb annually), dungeness crab, scallops, shrimp, and oysters from the Pacific Coast and Alaska
- Catfish, salmon, trout, oysters, and mussels from aquaculture operations in various locations

Fish harvested from tropical waters are reported to have a substantially longer shelf life than fish harvested from cold waters, possibly because of the bacterial flora naturally associated with the fish. Bacteria associated with fish from tropical waters are mainly gram-negative mesophiles, whereas those that cause spoilage of fish during refrigerated storage are usually gram-negative psychrophiles. The time required for this bacterial population shift (from mesophiles to psychrophiles) after refrigeration may account for the increased shelf life.

The major industrial fish used for fish meal and oil is menhaden from the Atlantic and Gulf coasts. Also, fish parts not used for human consumption are often used to manufacture fish meal and oil.

Fish meal and oil are the principal components of feed used in the aquaculture of trout and salmon, and is a dietary component for poultry and pigs. Fish oil is used in margarine, in paints, and in the tanning industry. It is also refined for pharmaceutical purposes.

This chapter covers preservation and processing of fresh and frozen fishery products; handling of fresh fish aboard vessels and ashore; the technology of freezing fish; and present commercial trends in freezing, frozen storage, and distribution of seafood.

See Chapter 27 for additional information regarding fishery products for precooked and prepared foods, and Chapter 31 for more on marine refrigeration.

HACCP System. Many procedures for control of microorganisms are managed by the Hazard Analysis and Critical Control Point (HACCP) system of food safety. Each food manufacturing site should have a HACCP team to develop and implement its HACCP plan. See Chapter 12 for additional information on sanitation.

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

FRESH FISHERY PRODUCTS

CARE ABOARD VESSELS

After fish are brought aboard a vessel, they must be promptly and properly handled to ensure maximum quality. Trawl-caught fish on the New England and Canadian Atlantic coasts, such as haddock and cod, are usually eviscerated, washed, and then iced down in the pens of the vessel's hold. Canadian (offshore), Icelandic, U.K., and other European fleets ice fish in boxes for optimum quality. Because of their small size, other groundfish (e.g., ocean perch, whiting, flounder) are not eviscerated and are not always washed. Instead, they are iced down directly in the hold of the vessel.

Crustaceans, such as lobsters and many species of crabs, are usually kept alive on the vessel without refrigeration. Warm-water shrimp are beheaded, washed, and stored in ice in the hold; on some vessels, however, the catch is frozen either in refrigerated brine or in plate freezers. Cold-water shrimp are stored whole in ice or in chilled sea water, or they may be cooked in brine, chilled, and stored in containers surrounded with ice.

Freshwater fish in the Great Lakes and Mississippi River areas are caught in trap nets, haul seines, or gill nets. They are sorted according to species into 50 or 100 lb boxes, which are kept on the deck of the vessel. In most cases, fishing vessels carry ice aboard, and fish are landed the day they are caught.

Freshwater fish in Canadian lakes are iced down in the summertime and stored at collecting stations on the lakes, where they are picked up by a collecting boat with a refrigerated hold. Winter-caught Canadian freshwater and Arctic saltwater fish are usually weather-frozen on the ice immediately after catching and are marketed as frozen fish.

Line-caught fish of the Pacific Northwest, such as halibut caught largely by bottom long-line gear and salmon caught by trolling gear, are eviscerated, washed, and iced in the pens of the vessel. Pacific salmon caught by seines and gill nets for cannery use are usually stored whole for several days, either aboard vessels or ashore in tanks of seawater refrigerated to 30°F. A small but significant volume of halibut is held similarly in refrigerated seawater aboard vessels. Tuna caught offshore by seiners or clipper vessels are usually brine-frozen at sea. However, tuna caught inshore by smaller trollers or seiners are often iced in the round or refrigerated with a brine spray.

Fish raised by aquaculture farms are usually harvested and sold as required by the fresh fish market. They are usually shipped in containers in which they are surrounded by ice.

Icing

Fish lose quality because of bacterial or enzymatic activity or both. Reducing storage temperature retards these activities significantly, thus delaying spoilage and autolytic deterioration.

Low temperatures are particularly effective in delaying growth of psychrophilic bacteria, which are primarily responsible for spoilage of nonfatty fish. The shelf life of species such as haddock and cod is doubled for each 7 to 10°F decrease in storage temperature within the range of 60 to 30°F.

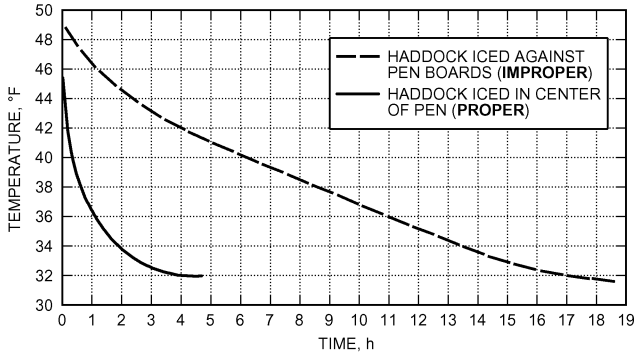

Fig. 1 Cooling Rate of Properly and Improperly Iced Haddock

To be effective, ice must be clean when used. Bacteriological tests on ice in the hold of a fishing vessel showed bacterial counts as high as 5 billion per gram of ice. These results indicate that (1) chlorinated or potable water should be used to make the ice at the plant, (2) ice should be stored under sanitary conditions, and (3) unused ice should be discarded at the end of each trip.

Both flake and crushed block ice are used aboard fishing vessels, although flake ice is more common because it is cheaper to produce and easier to handle mechanically.

The amount of ice used aboard vessels varies with the particular fishery and vessel; however, it is essential to provide enough ice around the fish to obtain a proper cooling rate (Figure 1). A common ratio of ice to fish used in bulk icing on New England trawlers is one part ice to three parts fish. Experiments on British trawlers in boxing fish at sea with one part ice to two parts fish demonstrated improved quality in the landed fish, and, as ice has become more plentiful and less costly relative to the value of fish, the ratio of ice to fish continues to increase. Some vessels use mechanical refrigeration to retard ice melting en route to the fishing grounds; however, the hold temperature must be controlled after fish are taken to allow the ice to melt for effective cooling of the fish.

Saltwater Icing

Iced fish storage temperatures must be maintained close to the freezing point of fish. To obtain lower ice temperatures, the freezing point may be depressed by adding salt to the water from which ice is made. Adequate amounts of ice made from a 3% solution of sodium chloride brine maintain a storage environment of about 30°F. Tests conducted on haddock storage in saltwater ice aboard a fishing vessel showed that, under parallel conditions, fish iced with saltwater ice cooled more quickly and to a lower temperature than fish iced with plain ice. However, the saltwater ice melted more quickly because of its lower latent heat and greater temperature differential. Therefore, once the saltwater ice melted, fish stored in this ice rose to a higher temperature than those in plain ice. Because it is not always possible to replenish ice on fish at sea, sufficient quantities of saltwater ice must be used initially to make up for its faster melting rate.

In making ice from water containing a preservative, rapid freezing and/or using a stabilizing dispersant is essential to prevent migration of the additive to the center of the ice block. This problem is not encountered in flake ice because flake ice machines freeze water rapidly into thin layers of ice, thus fixing additives within the flakes. Chapter 34 describes the manufacture of flake ice in more detail.

Use of Preservatives

In the United States and Canada, the use of antibiotics in ice or in dips for treatment of whole or gutted fish, shucked scallops, and unpeeled shrimp is prohibited by regulation.

Storage of Fish in Refrigerated Seawater

Refrigerated seawater (RSW) is used commercially for preserving fish. On the Pacific Coast, substantial quantities of net-caught salmon are stored in RSW aboard barges and cannery tenders for delivery to the canneries. Most salmon seiners now use RSW systems. It is often a condition of sale. On the East and Gulf coasts, RSW installations on fishing vessels are used for chilling and holding menhaden and industrial species needed for production of meal, oil, and pet food. On the east and west coasts of Canada, RSW installations are used for chilling and holding herring and capelin, which are processed on shore for their roe. Other, more limited applications of RSW include holding Pacific halibut and Gulf shrimp aboard a vessel; chilling and holding Maine sardines in shore tanks for canning, and short-term holding of Pacific groundfish in shore tanks for later filleting.

With groundfish and shrimp, RSW works well for short-term storage (2 to 4 days), but is not suitable for longer periods because excessive salt uptake, accelerated rancidity, poorer texture, and increased bacterial spoilage may result. These problems can be partially overcome by introducing carbon dioxide (CO_2) gas into the RSW; holding in RSW saturated with CO_2 can increase the storage life of some species of fish by about 1 week. Additionally, RSW reduces (1) handling that results from bulk storage of the fish and (2) pressure on the fish as a result of buoyancy, faster cooling, and lower storage temperature.

In many RSW systems, refrigeration is provided by ammonia flowing through external chillers (which gives the best results) or pipe coils in the tanks.

Boxing at Sea

There are many advantages to using containers or boxes instead of bulk storage aboard fishing vessels. Using containers reduces pressure on fish stowed in a vessel's hold. Because significant reductions in handling during and after unloading are possible, mechanical damage and product temperature rise may be virtually eliminated, and handling costs may be reduced. Fish can be sorted into boxes by size and species as soon as they are caught. Boxed fish lend themselves more readily to mechanized handling, such as machine filleting, because they are generally firmer and of more uniform shape; fillet yields are generally better than they are with bulk-stored fish.

Boxing at sea is not generally practiced in the United States, except by some inshore vessels. The principal problems with converting a fishing vessel from bulk to boxed storage are increased labor required by the crew for handling the boxes, reduced hold capacity, and relatively large investment for boxes. Many fisheries have difficulties working out the logistics for ensuring prompt return of properly cleaned boxes to the vessel. Most of these problems have been solved in European, Canadian (offshore), and South American (hake) fleets. Using nonreturnable containers for boxing at sea simplifies logistics and reduces initial capital outlay; it has proved justifiable in some U.S. fisheries.

Reusable containers for boxing at sea are usually made of plastic. Careful icing is necessary to minimize the surface area of fish in contact with the box. Plastic provides more heat transfer resistance than aluminum in vessels with uninsulated fish holds and for in-plant storage prior to processing.

All fish boxes must be equipped with drains, preferably directed outside the boxes on the bottom of a stack.

SHORE PLANT PROCEDURE AND MARKETING

Proper use of ice and adherence to good sanitary practices ensure maintenance of iced fish freshness during unloading from the vessel, at the shore plant, during processing, and throughout the distribution chain. Fish landed in good quality spoil rapidly if these practices are not carried out.

Table 1 Organoleptic Quality Criteria for Fish

Factor	Good Quality	Poor Quality
Eyes	Bright, transparent, often protruding	Cloudy, often pink, sunken
Odor	Sweet, fishy, similar to seaweed	Stale, sour, presence of sulfides, amines
Color	Bright, characteristic of species, sometimes pearlescent at correct light angles	Faded, dull
Texture	Firm, may be in rigor, elastic to finger pressure	Soft, flabby, little resilience, presence of fluid
Belly	Walls intact, vent pink, normal shape	Often ruptured, bloated, vent brown, protruding
Organs (including gills)	Intact, bright, easily recognizable	Soft to liquid, gray homogeneous mass
Muscle tissue	White or characteristic of species and type	White flesh pink to gray, spreading of blood color around backbone

Fish unloaded from the vessel are usually graded by the buyer for species, size, and minimum quality specification. A price is based in part on the quality in relation to market requirements. Fish also may be inspected by local and federal regulatory agencies for wholesomeness and sanitary condition. Organoleptic criteria are most important for evaluating quality; however, there is a growing acceptance, particularly in Canada and some European countries, of objective chemical and physical tests as indexes of quality loss or spoilage. Organoleptic (sensory) quality criteria vary somewhat among species, but the information in Table 1 can be used as a general guide in judging the quality of whole fish.

In New England and the Canadian Atlantic provinces, groundfish may be placed in boxes and trucked to the shore plant or conveyed directly from the hold or deck to the shore plant. Single- or double-wall insulated boxes are normally used; wooden boxes are rarely used because they are a source of microbiological contamination. Ice should be applied generously to each box of fish, even if the period before processing is only a few hours. Fish awaiting processing for more than a few hours should be iced heavily and stored in insulated containers or in single-wall boxes in a chill room refrigerated to 35°F. If refrigerated facilities are not available, boxes of fish should be kept in a cool section of the plant that is clean and sanitary and has adequate drainage.

Large boxes of resin-coated plywood or reinforced fiberglass that hold up to 1000 lb of fish and ice are used by some plants in preference to icing fish overnight on the floor. These **tote boxes** are moved and stacked by forklift, can be used for trucking fish to other plants, and make better use of plant floor space. Generally, fish awaiting processing should not be kept longer than overnight.

Fresh fish are marketed in different forms: fillets, whole fish, dressed-head on, dressed-headed (head removed), and, in some instances, steaks. The method of preparing fish for marketing depends largely on the species of fish and on consumer preference. For example, groundfish such as cod and haddock are usually marketed as fillets or as dressed-headed fish. Freshwater fish such as catfish and bullheads are usually dressed and skinned; lake trout are not skinned, but are merely dressed; and lake herring are marketed in dressed, round, or filleted form.

PACKAGING FRESH FISH

Most fresh fish is packaged in institutional containers of 5 to 35 lb capacity at the point of processing. Polyethylene trays, steel cans, aluminum trays, plastic-coated solid boxes, wax-impregnated corrugated fiberboard boxes, foamed polystyrene boxes, and polyethylene bags are used.

Fresh fish is often packaged while it still contains process heat from wash water. In these cases, it is advantageous to use a packaging material that is a good heat conductor. The fresh fish industry makes little use of controlled prechilling equipment in packaging. As a result, product temperatures may never reach the optimum level after packaging. Traditionally, institutional fresh fish travels packed in wet ice; in this case, it may cool to the proper level in transit even if process heat is initially present. However, there is a trend toward using leaktight shipping containers for fresh fish because modern transportation equipment is not designed to handle wet shipments. Also, some customers want to avoid the cost of transporting ice yet demand a product that is uniformly chilled to 32 to 36°F when it reaches their door. Shippers who use leaktight shipping containers have to upgrade their product temperature control systems to ensure that the fish reaches ice temperature before packaging. Rapid prechilling systems that result in crust freezing can be applied to some fresh seafood products, but this practice must be used with discretion because partial freezing harms quality.

Some general requirements for institutional containers that hold products such as fillets, steaks, and shucked shellfish are (1) sufficient rigidity to prevent pressure on the product, even when containers are stacked or heavily covered with ice; and (2) measures to prevent ice-melt water from contaminating the product. Some containers have drains to allow drip from the fish itself to run off. Others are sealed and may be gastight, which increases shelf life. One problem associated with sealed containers is a strong odor when the package is first opened. Although this odor may be foul, it soon dissipates and has no adverse effect on quality. Dressed or whole fish may be placed in direct contact with ice in a gastight container.

Leaktight shipping containers are used with nonrefrigerated transportation systems, such as air freight, and consequently require insulation. Foamed polystyrene is particularly suitable. For typical air freight shipments, the most economical thickness of insulation is between 1 and 2 in. To maintain product temperature in transit, shippers use either dry ice, packaged wet ice, packaged gel refrigerant, or wet ice with absorbent padding in the bottom of the container. Foamed polystyrene containers may be of molded construction or of the composite type, in which foam inserts and a plastic liner are used with a corrugated fiberboard box.

At the retail level, fresh fish may be handled in two ways. Stores with service counters display fish in unpackaged form. However, markets without service counters sometimes package fish before displaying for sale. Both types of outlets receive product in institutional containers. If fish is prepackaged at the market, labor and packaging costs may be high, and product temperature is likely to rise. Often, relatively warm fish is placed in a foam tray, wrapped, and displayed in a meat case at 40°F or more. This drastically reduces shelf life of the fish. Centralized prepackaging at the point of initial processing appears to have many important advantages over the present system. A number of retail chains have suppliers prepackage product under controlled temperature and sanitary conditions.

FRESH FISH STORAGE

The maximum storage life of fish varies with the species. In general, the storage life of East and West Coast fish, properly iced and stored in refrigerated rooms at 35°F, is 10 to 15 days, depending on its condition when unloaded from the boat. Generally, freshwater fish properly iced in boxes and stored in refrigerated rooms may be held for only 7 days. Both of these time limitations refer to the period between landing/processing and consumption.

Table 2 Optimal Radiation Dose Levels and Shelf Life at 33°F for Some Species of Fish and Shellfish

Species	Optimal Radiation Dose, Rads Air Packed	Shelf Life, Weeks
Oysters, shucked, raw	200,000	3 to 4
Shrimp	150,000	4
Smoked chub	100,000	6
Yellow perch	300,000	4
Petrale sole	200,000	2 to 3 (4 to 5 when vac pac)
Pacific halibut	200,000	2 (4 when vac pac)
King crabmeat	200,000	4 to 6
Dungeness crabmeat	200,000	3 to 6
English sole	200,000 to 300,000	4 to 5
Soft-shell clam meat	450,000	4
Haddock	150,000 to 250,000	3 to 4
Pollock	150,000	4
Cod	150,000	4 to 5
Ocean perch	250,000	4
Mackerel	250,000	4 to 5
Lobster meat	150,000	4

Cold-storage facilities for fresh fish should be maintained at about 35°F with over 90% rh. Air velocity should be limited to control ice loss. Temperatures less than 32°F retard ice melting and can result in excessive fish temperatures. This is particularly important when storing round fish such as herring, which generate heat from autolytic processes.

Floors should have adequate drainage with ample slopes toward drains. All inside surfaces of a cold storage room should be easy to clean and able to withstand corrosive effects of frequent washings with antimicrobial compounds.

Irradiation of Fresh Seafood

Ionizing radiation can double or triple the normal shelf life of refrigerated, unfrozen fish and shellfish stored at 33°F (Table 2). No off-odors, adverse nutritional effects, or other changes are imparted to the product by the radiation treatment. However, irradiation of fish is still not common and is not permitted in some jurisdictions.

Modified-Atmosphere (MA) Packaging

A product environment with modified levels of nitrogen, CO_2, and oxygen can curtail bacterial growth and extend shelf life of fresh fish. For example, whole haddock stored in a 25% CO_2 atmosphere from the time it is caught keeps about twice as long as it would in air. However, a modified atmosphere does not inhibit all microbes, and spoilage bacteria, because of their great number, usually restrict growth of the few pathogenic bacteria present. Traditionally, the obvious signs of spoilage serve as the safeguard against eating fish that may have dangerous levels of pathogenic bacteria.

Because modified-atmosphere packaging can be a safety hazard, it is being introduced slowly in several countries under close monitoring by regulatory agencies. This type of packaging requires complete knowledge of regulations and a good control system that maintains proper temperature and sanitation levels.

FROZEN FISHERY PRODUCTS

The production of frozen fishery products varies with geographical location and includes primarily the production of groundfish fillets, scallops, breaded precooked fish sticks, breaded raw fish portions, fish roe, and bait and animal food in northeastern states and in Atlantic Canada; round or dressed halibut and salmon, halibut and salmon steaks, groundfish fillets, surimi, herring roe, and bait and animal food in northwestern states and in British Columbia; halibut, groundfish fillets, crab, salmon, and surimi in Alaska (salmon roe in Alaska is called “ikura”); shrimp, oysters, crabs, and other shellfish and crustaceans in the Gulf of Mexico and southern Atlantic states; and round or dressed fish in the areas bordering on the Great Lakes.

Fish from these areas differ considerably in both physical and chemical composition. For example, cod or haddock are readily adaptable to freezing and have a comparatively long storage life, but other fatty species, such as mackerel, tend to become rancid during frozen storage and therefore have a relatively short storage life. The differences in composition and marketing requirements of many species of fish require consideration of the specific product’s quality maintenance and methods of packaging, freezing, cold storage, and handling.

Temperature is the most important factor limiting the storage life of frozen fish. Below freezing, bacterial activity as a cause of spoilage is limited. However, even fish frozen within a few hours of catching and stored at –20°F very slowly deteriorates until it becomes unattractive and unpleasant to eat.

Fish proteins are permanently altered during freezing and cold storage. This denaturation occurs quickly at temperatures not far below freezing; even at 0°F, fish deteriorates rapidly. Badly stored fish is easily recognized: the thawed product is opaque, white, and dull, and juice is easily squeezed from it. Although properly stored product is firm and elastic, poorly stored fish is spongy, and in very bad cases, the flesh breaks up. Instead of the succulent curdiness of cooked fresh fish, cooked denatured samples have a wet and sloppy consistency at first and, on further chewing, become dry and fibrous.

Other factors that determine how quickly quality deteriorates in cold storage are initial quality and composition of the fish, protection of the fish from dehydration, freezing method, and environment during storage and transport. These factors are reflected in four principal phases of frozen fish production and handling: packaging, freezing, cold storage, and transportation.

Today, many species are brought from warm and tropical waters where parasites and toxins could infect them. In addition, food dishes that use raw seafood, such as sushi and sashimi, have gained wide popularity, making them a potential health risk. Parasites are not life-threatening but can cause pain and inconvenience. They are easily destroyed by cooking or by deep freezing (–40°F). Marine toxins could be deadly and are not affected by temperature. Susceptible species should not be eaten during periods when toxins could be developed.

PACKAGING

Materials for packaging frozen fish are similar to those for other frozen foods. A package should (1) be attractive and appeal to the consumer, (2) protect the product, (3) allow rapid, efficient freezing and easy handling, and (4) be cost-effective.

Package Considerations in Freezing

Refrigeration equipment and packaging materials are frequently purchased without considering the effect of package size on freezing rate and efficiency. For example, a thin consumer package has a faster rate of product freezing, lower total freezing cost, higher handling cost, and higher packaging material cost; a thicker institutional-type package has the opposite qualities.

Tests indicate that the time required to freeze packaged fish fillets in a plate freezer is directly proportional to the square of the package thickness. Thus, if it takes 3 h to freeze packaged fish fillets 2 in. thick, it takes about 4.7 h to freeze packaged fish fillets 2.5 in. thick. Insulating effects of packaging material, fit of the product in the package, and total package surface area must be considered. A packing material with low moisture-vapor permeability has an insulating effect, which increases freezing time and cost.

The rate of heat transfer through packaging is inversely proportional to its thickness; therefore, packaging material should be (1) thin enough to produce rapid freezing and an adequate moisture-vapor barrier in frozen storage and (2) thick enough to withstand heavy abuse. Aluminum foil cartons and packages offer an advantage in this regard.

Proper fit of package to product is essential; otherwise, the insulating effect of the air space formed reduces the product's freezing rate and increases freezing cost. The surface area of the package is also important because of its relation to the size of the freezer shelves or plates. Maximum use of freezer space can be obtained by designing the package so that it fits the freezer properly. Often, however, these factors cannot be changed and still meet customer requirements for a specific package.

Package Considerations for Frozen Storage

Fish products lose considerable moisture and become tough and fibrous during frozen storage unless a package with low moisture-vapor permeability is specified. The package in contact with the product must also be resistant to oils or moisture exuded from the product, or the oils will go rancid and the package material will soften. The package must fit the product tightly to minimize air spaces and thereby reduce moisture migration from the product to the inside surfaces of the package.

Unless temperatures are very low or special packaging is used, fish oils oxidize in frozen storage, producing an off-flavor. One effective approach is to replace the air surrounding the frozen fish with pure nitrogen and seal the fish in a leak-proof bag made of an oxygen-impervious material.

Types of Packages

Packaging consists of either paperboard cartons coated with various waterproofing materials or cartons laminated with moisture-vapor-resistant films and heat-sealable overwrapping materials with a low moisture-vapor permeability. Paperboard cartons are usually made of a bleached kraft stock, coated with a suitable fortified wax, polyethylene, or other plastic material.

Overwrapping materials should be highly resistant to moisture transmission, inexpensive, heat sealable, adaptable to machinery application, and attractive in appearance. Various types of hot-melt-coated waxed paper, cellophane, polyethylene, and aluminum foil are available in different forms and laminate combinations to best suit each product.

Consumer Packages. These usually hold less than 1 lb and are generally printed, bleached paperboard coated with wax or polyethylene and closed with adhesive. Fish sticks and portions, shrimp, scallops, crabmeat, and precooked dinners and entrees are packaged in this way. For dinners and entrees, rigid plastic, pressboard, or aluminum trays are used inside the printed paperboard package. Rigid plastic or pressboard packages are more common because they are better for microwave cooking. Packaging these products is normally mechanized.

Materials such as polyethylene combined with cellophane, polyvinylidene chloride, or polyester and combinations of other plastic materials are used with high-speed automatic packaging machines to package shrimp, dressed fish, fish fillets, fish portions, and fish steaks before freezing. In some instances, wrapping material has been torn by fins protruding from the fish, but otherwise, this method of packaging is satisfactory and offers considerable protection against dehydration and rancidity at a comparatively low cost. This packaging method has also created new markets for merchandising frozen fish products. Boil-in-bag pouches made of polyester-polyethylene and combinations of foil, polyethylene, and paper are used for packaging shrimp, fish fillets, and entrees. These packages are also suitable for microwave cooking.

Institutional Packages. The 5 lb and larger cartons used in the institutional trade are commonly constructed of bleached paperboard that has been waxed or polyethylene coated. Folding cartons with self-locking covers, full-telescoping covers, or glued closures are used. Often, cartons are packaged inside a corrugated master carton or are shrink-wrapped in polyethylene film.

Products such as fish fillets and steaks are individually wrapped in cellophane or another moisture-vapor-resistant film and then packed in the carton. Fish, such as headed and dressed whiting and scallop meats, are packed into the carton and covered with a sheet of cellophane. The cover is then put in place and the package is frozen upside down in the freezer. Raw, unbreaded products, such as shrimp, scallops, fillets, and steaks, are sometimes individually quick frozen (IQF) before packaging. IQF products can be glazed to enhance moisture retention. This method is preferred over freezing after packaging because it leads to a product that is more convenient to handle and sometimes obviates the need to thaw the fish before cooking.

For institutional frozen fish, the trend is toward printed paperboard folding cartons coated with moisture-vapor-resistant materials instead of waxed paper or cellophane overwrap, though "shatter pack" bulk is also common. Some frozen fish products and seafood entrees for institutional markets are packaged in aluminum or rigid plastic trays so they may be heated within the package.

FREEZING METHODS

Product characteristics, such as size and shape, freezing method, and rate of freezing, affect quality, appearance, and production cost.

Quick freezing offers the following advantages:

- Chills the product rapidly, preventing bacterial spoilage
- Facilitates rapid handling of large quantities of product
- Makes use of conveyors and automatic devices practical, thus materially reducing handling costs
- Promotes maximum use of the space occupied by the freezer
- Produces a packaged product of uniform appearance, with a minimum of voids or bulges

For further information, see Chapters 9, 10, and 16.

Blast Freezing

Blast freezers for fishery products are generally small rooms or tunnels in which cold air is circulated by one or more fans over an evaporator and around the product to be frozen, which is on racks or shelves. A refrigerant such as ammonia, a halocarbon, or brine flowing through a pipe coil evaporator furnishes the necessary refrigeration effect.

Static pressure in these rooms is considerable, and air velocities average between 500 and 1500 fpm, with 1200 fpm being common. Air velocities between 500 and 1000 fpm give the most economical freezing. Lower air velocities slow down product freezing, and higher velocities increase unit freezing costs considerably.

Some factories have blast freezers in which conveyors move fish continuously through a blast room or tunnel. These freezers are built in several configurations, including (1) a single pass through the tunnel, (2) multiple passes, (3) spiral belts, and (4) moving trays or carpets. The configuration and type of conveyor belt or freezing surface depend on the type and quantity of product to be frozen, space available to install the equipment, and capital and operating costs of the freezer.

Batch-loaded blast freezers are used for freezing shrimp, fish fillets, steaks, scallops, and breaded precooked products in institutional packages; round, dressed, and panned fish; and shrimp, clams, oysters, and salmon roe (ikura) packed in metal cans.

Conveyor blast freezers are widely used to freeze products before packaging. These products include all types of breaded, precooked seafoods; IQF fillets, loins, tails, steaks, scallops, and shrimp; and raw, breaded fish portions. In the case of portions, which are sliced or sawed from blocks, the function of the blast freezer is to harden the batter and breading before packaging and lower the temperature of the frozen fish for storage if it has been tempered for slicing.

Dehydration of product (freezer burn) may occur in freezing unpackaged whole or dressed fish in blast freezers unless the air velocity is kept to about 500 fpm and the period of exposure to the air is controlled. Consumer packages of fish fillets or fish-fillet blocks requiring close dimensional tolerances bulge and distort during freezing unless restrained. In blast rooms or tunnels, product can be frozen on specially designed trucks, enabling distribution of pressure on the surfaces of the package and remedying this condition. It is difficult to control product expansion on conveyor installations.

Freezing times for various sizes of packaged fishery products are shown in Figure 2.

Plate Freezing

In the multiplate freezer, refrigerant flows through connected passageways in horizontal movable plates stacked vertically in an insulated cabinet or room. The plate freezer is used extensively in freezing fishery products in consumer cartons and in 5 and 10 lb institutional cartons. Fish to be plate frozen should be properly packaged to minimize air spaces. Spacers should be used between the plates during freezing to prevent crushing or bulging of the package. For most products, spacer thickness should be about 0.03 to 0.06 in. less than that of the package.

Where very close package tolerances are required, as in the manufacture of fish fillet blocks, a metal frame or tray is used to hold packages during freezing. The frame or tray is generally the same width as the package and the length of one or two blocks. It must be rigid enough to prevent bulging and to hold the fish block's dimensions. This is sometimes done with rigid spacers that limit the tray's weight and cost.

Fish blocks are available in two common sizes: 16.5 lb (19 by 10 by 2.5 in.) and 18.5 lb (19 by 11.5 by 2.5 in.). Other blocks are sized for special applications. Fish can be packed in the block with the long dimension of the fillets along the length of the frame (long-pack) or along the width of the frame (cross-pack). The orientation depends on the eventual cutting pattern and type of cutting used to convert the block into a finished product.

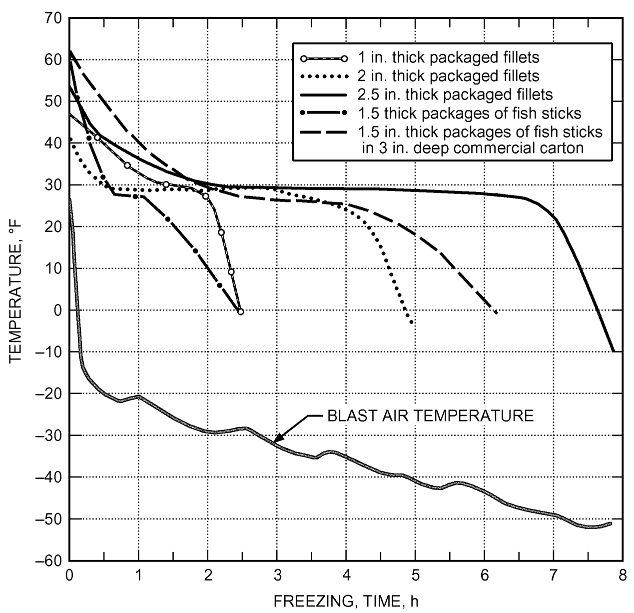

Fig. 2 Freezing Time of Fish Fillets and Fish Sticks in Tunnel Blast Freezer
Air Velocity 500 to 1000 fpm

A tray is not necessary for other packaged seafoods, such as shrimp, fillets, fish sticks, or scallops, where close package tolerances are not as essential. Therefore, an automatic continuous plate freezer with properly sized spacers is satisfactory for these products.

Plate freezers provide rapid and efficient freezing of packaged fish products. The freezing time and energy required for freezing packaged fish sticks is greater than that for fish fillets because heat transfer is slowed by the air space within the package. Energy required to freeze a unit mass of product increases with thickness. The freezing times of consumer and institutional size packages of fish fillets and fish sticks are shown in Figure 3.

Immersion Freezing

Immersion in low-temperature brine was one of the first methods used for quick-freezing fishery products. Numerous direct-immersion freezing machines were developed for whole or panned fish. These machines were generally unsuitable for packaged fish products, which make up the bulk of frozen fish production, and have been replaced by methods using air cooling, contact with refrigerated plates or shelves, and combinations of these methods.

Immersion freezing is used primarily for freezing tuna at sea and, to a lesser extent, for shrimp, salmon, and Dungeness crab, as well as king crab and Alaska snow crab (*C. opelio*). Extensive research has been conducted on brine freezing of groundfish aboard vessels, but this method is not in commercial use.

An important consideration is selection of a suitable freezing medium. The medium should be nontoxic, acceptable to public health regulatory agencies, easy to renew, and inexpensive; it should also have a low freezing temperature and viscosity. It is difficult to obtain a freezing medium that meets all these requirements. Sodium chloride brine and a mixture of glucose and salt in water are acceptable media. The glucose reduces salt penetration into the fish and provides a protective glaze.

Liquid nitrogen spray and CO_2 are coming into wider use for IQF seafood products such as shrimp. Although the cost per unit mass is high, fish frozen by these methods is of good quality, there is virtually no weight loss from dehydration, and there are space and equipment

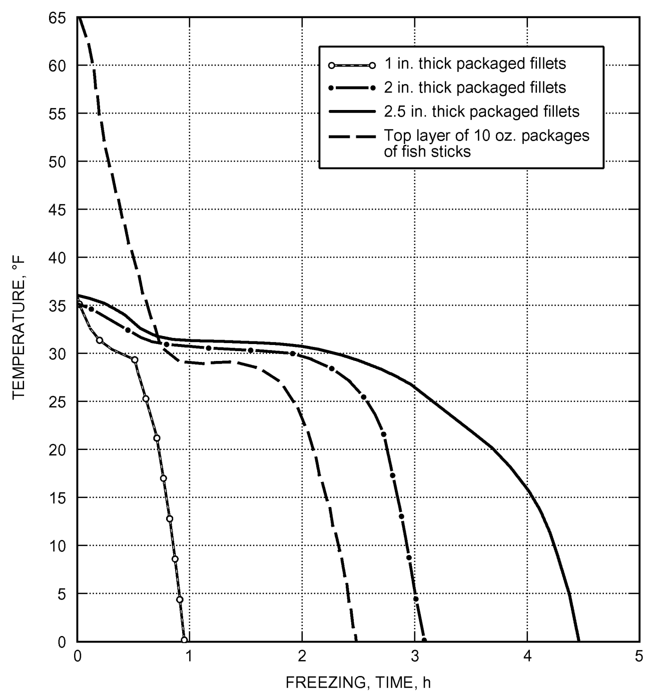

Fig. 3 Freezing Time of Fish Fillets and Fish Sticks in Plate Freezer

savings. Fish should not be directly immersed in the liquid nitrogen, because this will cause the flesh to shatter and rupture.

Immersion Freezing of Tuna. Most tuna harvested by the U.S. fleet is brine-frozen aboard the fishing vessel. Freezing at sea enables the vessel to make extended voyages and return to port with a full payload of high-quality fish.

Tuna are frozen in brine wells, which are lined with galvanized pipe coils on the inside. Direct expansion of ammonia into the evaporator coils provides the refrigeration effect. Wells are designed so that tuna can be precooled and washed with refrigerated seawater and then frozen in an added sodium chloride brine. After the fish are frozen, the brine is pumped overboard, and the tuna are kept in 10°F dry storage. Before unloading, the fish are thawed in 30°F brine. In some cases, the fish are thawed in tanks at the cannery. If the fish are thawed ashore, thawing on the vessel is not required beyond the stage needed to separate those fused together in the vessel's wells.

Sometimes tuna are held in the wells for a long time before freezing or are frozen very slowly because of high well temperatures caused by overloading, insufficient refrigeration capacity, or inadequate brine circulation. These practices have a detrimental effect on product quality, especially for smaller fish, which are more subject to salt penetration and quality changes. Tuna that are not promptly and properly frozen may undergo excessive changes, absorb excessive quantities of salt, and possibly be bacteriologically spoiled when landed. Some freezing times for tuna of various sizes are shown in Figure 4.

Specialized Contact Freezers. Fish frozen by this method are placed on a solid stainless steel belt that slowly moves the fillets through a tunnel, where they are frozen not only by air blast but also by direct contact between the conveyor belt and a thin layer of glycol pumped through the plates that support the belt. A refrigerant, such as ammonia or a halocarbon, also flows through separate channels in the plates. This provides the refrigeration effect with minimal temperature difference between the evaporating refrigerant and the product.

Freezing Fish at Sea

Freezing fish at sea has found increasing commercial application in leading fishery nations such as Japan, Russia, the United Kingdom, Norway, Spain, Portugal, Poland, Iceland, and the United States. Including freezer trawlers, factory ships, and refrigerated transports in fisheries, hundreds of large freezer vessels operate throughout the world. U.S. factory-freezer trawlers, factory surimi trawlers, and floating factory ships supplied by catcher vessels operate off Alaska, mainly processing Alaskan pollock, cod, and flounder.

Freezing groundfish at sea is uncommon in the northeastern United States, largely because fresh fish commands a better price than frozen fish. For the same reason, East Coast U.S. producers avoid putting their product into frozen packs if they can sell it fresh. Hence, much of the frozen fish used in the United States (except Alaskan fish) is imported.

Factory vessels are equipped to catch, process, and freeze fish at sea and to use the waste material to manufacture fish meal and oil. A large European factory vessel measures 280 ft in length, displaces 3700 tons, and is equipped to stay at sea for about 80 days without being refueled. About 65 to 100 people are required to operate the vessel and to process and handle the fish. Most vessels of this type use contact-plate freezers. The freezers can freeze about 30 tons of fish per day, and the total capacity of the frozen fish hold may be as high as 750 tons.

Because the factory trawler stays at sea for long periods, it can fully use its space for storing fish. However, because of limited available labor, frozen packs are generally of the less labor-intensive types.

The freezer trawler was designed to resolve the disadvantages associated with factory freezer vessels. It is smaller and equipped to freeze fish in bulk for later thawing and processing ashore. Freezer trawlers use vertical plate freezers to freeze dressed fish in blocks of about 100 lb.

Some countries use freezer trawlers to supply raw material to shore-based processing plants producing frozen fish products. This allows the trawlers to fill their holds in distant waters and transport the fish to home base, where it becomes frozen raw material that is held in storage until required for processing. In some cases, trawlers have been designed as dual fisheries, fishing and freezing groundfish blocks during part of the year and catching, processing, and freezing Northern shrimp for the rest of the year.

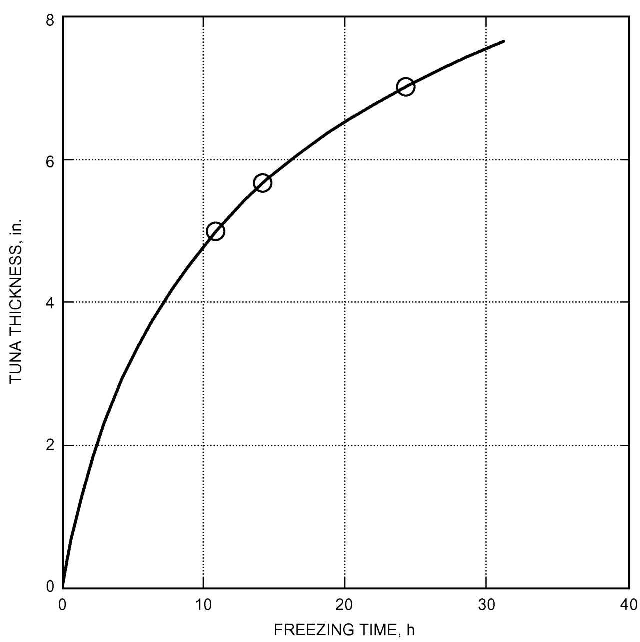

Fig. 4 Freezing Time for Tuna Immersed in Brine

STORAGE OF FROZEN FISH

Fishery products may undergo undesirable changes in flavor, odor, appearance, and texture during frozen storage. These changes are attributable to dehydration (moisture loss) of the fish, oxidation of oils or pigments, and enzyme activity in the flesh. The rate at which these changes occur depends on the (1) composition of the species of fish, (2) level and constancy of storage room temperature and humidity, and (3) protection offered by suitable packaging materials and glazing compounds.

Composition

The composition of a particular species of fish affects its frozen storage life considerably. Fish with high oil content, such as some species of salmon, tuna, mackerel, and herring, have a comparatively short frozen storage life because of rancidity that results from oxidation of oils and pigments in the flesh. Certain fish, such as sablefish, are quite resistant to oxidative deterioration in frozen storage, despite their high oil content. Rancidity development is less pronounced in fish with a low oil content. Therefore, lean fish such as haddock and cod, if handled properly, can be kept in frozen storage for many months without serious loss of quality. The relative susceptibility of various species of fish to oxidative changes during frozen storage is shown in Table 3.

Storage Conditions

Temperature. Quality loss of frozen fish in storage depends primarily on temperature and duration of storage. Fish stored at –20°F has a shelf life of more than a year. In Canada, the Department of Fisheries recommends a storage temperature of –15°F or lower. Storage above –10°F, even for a short period, results in rapid loss of quality. Time/temperature tolerance studies show that frozen seafoods have memory; that is, each time they are subjected to high temperatures or poor handling practices, the loss in quality is recorded. When the product is finally thawed, the total effect of each mistreatment is reflected in product quality at the consumer level. Continuous storage at temperatures lower than –15°F reduces oxidation, dehydration, and enzymatic changes, resulting in longer product shelf life. From the time they are frozen until they reach the consumer, frozen seafoods should be kept as close to –15°F as possible. The shelf life of frozen fish products stored at different temperatures is given in Table 4. Note the increase in shelf life at the lowest temperatures.

For many years, it was thought too costly to operate refrigerated warehouses below –10°F. However, improvements in design and operation of refrigeration equipment have made such temperatures economically possible. Surimi production by West Coast-based factory ships has led to construction of ultracold storage rooms. Japanese standards call for this product to be kept at –22°F.

Table 3 Relative Susceptibility of Representative Species of Fish to Oxidative Changes in Frozen Storage

Severe	Moderate	Minor	Very Slight
Pink salmon	Chum salmon	Cod	Yellow pike
Rockfish	Coho salmon	Haddock	Yellow perch
Lake chub	King salmon	Flounder	Crab
Whiting	Halibut	Sole	Lobster
Red salmon	Ocean perch	Sablefish	
	Herring	Oysters	
	Mackerel		
	Tuna		
	Lake herring		
	Sheepshead		
	Lake trout		

Table 4 Effect of Storage Temperature on Shelf Life of Frozen Fishery Products

Product	Temperature, °F	Shelf Life, Months
Packaged haddock fillets	10	4 to 5
	0	11 to 12
	–20	Longer than 12
Packaged cod fillets	10	5
	0	6
	–10	10 to 11
Packaged pollock fillets*	20	1
	10	2
	0	8
	–10	11
	–20	24
Packaged ocean perch fillets	15	1.5 to 2
	10	3.5 to 4
	0	6 to 8
	–10	9 to 10
Packaged striped bass fillets	15	4
	0	9
Glazed whole halibut	10	3
	0	6
	–10	9
	–20	12
Whole bluefin tuna	10	4
	0 to –5	8
	–20	12
Glazed whole herring	0	6
	–17	9
Packaged mackerel fillets	15	2
	0	3
	–10	3 to 5

*Prepared from 1 day old iced fish.

Humidity. High relative humidity in cold-storage rooms tends to reduce evaporation of moisture from the product. The relative humidity of air in the refrigerated room is directly affected by the temperature difference between room cooling coils and room temperature. A large temperature difference decreases relative humidity and accelerates the rate of moisture withdrawal from the frozen product; a small temperature difference has the opposite effect.

Relative humidity in commercial cold storages is 10 to 20% higher than that of an empty cold storage because of constant evaporation of moisture from the product. In a cold storage operating at 0°F, with 70% rh and pipe coil temperature of –10°F, the moisture-vapor pressure of air in the package (in direct contact with the frozen fish) is 0.0185 psia; air in the cold storage is at a vapor pressure of 0.0132 psia, and the moisture-vapor pressure at the coils is 0.0108 psia. These differences in moisture-vapor pressure result in considerable product moisture loss unless it is adequately protected by suitable packaging materials or glazing compounds. The evaporator coils in the freezer should be sized properly so that the desired high relative humidities can be obtained. However, because of material costs and space limitations, a temperature difference of 10°F between evaporator coils and room air is the most practical.

Packaging and Glazing

Adequate packaging of fishery products is important in preventing product dehydration and consequent quality loss, as discussed in the Packaging section under Frozen Fishery Products. Individual fish, whether frozen in the round or dressed, cannot usually be suitably packaged; therefore, they must be protected by a glazing compound.

A glaze acts as a protective coating against the two main causes of deterioration during storage: dehydration and oxidation. It protects against dehydration by preventing moisture from leaving the product and against oxidation by mechanically preventing air contact with the product. It may also minimize these changes chemically with an antioxidant.

Storage life of fishery products can be maximized by using the following procedures:

- Select only high-quality fish for freezing.
- Use moisture-vapor-resistant packaging materials and fit package tightly around product, or use a modified atmosphere and oxygen-barrier package.
- Freeze fish immediately after processing or packaging.
- Glaze frozen fish before packaging.
- Glaze round, unpackaged fish before cold storage.
- Put fish in frozen storage immediately after freezing and glazing, if required.
- Store frozen fish at –15°F or lower.
- Renew glaze on round, unpackaged fish as required during frozen storage.

The recommended protection and expected storage life for various species of fish at 0°F are shown in Table 5.

Space Requirements

Packaged products such as fillets and steaks are usually packed in cardboard master cartons for storage and shipment. These master cartons are stacked on pallets and transferred to various areas of the cold-storage room by forklift. Master cartons are strong enough to support one or two pallet loads placed on the shelf of each rack in cold storage. In cold storages without racks, cartons should be stacked to a height that does not crush the bottom cartons. Cartons for products in packages that contain a lot of air, such as IQF fillets,

Table 5 Storage Conditions and Storage Life of Frozen Fish

Fish	Recommended Protection*	Storage Life (0°F), Months
Chub, pink salmon	Ice glazing and packaging	4 to 6
Mackerel, sea herring, pollock, chub, smelts	Ice glazing and packaging	5 to 9
Pacific sardines, tuna	Packaging	4 to 6
Buffalofish, flounder, halibut, ocean perch, rockfish, sablefish, red, sockeye, silver or coho salmon, whiting, shrimp	Packaging	7 to 12
Haddock, blue pike, cod, hake, lingcod	Packaging	Over 12

*All packaging should be with moisture-resistant films.

Table 6 Space Requirements for Frozen Fishery Products

Commodity	Product Package	Container for Storage	Space Required, lb/ft^3
Fish sticks, breaded shrimp, breaded scallops	8 or 10 oz	Corrugated master containers	25 to 30
Fillets, steaks, small dressed fish	1, 5, or 10 lb	Corrugated master containers	50 to 60
Shrimp	2.5 and 5 lb	Corrugated master containers	35
Panned, frozen fish (mackerel, herring, chub)	None	Wooden or fiberboard boxes	35
Round halibut	None	Wooden box	30 to 35
		Stacked loose	38
Round groundfish (cod, etc.)	None	Stacked loose	32
Round salmon	None	Stacked loose	33 to 35

must be stronger than those for solid packages of fish to resist crushing during storage.

Whole or dressed fish frozen in blocks in metal pans, such as mackerel, chub, or whiting, are removed from the pans after freezing, glazed, and then packaged in wooden boxes lined with wax-impregnated paper or in cardboard cartons.

Round fish stored in wooden boxes can be easily reglazed periodically during frozen storage. Space requirements for storing fishery products are shown in Table 6.

Thawing Frozen Fish. Frozen fishery products can be thawed by circulating air or water. Thawing fish should not be allowed to rise above refrigerated temperatures; otherwise, rapid deterioration may occur. Thawing is slower and more difficult than freezing when done to ensure quality maintenance. Each application should be carefully designed.

TRANSPORTATION AND MARKETING

Temperature and humidity conditions recommended for frozen storage should also be applied during transportation and marketing to minimize product quality loss. Shipment in nonrefrigerated or improperly refrigerated carriers, exposure to high ambient temperatures during transfer from one environment to another, improper loading of common carriers or display cases, equipment failure, and other poor practices lead to increased product temperature and, consequently, to quality loss.

Frozen fish is transported under mechanical refrigeration in trucks, railroad cars, or ships. Most of these vehicles can maintain temperatures of 0°F or lower. Additional information on equipment used in the transportation and marketing of frozen fish and other foods is given in Chapters 11, 13, 14, 30, 31, 32, and 46 of this volume and in Chapter 28 of the 1994 *ASHRAE Handbook—Refrigeration*.

To minimize quality loss during transportation and marketing, use the following procedures:

1. Transport frozen fish in refrigerated carriers (mechanical or dry ice systems) with ample capacity to maintain 0°F over long distances.
2. Precool refrigerated carriers to at least 10°F before loading.
3. Remove frozen products from the warehouse only when the carrier is ready to be loaded. Load directly into the refrigerated carrier; do not allow product to sit on the dock.
4. Check fish temperature with a thermometer before loading.
5. Do not stack frozen fish directly against floors or walls of the carrier. Provide floor and wall racks or strips to allow air circulation around the entire load.
6. Continuously record the refrigerated carrier temperature during transit. Use an alarm to warn of equipment failure.
7. Measure product temperature when it is removed from the common carrier at its destination.
8. If products are shipped in an insulated container, apply sufficient dry ice to maintain temperatures of 0°F or lower for the duration of the trip.
9. Maintain food delivery or breakup rooms at 0 to 10°F. Do not hold products in breakup rooms any longer than necessary.
10. When received at the retail store, place the product in a 0°F storage room immediately.
11. Hold display cases in retail stores at 0°F or lower.
12. Do not overload display cases, especially above the frost line.
13. Record display case temperature. Provide an alarm to warn of an excessive rise in temperature.
14. Because of the accelerated deterioration of frozen fish products in the distribution and retail chain, hold products in these areas for as short a period as possible.

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