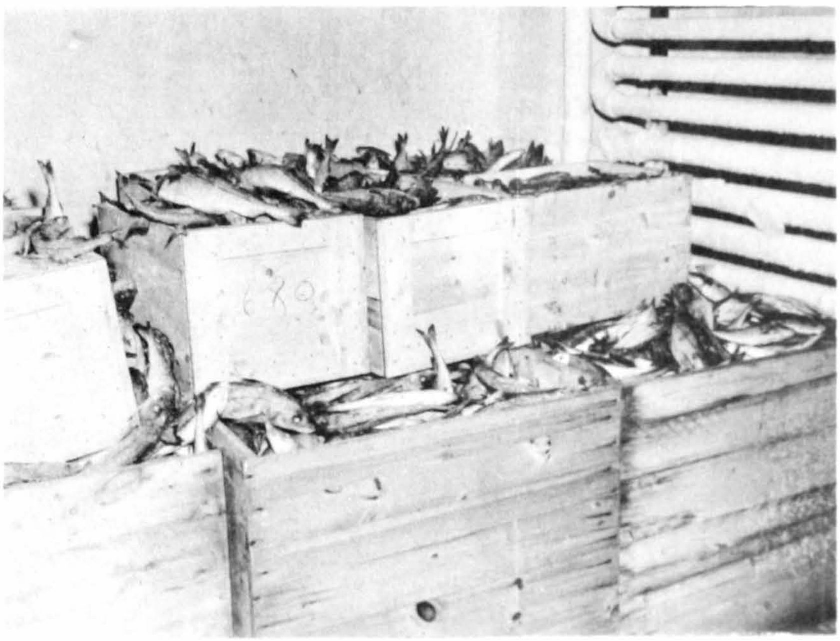
FRIGERATION OF FISH - PART 3

FACTORS TO BE CONSIDERED IN THE FREEZING AND COLD STORAGE OF FISHERY PRODUCTS



UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

FISH AND WILDLIFE SERVICE
John L. Farley, Director

Fishery Leaflet 429

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REFRIGERATION OF FISH - PART THREE

FACTORS TO BE CONSIDERED IN THE FREEZING AND COLD STORAGE OF FISHERY PRODUCTS

By Maurice E. Stansby (Sections 1 and 2), S. R. Pottinger and David T. Miyauchi (Section 3)

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This leaflet is part three of a series of five to be prepared within the broader overall subject matter of the refrigeration of fish. Titles of the four leaflets not yet published are:

Fishery Leaflet 427 - Cold Storage Design and Refrigeration Equipment
Fishery Leaflet 428 - Handling Fresh Fish
Fishery Leaflet 430 - Preparing, Freezing, and Cold Storage of Fish, Shellfish, and Precooked Fishery Products
Fishery Leaflet 431 - Distribution and Marketing of Frozen Fishery Products

The five leaflets in this series are prepared under the general supervision of Charles Butler, Chief, Technological Section, Branch of Commercial Fisheries, Washington, D. C., and edited by Joseph W. Slavin, Refrigeration Engineer, Fishery Technological Laboratory, East Boston, Massachusetts, and F. Bruce Sanford, Chemist, Fishery Technological Laboratory, Seattle, Washington

SECTION 1

CHANGES TAKING PLACE DURING FREEZING OF FISH

By Maurice E. Stansby, Chief, Pacific Coast
and Alaska Technological Research *

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INTRODUCTION

When fish which have been frozen and held in cold storage for an extended period of time are thawed and examined, a number of changes are found to have taken place which differentiate them from unfrozen fish. The flesh of the thawed fish will consist of two phases, the solid flesh plus a fluid known as drip which was not reabsorbed by the flesh after thawing. The texture of the thawed fish will be soft, and additional drip can be expressed by applying a small amount of pressure. The surface may have become desiccated by loss of moisture. The color of the surface may have altered in some way. After cooking, the fish may be found to have acquired an off flavor, or the normal flavor may merely be lacking. The cooked fish may be tough or fibrous.

These changes from the condition of the original, unfrozen fish are sometimes said to be due to the freezing process. Actually, almost all of such changes are caused, not by the freezing of the fish, but rather by the subsequent cold storage of the frozen product. If fish are rapidly frozen 1/ and then immediately thawed and examined, very few changes are noted, and those changes that do occur are of a very minor nature. Such a fish, frozen and then immediately thawed, generally exhibits a very small amount of drip, and the texture of the flesh is usually slightly softer than that of fish that never have been frozen. A careful examination may reveal a sort of honeycomb appearance caused by spaces being left where ice crystals had formed. Such a condition would be noted only if the fish had been frozen very slowly, as may occur with large fish. In case of fish frozen in high velocity air without a protective covering some evidence of surface desiccation would also be present.

Properly frozen and immediately thawed fish cannot be distinguished by the average person from fish that never were frozen. Even an expert might be unable to distinguish such fish after they had been cooked. Although the changes in fish brought about by the freezing process itself are very minor, nevertheless changes do take place, and these will be discussed in some detail after consideration is given to the manner in which fish freeze.

1/ Fish are said to be quick frozen or slow frozen, and freezing equipment is referred to as quick and slow freezers. These terms are not specific to two different kinds of phenomena. Rather there is a regular gradation in the rate of freezing from one extreme to the other with no definite dividing line between. Furthermore, equipment which might freeze one type of product at a relatively quick rate will freeze another type at a slow rate. The terms quick and slow frozen when used in this section will be employed only in a general sense to indicate freezing rates at different extremes as practiced commercially but with the understanding that these are not specific terms subject to precise definition.

TEMPERATURE CHANGES DURING FREEZING

Fish do not possess a well defined freezing point like water or other pure chemical substances. Rather, they freeze over a range of temperatures, and while most of the water in the fish is frozen at 18° F., a small part remains unfrozen even at temperatures far below 0° F. Table 1 shows the proportion of water frozen at different temperatures.

Table 1.--Proportion of water frozen from fish at different temperatures 1/

Temperature	Proportion of water frozen
Degrees F.	Percent
30.3	0
30	32
28	61
26	76
24	83
22	86
18	89

1/ As reported by Finn (1932)

A fish first starts freezing when its temperature is lowered to about 30.3° F. Freezing begins at the outside of the fish and progresses inward, the center of the fish being the last part to freeze. Thus, if thermocouples are placed at the outside and at the center of a fish and temperatures recorded as the fish freezes, it will be found that a much longer time elapses before the center freezes than does the surface layer (figure 1). This is due to the fact that the cooling medium is in contact with the external surfaces of the fish. Therefore, the zone of frozen tissue progresses from the outside surface of the fish to the center, so that tissue at the center does not start to freeze until long after that at the outside surface has frozen. The increased time required to freeze the center of the fish in a particular type freezer is a function of the thickness of the fish. The effect of the thickness of fish on the freezing time is discussed in section 3 of Fishery Leaflet 427. "The Refrigeration of Fish."

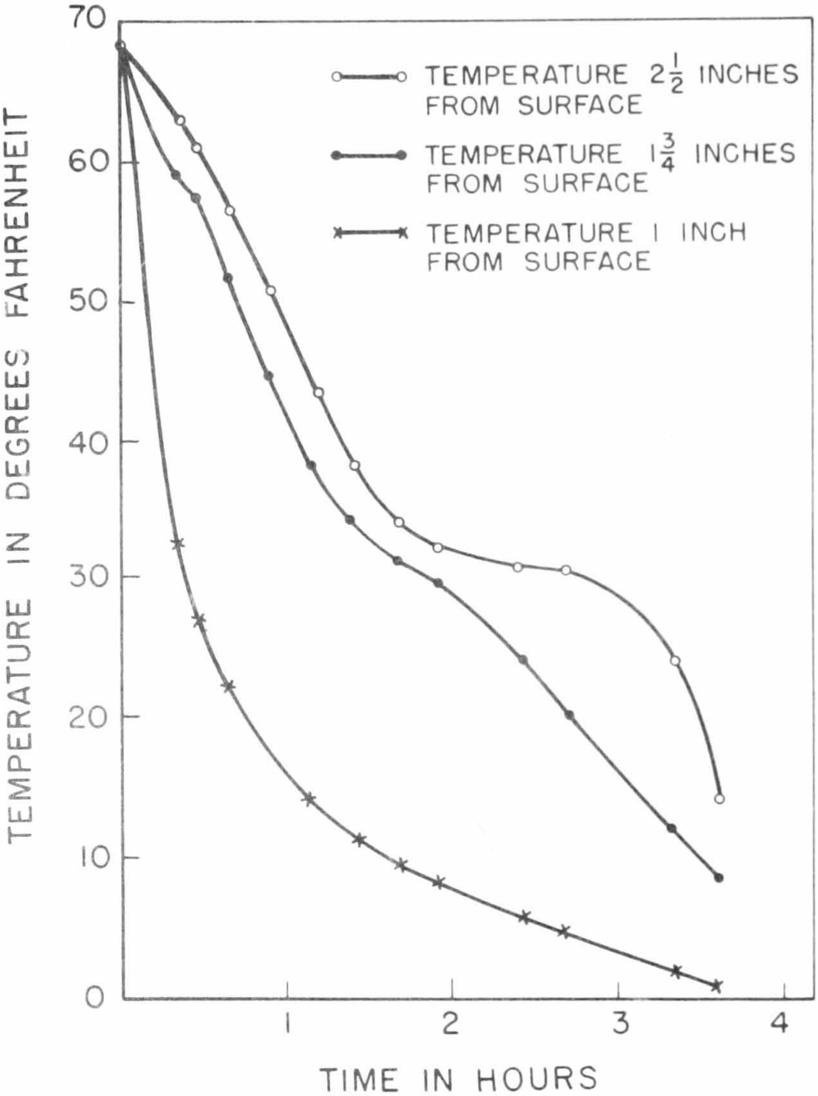

Figure 1.--Cooling rate at different distances from surface during freezing of fish.

The fact that the moisture in fish freezes over a range of temperatures rather than sharply at a single temperature gives rise to a curve when temperature is plotted against the freezing time, such as is shown in figure 2. The time during which most (about 85 percent) of the water is freezing (shaded area figure 2) has been termed the critical zone, and it has been suggested that the shorter the time required to pass through this zone, the less damage is done to the fish.

THEORIES FOR CAUSES OF TEXTURE CHANGES RESULTING FROM FREEZING

It has long been known that fish which are frozen at a very slow rate show a greater difference from fresh, unfrozen fish than do fish frozen at a rapid rate. Thus, slow-frozen fish tissue yields, upon thawing, a somewhat greater quantity of drip than does quick-frozen fish tissue. The size of the crystals which form in slow-frozen fish are larger than those in quick-frozen fish. Several theories have been proposed to account for these differences caused by different freezing rates.

Reuter's Theory

One of the earliest and still one of the most comprehensive investigations on the effect of the rate of freezing on changes in fish tissue was carried out by Reuter (1916). Reuter's work has been summarized by Nuttall and Gardner (1917) from which the following excerpt is taken:

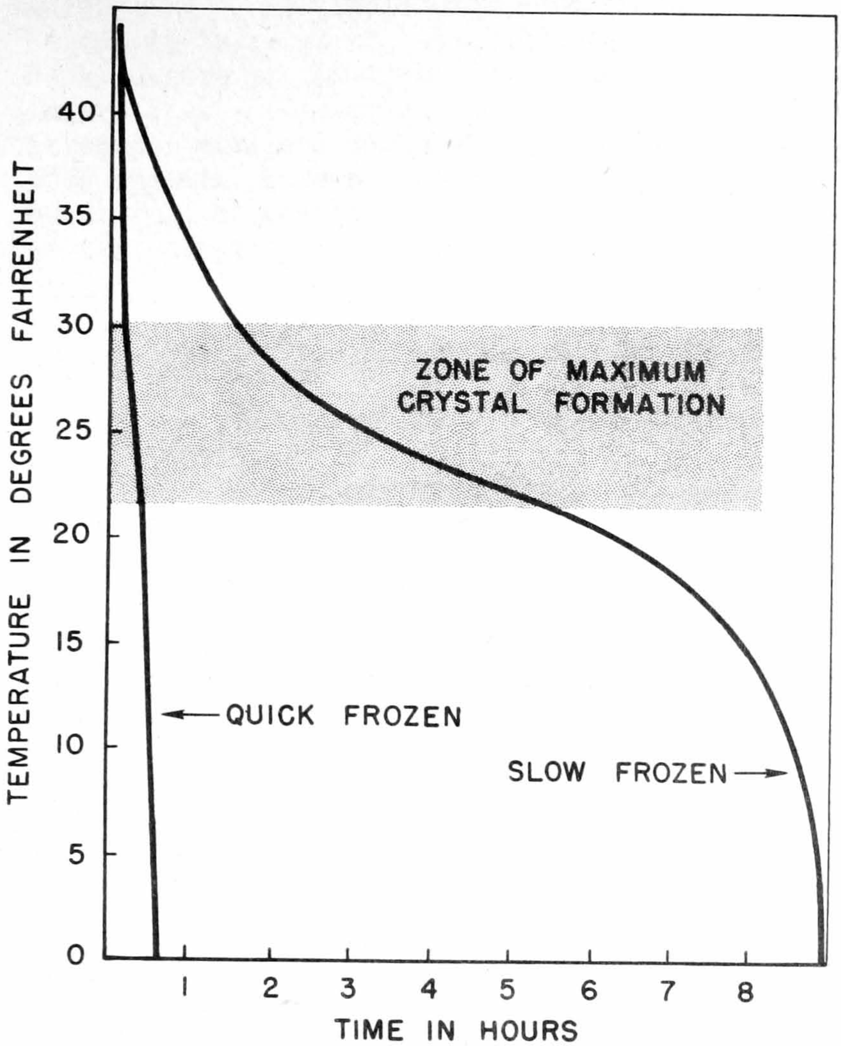

Figure 2.--Effect of rate of freezing on time in zone of maximum crystal formation.

"In all colloids the time required for imbibition and the reversal of this process is much longer than in bodies having a crystalloid structure. The assumption is therefore justified that the separation of water will be more complete, the more slowly it is cooled down to the point where it solidifies. Conversely, the separation of fluid will be lessened in proportion to the rapidity with which the temperature of solidification is attained. By using liquid CO_2, small pieces of muscle could be so rapidly frozen that no changes were produced. Freezing took place within one or two seconds, and sections only showed the effect of freezing on their edges, the greater part of the tissue presenting the appearance of normal unfrozen muscle. No exudation of fluid into the connective tissue, and no aggregation into columns within the seaprate fibers could be seen.

"The conclusion from the above observations is that in very rapid freezing, the water of the muscle albumin freezes in an invisible molecular state. In less rapid freezing, a number of small columns of fluid are formed in each muscle fiber, and, if time permits, these fuse to form a single column. In still slower freezing, the fluid ruptures the sarcolemma and escapes into the connective tissue, forming large spaces filled with ice."

Thus, Reuter believed that the difference in the condition of quick- and slow-frozen fish was primarily due to colloidal differences caused by different rates of lowering of the temperature below freezing. Fish which pass through the critical zone (figure 2) most quickly undergo the least change in their colloidal state, and when thawed such fish more closely resemble fish which has never been frozen than does fish which, in freezing, has passed through the critical zone more slowly.

Cell-puncture Theories

A somewhat different theory was advanced shortly after the work of Reuter (1916). He had shown that, in extremely slow freezing, the sarcolemma (the thin layer of tissue covering the muscle fibers) is ruptured to allow passage of moisture which then freezes between the muscle fibers. The idea of mechanical damage of the fish tissue was greatly expanded by subsequent workers. A theory was built up to account for the formation of drip in thawed fish solely on the basis that formation of ice crystals within the cells ruptured them and allowed moisture to pass through and then freeze outside. It was postulated that upon thawing, only a portion of the moisture returned to within the cell. The remainder was held in the fish tissue like moisture in a sponge and would drip out or could be expressed by mild pressure. Since slow-frozen fish has larger ice crystals than do those that are fast frozen, it was assumed that these larger crystals did correspondingly greater damage to the cell walls, resulting in formation, upon thawing, of larger quantities of drip. This theory seemed to be confirmed by photomicrographs of sections of fish tissue. For many years belief in this theory was widespread, especially by authors of popular articles in which an attempt was being made to explain the advantages of quick freezing to the lay public.

Recent Theories

Recent work seems to have disproved the theory of mechanical damage to cells by crystals formed during freezing, or at least to indicate that such changes are of secondary importance. Most of the photomicrographs used to support this theory were taken after the tissue had been prepared by the usual histological techniques involving use of a fixing agent followed by imbedding with paraffin and cutting of sections with a microtome. Lebeaux (1947) has shown that when photomicrographs are taken with the polarizing microscope where none of these histological techniques is employed and where pictures of the tissue can be taken while the fish is still frozen or even while the freezing process is going on, there is no evidence for the cell-puncture theory. Although large crystals were formed when fish tissue was frozen, no damage to the cell walls took place. The cell walls were found to stretch and deform during freezing, but no actual rupture occurred. Apparently, damage to cells previously demonstrated by photomicrographs had occurred, not as a result of freezing, but rather as a result of the histological preparation of the tissue for microscopic examination.

A new chemical technique for investigating tissue alteration caused during freezing has recently been proposed by workers at the Torry Research Station, British Food Investigation Board (Anonymous 1954; Love 1955). This technique is based upon a determination of the quantity of desoxypentose nucleic acid (DNA) occurring in the press juice of the thawed fish. DNA occurs only in the nucleus if the cells are unaltered. Hence, it is reasoned that its concentration in the press juice will be a measure of the extent of liberation of nuclear material into the interstices. Concentration of DNA has been shown to vary in a rather irregular pattern with rate of freezing. This technique has not yet been applied sufficiently to give very much information on changes occurring, but it offers considerable promise that in the future a better understanding of the nature of such changes can be reached.

EFFECT OF ICE CRYSTAL SIZE

There can be no doubt that the size of ice crystals which form during freezing of fish is a function of the rate of freezing. This relationship has been shown by many workers. Thus, Weld (1927) showed that crystal size was determined by the thickness of the fish or portion of fish frozen and by the rate of freezing but not by freshness of the fish. There is no proof, however, that any extensive damage to the fish (e. g., marked increase in drip after thawing) is due to the larger crystal obtained by slow freezing. In cases, however, where extremely slow freezing has resulted in formation of very large ice crystals, the thawed fish may have a porous texture with tiny holes appearing in the flesh, in some cases approaching a honey-comb-like appearance (see figures 3 and 4).

ADVANTAGES OF QUICK FREEZING

In the early development of the frozen-fish industry, it was believed that one of the major factors in producing a frozen product of proper texture was that the product must be quick frozen. As we have seen, this belief rested upon certain hypotheses which have since proved to be untenable. When the texture of a large fish such as a 150-pound halibut which was frozen in still air is compared with that of a 1-pound fish fillet which was quick frozen in a plate freezer, a very definite difference in favor of the texture of the quick-frozen product is found. This difference is large only in case of such extremes. Differences in texture, immediately after freezing, of the same type of product frozen by standard commercial quick- and slow-freezing techniques are small, sometimes indistinguishable.

This does not mean that slow freezing is as good as quick freezing. Quick freezing possesses several very important advantages over slow freezing which are in no way connected with actual changes brought about by the freezing process itself.

Rate of Chilling

Fish to be frozen must first be chilled to the freezing temperature before they will start to freeze. When large quantities of fish are placed in a freezer, it takes some definite period of time for their

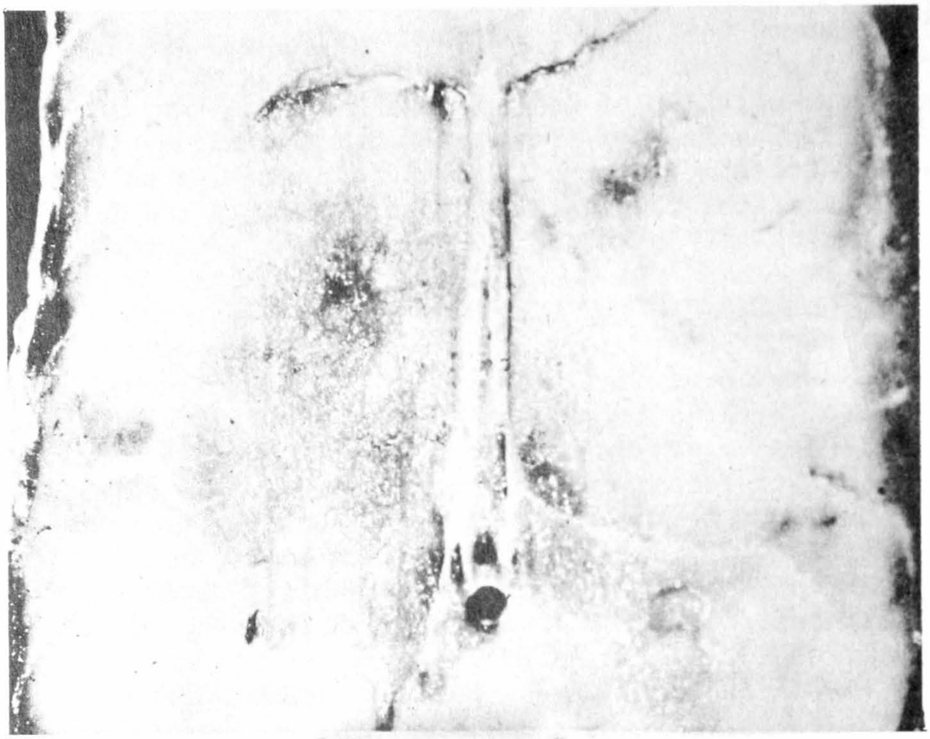

Figure 3.--Enlarged view of quick-frozen fish (freezing time 35 minutes).

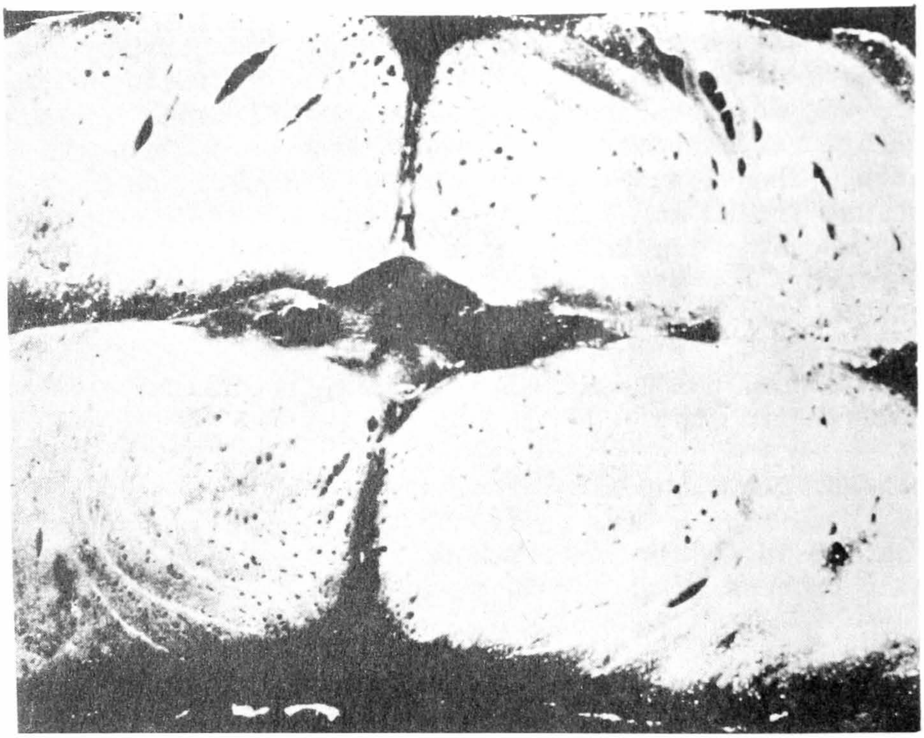

Figure 4.--Enlarged view of slow-frozen fish (freezing time 24 hours). Note the many small "pin point" holes resulting in a sort of honeycomb appearance.

temperature to be lowered to the freezing point. The center of large fish will require a longer period of time for this cooling to take place before freezing can commence than will the outer portions. During this cooling period, bacterial spoilage can proceed.

In cases where the initial temperature of the fish is high and either where abnormally large quantities of fish are involved, or where the refrigeration capacity of the freezer to too low, this chilling period may be quite long--from a few hours up to several days. In the latter case extensive spoilage can occur while the fish is in the freezer but before freezing commences. Such spoilage has occurred to an extensive degree in commercial operations where tuna or salmon have been frozen aboard the fishing vessel in brine at too slow a rate because of inadequate refrigeration capacity or overloading of the brine wells with excessive quantities of fish. In commercial operations ashore, fish have spoiled where excessively large batches have been placed, without pre-chilling, in freezer rooms without adequate air circulation. Spoilage in such cases occurs locally at the center of a stack of cartons or fish. Quick freezers are far more efficient than slow freezers in rapidly lowering fish temperatures to the freezing point, and they thus minimize spoilage.

Refrigeration Capacity

At periods when large quantities of fish must be frozen in a short time, the availability of quick-freezing equipment may have a very real advantage from a production standpoint. Furthermore, during periods when unusually large quantities of fish must be frozen, the possibility of overloading slow freezers is greater than for quick freezers. In some instances the fish within the slow freezer are packed together so tightly that the circulation of air is greatly restricted, resulting in some of the fish not being frozen when removed from the freezer.

Sometimes fish are slow-frozen by merely placing them directly in cold storage rooms containing fish which are already frozen. This practice may lengthen considerably the period of time required for the product to freeze and possible product spoilage in extreme cases. Also, if a sufficient amount of refrigeration is not available to compensate for the increased load of warm fish, a drastic rise in the temperature of the room may occur. This rise will damage the rest of the frozen fish within the room by their being held at too high a storage temperature.

Freezing Under Pressure

A third advantage of some types of quick-freezing equipment rests in the possibility of freezing the fish under pressure. As is described in more detail in the section on cold storage changes, packaged fish frozen under pressure in plate-type quick freezers possesses greater storage life, owing to the elimination of air voids from the package. This can be a very important factor in favor of such plate freezing when dealing with certain species of fish which are subject to rapid oxidation. Such freezing also prevents buckling of the packages.

Choice of Freezing Equipment

From what has been said in the foregoing, it will be apparent that quick-freezing equipment is always to be preferred to slow-freezing installations, and whenever at all possible the quick-freezing installation should be employed. The question as to just what types of freezers may be classified as quick or slow freezers may occur. In general, freezers employing a freezing medium other than air (e.g., brine), those using contact of the product with plates from two sides and under pressure, and those utilizing blasts of air are classified as quick freezers. Stacking fish in storage-type rooms in still air results in slow freezing. The practice whereby fish are frozen by placing them on shelves made up of pipes or plates containing the refrigerating medium (sharp freezers) but without rapidly circulating air may result in a relatively quick freezing or a slow freezing, depending upon the product being frozen and the manner in which it is stacked in the room. If small packages of fillets are placed directly on such sharp freezer shelves and the shelves are not overcrowded, it is possible to attain a relatively rapid rate of freezing. On the other hand, when such rooms are overloaded with large fish, a very slow rate may result. Quick and slow freezing are only relative terms with no sharp line of demarcation separating them. Similarly, freezing equipment does not always fall into one or the other of these categories. The use of the same equipment in one way with a certain product may result in quick freezing, with another product handled otherwise, in slow freezing.

THAWING AND REFREEZING

From a theoretical point of view it would seem that fish thawed slowly might return to the condition of the unfrozen state more closely than if they were thawed rapidly. A slow thawing might give the water from the melting ice crystals in the tissue a longer time to be reabsorbed than a more rapid thawing. This question has been investigated by a number of workers, but no clear-cut solution to the problem has been obtained. Apparently, the rate of thawing is not a major factor in the determination of the completeness of reabsorption of fluids by the tissue.

A distinction exists between the rate of thawing and the temperature of thawing. While it is true that a sample of fish thaws more rapidly at a high temperature than at a low one, it is possible to thaw samples at different rates at the same temperature. Some experiments along these lines were carried out at the Seattle Fishery Technological Laboratory of the Fish and Wildlife Service by Odan (1952). Frozen fillets of cod were thawed in air and in water at 34° F. and at 80° F., and the total free drip was determined in each case. When the quantity of free drip was compared in samples thawed at the same temperature in air and in water, the rate of thawing made very little if any difference in the amount of drip forming in the thawed fish. On the other hand, the temperature of thawing made a considerable difference. Free drip formed at 34° F. averaged 5.5 percent as compared to 11.4 percent at 80°F.

When fish is frozen, thawed, refrozen, and thawed again, the drip is greater after the second thawing than after the first, but the difference is only a small one. Successive refreezing and thawings make for less and less increase in drip as the process is continued. Accordingly, it is entirely feasible to thaw whole frozen fish, cut fillets, package, and refreeze without any important deterioration in quality of the refrozen fillets resulting from the second freezing (Stansby and Dassow 1948; Magnusson 1955).

SALT ABSORPTION

Whole fish are often frozen in brine. When this is done, salt is absorbed by the fish during the freezing process. The extent of salt absorption depends upon a number of factors, one of which is the species of fish. Non-oily species like cod and haddock absorb salt more rapidly and to a greater extent, especially after freezing has been completed, than do oily ones such as tuna and salmon. A comprehensive investigation of the factors controlling salt penetration into whole haddock when they are brine frozen has been carried out by Holston and Pottinger (1954). They showed that the temperature of the brine is an important factor governing salt absorption. About three times as much salt is absorbed in the $\frac{1}{4}$-inch outer layer of haddock when frozen at +15° F. as when frozen at -6° F. Another important factor is the brine concentration. Under certain conditions, 1.2 percent salt was absorbed when the fish were frozen in 23-percent (eutectic) brine. Under identical conditions, except that a brine of 15-percent concentration was used, 0.72 percent salt was absorbed. The amount of salt absorbed increases with the length of immersion time, and brine continues to be absorbed even after the fish have been completely frozen. In one test, haddock were frozen in 23-percent brine at 5° F., and the amount of salt absorbed in the outer $\frac{1}{4}$-inch layer of meat was measured. After 1, 2, 4, and 24 hours, the amount of salt found was 0.5, 0.9, 1.2, and 2.1 percent, respectively. After 10 days in brine, 10.6 percent salt had been absorbed.

In handling oily fish like salmon and tuna, the rate of absorption of salt is much slower. Particularly after the fish has been hard frozen, little or no salt penetrates into the flesh. For example, Miyauchi and Heerdt (1954) report that the salt content of chum salmon frozen in brine and held after freezing for 2 weeks in the brine was only 1.1 percent. It is common commercial practice aboard tuna clippers to freeze and hold frozen tuna in brine for several weeks. Salt uptake of tuna is relatively slow at least compared to the rate of salt absorption by haddock under similar conditions. Salt absorption is, however, sometimes a considerable problem even with oily species of fish. For example, in recent years the average size of tuna taken has decreased. This decrease in size has resulted in a greater salt absorption (due to the greater ratio of exposed surface to weight, for small fish) to such an extent that some small tuna being landed contain so much salt that, even after the usual thawing and precooking procedures, the ultimate canned tuna retains salt in excess of what is desirable from a flavor standpoint.

MISCELLANEOUS CHANGES CAUSED BY FREEZING

A change in the protein of fish, known as denaturation, occurs when the fish is frozen. This change is one in which the extent of change is dependent upon the length of time the sample remains in the frozen condition. For this reason, the discussion of denaturation is given in section 2 on changes in frozen fish held in cold storage. Similarly, changes caused by oxidation, which may start in a small way during freezing but which do not attain any great importance until after prolonged storage, are likewise discussed in section 2.

Fish may become dehydrated during the freezing process. Products protected by packaging materials or frozen in still air do not dehydrate to any significant extent during freezing, but in cases where whole fish are frozen in blast freezers, extensive surface dehydration usually occurs. This dehydration occurring during freezing is termed "freezer burn." Sometimes freezer burn is erroneously attributed to exposure of the fish to too low a temperature. Actually this condition results only from loss of moisture from the surface of the fish and is not in any direct way associated with freezing temperature. Of course, very cold air may have a lower relative humidity which in turn will cause more moisture to be lost from a fish frozen in a blast of such air than if warmer air having a higher relative humidity had been used. For details on problems concerned with dehydration, the reader is referred to section 2.

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SECTION 2

CHANGES TAKING PLACE DURING COLD STORAGE OF FISH

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INTRODUCTION

To many, the words frozen fish connote fish of low quality. If only fresh, unspoiled fish are frozen, the resulting product resembles the original, fresh fish more closely than fish preserved in any other way. Any alteration in flavor, color, or texture is primarily due to changes brought about during subsequent cold storage. Especially when inadequate precautions are taken during this storage period, very extensive changes may occur which will result in drastic alteration in quality. Thus the popular concept that frozen fish may be fish of low quality is not due to the freezing process itself. Rather, if such is the case, it is due either to the fish having already been of low quality before it was ever frozen, or to its having been stored improperly or for too long a period of time.

Two chief types of adverse changes occurring during storage of fish will be described in this section. The first of these involving alteration in texture occurs to some extent with all species of fish and results in such changes as toughening and separation, when the fish thaws, of a fluid called "drip." The second type of change is caused by oxidation of oils and pigments in the flesh and results in the development of off flavors and in the discoloration or fading of colors. This second type of change occurs to a much greater extent in some species of fish than in others.

CHANGES IN TEXTURE OF STORED FISH

As already indicated, one of the most important changes which takes place when frozen fish are held in cold storage is the alteration in texture. Unfrozen raw fish has a firm, gelatinous consistency, and application of pressure does not result in expression of any fluid from the tissues. Frozen fish held in cold storage for an extended period of time and then thawed consists of a solid phase plus drip. Upon applying pressure to the solid flesh, considerable additional drip is expressed.

Similarly, the texture of stored frozen fish may be different, when it is thawed and then cooked, from the texture of unfrozen, cooked fish. Cooked fish which has never been frozen and stored is of a moist, flaky texture, firm but not tough. Only a small quantity of fluid separates from such fish during the cooking process. When frozen fish which has been held in cold storage for a long time is thawed and cooked, considerable "cook drip" separates during the cooking process. The cooked fish itself may be extremely soft rather than flaky. In other cases it may be woody, fibrous, stringy, or tough.

All these changes in texture involve, either directly or indirectly, the moisture in the fish. In some cases a surface desiccation or drying during cold storage occurs, resulting in actual loss by evaporation of a part of the water. In other cases there may be a change in the manner in which the moisture is held in the fish flesh. Lean fish tissue contains about 80 percent moisture held by colloidal bonds to about 16 percent protein. Alterations which occur to the protein during cold storage of frozen fish result in lowering the capacity of the protein for holding moisture. When the fish thaws, not all of the fluid is readsorbed. The resulting tissue is spongy, and additional moisture can be expressed; the texture may be fibrous and tough.

These changes in the moisture relationship to the fish tissue occur to a very small extent in fish which is frozen and immediately thawed. They become progressively worse as the time which the fish is stored or the temperature of storage is increased.

Some of these changes in moisture in the fish result in alteration of the appearance as well as the texture. Such alteration in appearance will be discussed under the section on desiccation rather than under that on changes in color and flavor.

Desiccation

Adverse Effects of Moisture Loss

When frozen fish is inadequately protected against moisture loss by improper packaging or glazing, or when storage conditions are not optimum, considerable moisture may be lost. This loss of moisture has several bad effects upon the product. In the first place, there is the economic loss in the weight of the fish. This may amount to a considerable monetary loss since weight decreases of 5 percent or more may be obtained under adverse conditions. Exact-weight-labeled cartons of fish may lose sufficient moisture to require relabeling.

More serious even than this loss in weight of the product is the very detrimental loss in quality of the fish which, in extreme cases, may mean that it becomes completely unmarketable. Loss of moisture takes place to the greatest extent at the surface of the fish, and this results in "freezer burn." Cut surfaces such as fillets or steaks become dry and lose their glossy appearance and, on further desiccation, become pitted with tiny holes so that a honeycomb effect results. At the last stage the surface becomes chalk-white in color. With whole fish, loss of moisture may alter the color of the skin, and the skin dries out to a dull surface.

When badly desiccated fish is cooked, the texture is "woody" or fibrous, especially in portions at the surface where dehydration begins and becomes most extreme. The fish is generally dry rather than moist, and the flaky texture is lost.

Minimizing Desiccation by Proper Packaging

Loss of moisture during storage of fish can be completely eliminated by enclosing the fish in a hermetically sealed container or covering which adheres closely to the surface at all points of contact with the fish.

This can best be accomplished by completely covering the surface with a glaze of ice or by freezing the fish in block form and then dipping the frozen block in water to form an ice glaze. Such methods are used both for whole fish and, to a lesser extent, for fillets and steaks. Such glazed fish are protected completely against moisture loss so long as the ice glaze remains intact. Any loss in moisture occurs from the ice glaze rather than from the product. This loss in glaze through evaporation may eventually reach the stage where the fish is exposed. Desiccation will then take place unless the glaze is renewed.

Ordinarily it is considered undesirable to glaze consumer-sized cuts of frozen fish, and some kind of packaging material must be employed. A more detailed discussion of packaging materials is given later in this section under changes in color and flavor as well as in section 4 of this leaflet (q.v.). Moisture loss occurs through all types of packaging materials to a greater or lesser extent except through hermetically sealed metal or glass containers. When a highly moisture-vapor-proof wrapper is employed, the moisture loss may be held to a few tenths of a percent per year under good storage conditions, and this loss, both from an economic and quality standpoint, is almost negligible.

When fish is packaged in such a manner that large air spaces occur within the package, desiccation may occur within the package. Moisture is transferred from the surface of the fish at the air pocket to the inner surface of the packaging material where it collects as frost. With large air voids, this moisture transfer may occur to an extensive degree resulting in serious freezer burn. In a similar manner, when fillets are frozen in paperboard boxes (waxchip board), overwrapped with packaging material, and a number of them cartoned together, moisture may pass from the fish to the inside of the overwrap and eventually through the overwrap to the carton. While little or no over-all moisture loss takes place from the carton, appreciable freezer burn may occur to the fish.

Minimizing Desiccation by Proper Cold Storage Practice

Although it is theoretically possible to prevent all desiccation by using ideal packaging methods, this is difficult or impossible to attain under practical, commercial conditions. Where moisture is being lost from the fish, the loss can be held at a minimum by using some of the precautions listed below in operation of the cold storage rooms.

Temperature differential.--When frozen fish is stored in a cold storage room which is refrigerated in the usual manner with pipes containing the refrigerant, the pipes are always at a lower temperature than the air and the fish. Moisture vapor then travels from the ice of the (relatively) warmer frozen fish and is deposited as ice on the colder pipes. If the pipes were made somewhat warmer than the fish (e. g., if the fish temperature were 0° F. and the refrigerant in the pipes were suddenly replaced with brine at 20° F.) then ice from the refrigerating pipes would sublime and be deposited upon the fish.

The rate at which the moisture from the fish is transferred to the refrigeration pipes is dependent in part upon the temperature difference between the fish and the pipes. With no temperature difference, no such transfer would take place. By keeping the temperature differential as low as possible, the tendency for transfer of moisture from the fish to the pipes is held to a minimum.

Lowering of this temperature differential is achieved by increasing the ratio of exposed pipe surface to volume of cold storage content. Economic considerations will limit the amount of piping which can be feasibly employed in a cold storage room.

Humidity.—Moisture is transferred from fish to refrigeration coils by first subliming from ice to moisture vapor. The moisture vapor may be considered to dissolve in the air just as salt dissolves in water. In a similar manner as water will dissolve only a certain maximum amount of salt at a given temperature and then becomes saturated, the air will dissolve only a certain maximum quantity of moisture vapor at a given temperature. When the air is saturated with moisture (at any given temperature), the relative humidity is 100 percent; when half this amount of moisture is present in the air (at the same temperature), the relative humidity is 50 percent, and a considerable capacity for taking up additional moisture vapor exists. Thus, desiccation of frozen fish in cold storage can be minimized by keeping the relative humidity as close to 100 percent as is feasible. A few installations have been made whereby the relative humiduty is kept high by injecting steam into the cold storage rooms, but such systems are not entirely satisfactory. High humidities are best achieved by keeping the temperature differential between pipes and product at a minimum. Since this means increasing the area of refrigeration pipes, there is a limit to the maximum relative humidity that it is feasible to maintain by this method. Ordinarily an 85 percent relative humidity is as high as is economically feasible.

Air circulation.—Transfer of moisture, dissolving in the air adjacent to the frozen fish, depends also upon circulation of the air within the room from the fish to the refrigeration pipes. Any means of cutting down this air circulation will retard desiccation. Complete blocking of circulation of air from fish to refrigeration coils is accomplished by means of jacketed cold storage rooms as proposed for fish by Young (1933). Several such commercial installations are in use on the West Coast and give excellent results. In this system the cold storage room is sealed inside a second room very slightly larger. The small space between the two rooms contains air circulated from the refrigeration pipes by a blower fan. This refrigerated air, circulating in the jacketed space, adsorbs heat coming from the outside and thus maintains the proper storage temperature in the inner storage room. The air which surrounds the cold storage room never comes in contact with the fish, and hence no transfer of moisture from fish to refrigeration pipes is possible.

In standard cold storage rooms, air circulation can be restricted by proper stacking of the frozen product. When the frozen fish is first placed in cold storage, however, stacking must be made in such a way as to encourage air circulation if the fish is at a temperature higher than that of the storage room; otherwise there would be danger that the fish would not be lowered to the room temperature for an extended period. Proper initial stacking calls for a 2-inch to 3-inch space at floor level and provision of air space by use of "dunnage" sticks or spacers between every second layer of cartons of packaged fish. This provides space for air circulation of about 3/8 inch between alternate layers of cartons. A space of 6 inches is generally left adjacent to walls and ceiling of inside rooms and at least twice this amount (sometimes 18 inches under refrigeration coils) for outside rooms.

Fluctuation of storage temperature.--Storage temperature can never be held absolutely constant. Some fluctuation always occurs during the on-off cycle of the refrigeration compressors. Greater fluctuation will occur when doors are opened frequently or when large quantities of warmer fish are deposited in cold storage rooms. At one time it was believed that these fluctuating temperatures were harmful to the quality of the fish by causing large ice crystals to form within the fish tissue which might result in alteration in texture. Experiments by Pottinger (1951) on fish and by others on similar frozen commodities have shown that no such damage occurs.

There are, however, other disadvantages of fluctuating temperatures. If the storage temperature averages 0° F. but fluctuates from -5° to +5° F., the fish, being stored a part of the time at +5° F., are subject to the greater damage (such as oxidative changes) caused by this higher storage temperature than would be the case if the temperature never rose above 0° F. Fluctuating storage temperatures also are favorable to causing somewhat larger quantities of frost to collect inside packages of fish where air voids are present.

Drip in Frozen Fish

Nature of Drip

Drip is the clear or sometimes slightly cloudy fluid which is not reabsorbed by the fish tissue when frozen fish thaws. The fluid consists of water in which is dissolved protein and other nitrogenous constituents as well as minerals. The nitrogen content averages about 1.5 percent. The quantity of drip depends upon a number of factors including the species of fish involved and the length and temperature of storage prior to thawing. Drip may be less than 1 percent or more than 20 percent of the weight of the fish.

Factors Controlling Drip

The quantity of drip forming varies greatly with the particular species of fish involved. Where the moisture content of a species is unusually high or the protein content very low, the quantity of drip is apt to be high. Thus the drip in oysters is considerably greater in quantity than is the case with most other species.

The rate at which the fish is frozen is one factor in determining the quantity of drip formed, slow frozen fish usually containing more drip than quick frozen ones. Thus in the case of "sole" fillets, Stansby and Harrison (1942) found an average of 5.1 percent drip from quick-frozen fish stored for 6 months at -5° F. as compared to 7.8 percent for slow-frozen fish handled in an identical manner.

The rate of thawing appears not to be an important factor in controlling the amount of drip. The temperature at which the fish is thawed is of more importance, a greater quantity of drip forming at the higher thawing temperatures. Thus Odan (1952) found that fish thawed in air and water at the same temperature gave no significantly different quantities of drip. In one experiment in which fish were thawed in air at 34° and 80° F., the amount of drip was 4.9 percent and 10.1 percent, respectively.

The most important factor in determining the quantity of drip forming when fish thaws is the condition and length of storage. The longer the fish is held in cold storage and the higher the storage temperature, the greater is the quantity of drip. These relationships as determined for chum salmon are shown in figure 1.

Cook Drip

When thawed fish is cooked, a fluid separates during the cooking process which is termed "cook drip." Sumerwell (1955) has described a method for measuring its quantity. The cook drip is usually greater in amount than that which forms when the fish thaws before cooking. It is generally a clear fluid while still hot. Upon cooling, protein may precipitate to form a viscous or gelatinous paste.

Disadvantages of Drip

The appearance of thawed fish containing much drip is so different from that of unfrozen fish as to make the frozen product unappetizing. Since the drip is ordinarily discarded, any dissolved protein, mineral, and flavor components will be lost. Usually the texture of thawed fish from which much drip has exuded is undesirably dry after cooking, and it may be of a woody or tough texture. <u>Accordingly, an unusually large quantity of drip may be an indication that other more serious alterations in texture have taken place</u>.

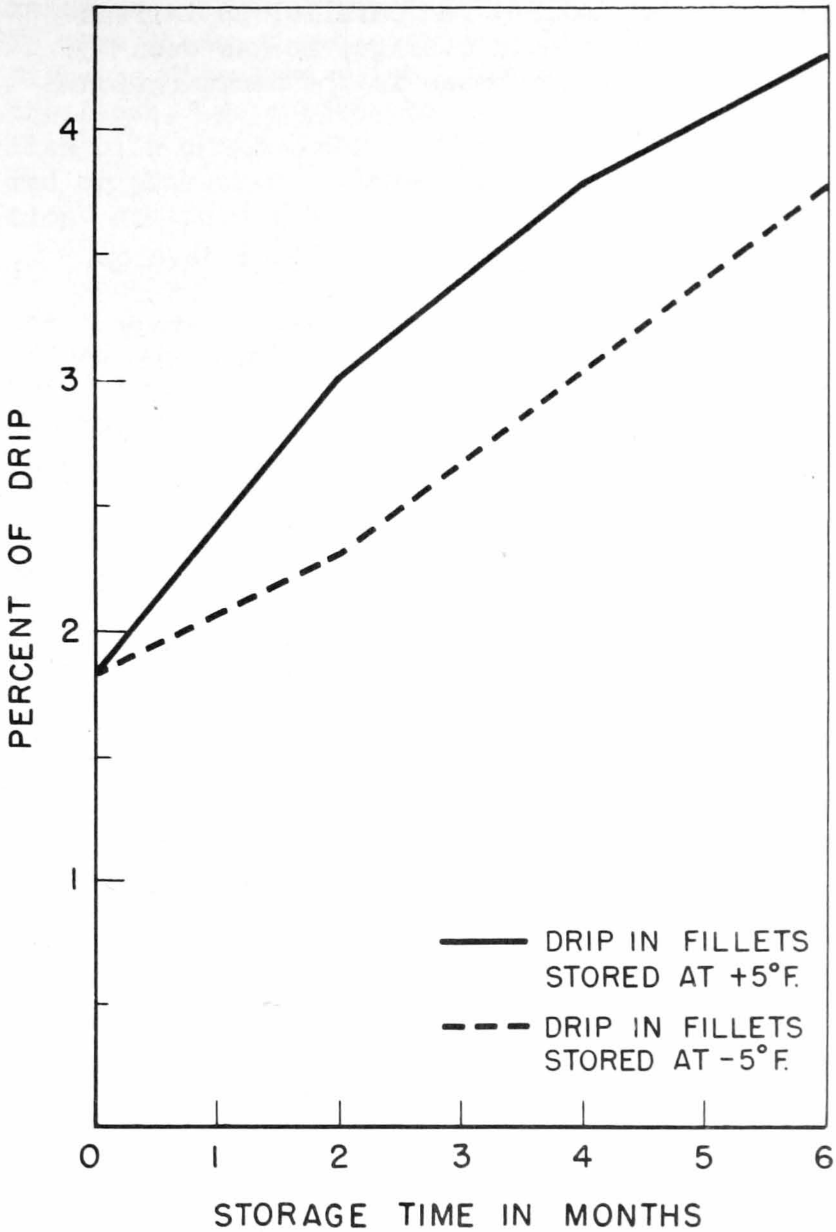

Figure 1.--Drip formation during storage of frozen chum salmon.

Retarding Drip Formation

Aside from keeping the storage temperature low and the storage time short, there is no good way of markedly reducing the quantity of drip which will form when frozen fish is thawed. One method often employed to reduce the apparent quantity of drip is to brine the fillets before freezing. Lean (non-oily) fillets are ordinarily dipped for about 20 seconds in a salt brine of about 6 percent sodium chloride content. Oily fillets (of species with which rancidity may be a problem) are generally dipped for about 10 seconds in brine of the same strength. Thus Stansby and Harrison (1942) reported 5.1 percent drip from control (unbrined) "sole" fillets stored for 6 months at -5°F. as compared to 1.7 percent for brined fillets otherwise handled in an identical manner.

Alteration in Texture

As frozen fish remains in cold storage, the texture becomes progressively tougher, and as we have seen in the last section, the amount of drip increases after the fish is thawed. Some changes must be going on within the fish during cold storage to account for these alterations in texture. The theory has been advanced that the changes responsible for these texture alterations involve a denaturation of the fish protein.

Snow (1950) reports a loss of solubility of the principal fish protein, actomyosin, as the storage period or storage temperature of the frozen fish increases. This change in solubility is attributed to protein denaturation since the solubility of denatured protein is lower than that of the native protein.

Because such changes in protein solubility run parallel to increasing toughness of the fish as they remain in cold storage, it has been postulated that the principal cause of the toughness is the denaturation of the fish protein.

CHANGES IN COLOR AND FLAVOR OF STORED FISH

When fish are held in storage, changes in color and flavor develop. Since these changes, though quite different with respect to the final quality of the product, are caused by the same factor—oxidation—they will be treated together. Oxidation is caused by chemical combination between oxygen and some constituent of the fish tissue such as the oil or one of the pigments. This process may be a purely chemical reaction, or it may be one involving certain biocatalysts such as enzymes. A discussion of the nature of these changes is given under "Mechanism of oxidation of fish oils in frozen fish" later in this section.

Color Changes in Stored Fish

Changes in color of fish occur shortly after they are removed from the water. In very freshly caught fish, that portion of the blood remaining in the tissue is bright red in color. Thus, in skinned, fresh fish fillets, a pattern of red blood is especially noticeable at the skinned surface where blood vessels still retain some of the blood. If the fish have been held in ice for a few days before the fillets are cut, the color of any remaining blood, instead of being bright red, is a dull red. With fish held still longer, the color may be light brown or even dark brown. These color changes result from a change in the state of oxidation of the bright red pigment, hemoglobin, which occurs in the blood.

Most fish contain two types of flesh, a dark and a light meat. The light meat is usually white or light gray. The dark meat which occurs in the tissue at certain localized areas such as along the lateral line and at the tip of the nape varies with the species and may be a light yellow or light gray. Pigments in these dark flesh areas are especially subject to oxidation (probably because of localized concentration of biocatalysts) which results in a darkening of the colors to deep yellow, dark brown, or in some cases to almost a black. These color changes take place in the frozen fish after they have remained in cold storage for an extended period of time. Such changes, when extreme, may result in so unsightly an appearance as to render the fish unsalable.

Some fish such as salmon have a pink or red light meat. The pigments which cause these colors are slowly oxidized when the frozen fish is held in cold storage, resulting in a fading of the pink or red color. In extreme cases, caused by extended storage periods, the pink or red may completely disappear.

The natural oil occurring in fresh fish varies in color, depending upon the species. With some species, the oil may be almost colorless;

in others, it is light yellow; with a few species, notably salmon, it is some shade of red or pink. The color of the oil is caused by colored pigments dissolved in it. These pigments, similarly to the pigments in the flesh, are subject to oxidation. The colorless or light yellow fish oils change, when oxidized, to deep yellow, orange, or brown. The red or pink oils of salmon first fade in color, as a result of oxidation, and then alter to yellow or brown.

The oils in frozen fish may oxidize and darken while present in the tissue. A more rapid oxidation occurs when a part of the oil is forced out of the tissue during freezing and oozes to the surface. This occurs especially with fish frozen whole. The oil, working its way to the surface owing to the pressures built up by expansion of water as it changes to ice during the freezing process, collects on the outside surface of the skin of the fish and alters to form a brown color. Such fish are said to have "rusted." This development of a brown rust color has been shown to involve not only oxidation of the oil but also reaction with nitrogenous constituents of the flesh (Brocklesby 1929). A similar condition may occur, but to a less noticeable extent, with frozen, dressed fish such as fillets or steaks. With certain wrappers used for such forms of frozen fish, the oil may be absorbed by the wrapper. This exposes a large area of oil to oxygen of the air and may cause a rapid oxidation and discoloration of the pigments in the oil.

Flavor Changes in Stored Fish

Flavor in Fresh and Frozen Fish

Fresh and frozen fish is often described as having a "fishy" flavor. It is not always recognized that this so-called fishy flavor is not the normal flavor of the freshly caught fish. Rather it is an altered flavor which has developed through some faulty or too prolonged handling. In the case of frozen fish, this may be due to the fish having been stored in ice for too long a period of time before it was frozen, or it may have resulted from improper protection or excessively long holding of the frozen fish during cold storage after freezing.

Quite different from the rather unpleasant "fishy" flavor characteristic of improperly handled fish is the pleasing taste of freshly caught fish. This palatable flavor is fully retained if the fish is promptly frozen, and under favorable cold storage conditions, the fish will reach the consumer in a condition closely resembling its high quality immediately after it was caught.

Unfortunately the changes which result in a transformation of these pleasing fresh flavors to unpleasant "fishy" ones occur very rapidly with certain species of fish, and these changes can be avoided only by prompt and careful handling. The alteration in flavor takes place in two stages: loss of characteristic flavor, followed by development of abnormal flavor.

Loss of Flavor

Each species of fish has its own characteristic flavor. This flavor is not the "fishy" one which develops upon protracted storage; neither is it a bland, flat flavor or absence of taste. Rather, it is the delicate flavor which distinguishes one species from another when they are eaten. We do not know very much about the chemical compounds present in fish which give rise to these characteristic flavors. We do know that the compounds which give the fish these individual flavors are very unstable. Shortly after the frozen fish is placed in cold storage, these delicate flavors slowly disappear. Such changes take place early in the storage of the fish and considerably earlier than the development of any "off" flavors. Eventually all, or nearly all, of the flavor characteristic of the particular species disappears.

While no systematic study of the cause of the loss of these naturally occurring flavors in fish has been made, it is probable that such loss is due to an oxidation of the chemical constituents causing the flavor. Samples of fish stored in evacuated tin containers retained the characteristic flavor longer than did samples stored with greater access to air (Heerdt and Stansby 1955).

Development of Abnormal Flavor

Shortly before the disappearance of the last trace of the normal flavor in fish held frozen in cold storage, an abnormal flavor starts to develop. This flavor, which is described as a rancid one, is characterized by a bitter taste which persists in the mouth long after the fish has been eaten. In the initial stages of rancidity, this flavor may not be objectionable to all persons eating the fish. As a matter of fact, frozen fish so often have become slightly rancid at the time that they are consumed that many persons are unaware that this flavor is not a normal one. As the rancid flavor develops, it becomes more objectionable until a point is reached where the fish become unmarketable.

This rancidity development in frozen fish is caused by an oxidation of the fish oils to produce carbonylic compounds. The reaction whereby the fish oil becomes oxidized may be a purely chemical change (autoxidation) or one which is catalyzed by biocatalytic systems occurring in the flesh of the fish.

Mechanism of Oxidation of Fish Oils in Frozen Fish

When fish oils which have been extracted from fish tissue are exposed to the action of air and light, they oxidize spontaneously according to a typical autoxidation type of reaction. Such reactions follow a pattern whereby the oil is at first oxidized very slowly (this stage is known as the induction period) and then the rate of oxidation increases at a rapidly accelerating pace until a maximum rate is reached, after which the oxidation rate decreases. Autoxidation of fish oils is accelerated by high temperatures, by the presence of light, and by the presence of pro-oxidants (certain chemicals such as metals like copper and iron). It is retarded by limiting access of the oil to air and by the presence of antioxidants (various chemicals, including certain phenolic-type compounds). The reaction of the fish oils with oxygen occurs first as an oxidation of the fish oil fatty acids to form peroxide-type compounds which then decompose to form numerous carbonyl types of compounds which are responsible for the rancid odors and flavors.

When fish oils oxidize in fish flesh under the conditions that occur during development of rancidity in frozen fish, another type of oxidation is involved, at least in part. Banks (1937) has shown that, in the oxidation of herring oil in frozen herring held in cold storage, the oxidation is catalyzed by the presence of some biocatalytic substance present in the herring flesh. Khan (1952) has more recently investigated the reactions which he attributes to enzymatic oxidation of the oil in frozen salmon. Tappel (1953) has carried out studies with certain meat products and concludes that hematin is a powerful catalyst in accelerating the oxidation. Similar studies are now under way on the effect of hematin on oxidation of oils in frozen stored fish.

Our present knowledge would indicate that the reaction mechanism whereby rancidity develops in frozen fish is predominately a biocatalyzed reaction, although autoxidation probably plays a part.

Types of Fish Most Susceptible to Color and Flavor Changes

Oxidation of fish oils and pigments is a more serious problem with some species than with others. If a species of fish contains only a small quantity of oil (under 1 percent), rancidity is ordinarily of minor importance. Such fish as haddock and cod can be kept in cold storage for many months with only very slight alteration in flavor. Even with these species, however, some rancidity does develop. When salt cod is stored at room temperature, the small amount of oil present in the flesh oxidizes to a considerable extent because of the relatively high temperature of storage. This oxidation leads to development of a rancid flavor typical of salt cod which is sometimes described as a "salt fish flavor." This same "salt fish flavor" develops to a lesser extent in frozen haddock and cod stored for extended periods of time. Because the flavor is not as pronounced as occurs with more oily species of fish, it is often not recognized as a rancid flavor.

The content of oil in the flesh of the fish is not the only factor involved in the susceptibility of the species to rancidity development. A good example of this is the case of the five species of salmon which contain an average oil content in their flesh, as follows: king salmon, 16 percent; red salmon, 11 percent; coho salmon, 8 percent; pink salmon, 6 percent; and chum salmon, 5 percent. Of these five species the pink salmon, containing only about 6 percent oil (next to the leanest) is by far the most susceptible to development of rancid flavors (as well as to change in color). Pink salmon steaks become rancid and badly discolored in less than one-tenth the time that the much more oily king salmon reach the same stage of alteration under identical storage conditions. Whether this is due solely to the fact that the pink salmon oil is more unsaturated than the king salmon oil (iodine value about 165 for the pink salmon as compared to about 115 for the king salmon), or whether there are more active lipoxidase or other biocatalytic systems, or less naturally occurring antioxidants, is not defintely known. It would appear that some of the latter factors must be of importance.

Many other examples of this difference in oxidation rate of oils in frozen fish occur. Thus oil in sablefish (a species averaging about 15 percent oil) develops rancidity at an extremely slow rate--less than one-twentieth the rate of rancidity development of the oil of lake chub (<u>Leucichthys</u> species) which contains a similar quantity of oil.

In a similar way, the degree of discoloration which occurs in frozen fish depends to a large extent upon the particular species. The dark flesh of rockfish (a relatively non-oily species containing about 3 percent oil in the flesh) discolors at a rapid rate. After 6 months' storage at 0° F. in fillet form, the dark flesh of one common species of rockfish (<u>Sebastodes pinniger</u>) changes from a neutral gray to a dark brown, sometimes nearly black color. After two years' storage under identical conditions, the dark flesh of yellow pike (<u>Stizostedion vitreum vitreum</u>) changes very little, if at all.

In general, the rates of the discoloration and rancidity development run parallel for the various species. When rancidity is a severe problem, discoloration is also usually severe. When rancidity develops slowly, discoloration is usually a minor problem. This correlation suggests that the underlying cause for rates of both rancidity development in the oil and discoloration of pigments in the flesh may be primarily a matter of the particular biocatalytic systems (or their degree of activity) present in the flesh.

Table 1 shows some of the commercially important species of fish classified according to their susceptibility toward oxidative changes.

<u>Minimizing Color and Flavor Changes</u>

<u>Keeping Air away from the Fish</u>

The most important consideration in retarding changes in fish brought about by oxidation is to keep air (and hence oxygen) away from the fish. When this condition is completely attained, no oxidation can occur, and consequently no flavor or color change in the frozen fish will develop. Keeping <u>all</u> oxygen away from the fish, however, is beyond the present practical means in handling frozen fish.

Table 1.--Relative susceptibility to oxidative changes

Degree of susceptibility			
Severe	Moderate	Minor	Very slight
Pink salmon Lake chub	Flounders and "sole" Herring Mackerel Chum salmon Sheepshead Smelt Ocean perch Lake trout Tuna	Haddock Cod Oysters Halibut Lake herring Sablefish Coho salmon King salmon Red salmon	Yellow pike Yellow perch Crab Lobster

The amount of oxygen which will cause discoloration or rancidity to develop is exceedingly small. For example, fish frozen in an evacuated hermetically sealed tin can does not, of course, contain a perfect vacuum. Even the small amount of air left in such a can will discolor to some extent the surface of the fish adjacent to the headspace. Likewise, when fish is covered with an ice glaze, a small quantity of air (and hence of oxygen) is dissolved both in the glazing water and in the water contained in the tissues of the fish. Even this small quantity of oxygen is sufficient to cause a small (though sometimes quite perceptible) slow development of slight degrees of discoloration and of rancidity.

The problem of keeping air away from fish during frozen storage consists first of eliminating as much as possible of the air in contact with the fish within the packaging medium and secondly of preventing further air from entering the package. An ice glaze renewed as required is by far the best method of attaining the first objective. A thick ice glaze, when properly applied, effectively forms a barrier between the fish and the outside atmosphere. No pockets of air whatever are left between the fish and the glaze. Because the ice glaze slowly evaporates under most cold storage conditions, and in some cases cracks and is lost, the ice glaze alone is not necessarily permanent protection.

A hermetically sealed tin can provides the best solution of the second problem of keeping air from entering the packaged frozen fish (Stansby 1955). In fact, it provides a complete solution to the problem since no additional air whatever can enter once the can is sealed.

As previously pointed out, fish frozen in a tin can contains, even under the best conditions, a sufficient trace of air to bring about some slight oxidation. The best means for preventing all but a trace of oxidation is packing the ice glazed fish within an evacuated tin can. This method is not at present a commercially acceptable means for handling frozen fish. For round fish, an ice glaze, renewed at suitable intervals, represents the most feasible and usually entirely adequate means of preventing oxidative changes. For dressed fish products such as fillets and steaks, the products, if ice glazed and then packaged in a suitable moisture-vapor and oxygen-proof packaging material, such as a good grade of cellophane, will have excellent protection.

Where an ice glaze cannot be used, the method of applying the packaging material to avoid pockets of air within the package is extremely critical. In addition to application of the wrapping material in the proper manner, filling of the packages completely and freezing under pressure aids in the elimination of air pockets to a very great extent.

Choice of a packaging material which cuts down on oxygen transmission through the package is also of extreme importance. As a general rule those papers having a high resistance to moisture-vapor transmission are also effective in cutting down on oxygen or air transmission through the wrapper.

The packaging material should also be grease-proof. Wrappers which adsorb oil will form a thin layer of fish oil at the surface where air, slowly passing through the package, will cause rapid oxidation. According to Lavers (1947), the following papers are, in the order given, of descending quality as far as grease-proofness is concerned: cellophane, pliofilm, vinyl derivatives, polyethylene, glassine, vegetable parchment, "grease-proof" papers, waxed papers. A more detailed discussion of packaging materials and equipment will be found in section 3 of this leaflet.

Keeping Fish Temperature Low

The second most important precaution in retarding oxidative changes in frozen fish is to keep the temperature of the frozen fish as low as possible. Some handlers of frozen foods believe that fish can be safely stored at temperatures considerably higher than those used for other frozen foods. Fish which appear to be "hard frozen" are considered by such handlers of frozen fish to be at their optimum storage temperature. Occasionally, special storage rooms at about 20° F. are used for fish, while frozen fruits and other products are held at 0° F. or even lower. This practice is completely unfounded. It probably originated from the fact that fish appear to be frozen quite hard at 20° F., whereas fruits frozen in sugar syrups are not hard until a temperature of 0° F. or lower is reached. Actually, the hardness of the product has nothing whatever to do with the determination of the proper storage temperature.

The oxidative changes occurring with fish are greatly retarded by lowering the temperature, and fish held at 0° F. are oxidized at only about half the rate at 20° F. Similarly an equal diminishing in oxidation rate occurs if the temperature is lowered from 0° to -20° F. Since frozen fishery products are subject to greater oxidative changes than almost any other frozen food, these products should always be stored at the lowest economically feasible temperature.

Avoidance of Pro-oxidants

As pointed out previously, certain chemicals, when in contact with fish, accelerate the rate of oxidative changes. These substances include copper and iron, and fish should be processed in such a manner as to avoid contact with these metals as much as possible. Common salt, when present in large quantities, also has an accelerating effect on the oxidative changes in frozen fish (Banks 1937). Where salt dips are used to minimize drip formation in the frozen, thawed fish, it is advisable to use weaker brines or shorter brining periods when dealing with species which give trouble with rancidity or discoloration than with other species. Furthermore, salts such as those of calcium and magnesium, which sometimes occur as impurities in common salt (sodium chloride), cause a greater acceleration in rancidity development than does the sodium chloride itself (Tressler and Murray 1932). Hence only salt of relatively high chemical purity should be used for preparing brine dips for species of fish which are especially subject to oxidative changes.

Use of Antioxidants

Antioxidants are effective in retarding autoxidation of oils. When the oils are present in the tissue, as is the case with frozen fish, the effectiveness of the antioxidant, in the presence of moisture from the fish, is greatly diminished. Furthermore, antioxidants which give protection to oils autoxidizing may be of limited or of no value to protect oils which oxidize through the action of biocatalysts. In the experience of the writer, application of such commonly used antioxidants as ascorbic acid or mixtures of ascorbic and citric acids, propyl gallate, and nordihydroguaiaretic acid are ineffective in retarding rancidity development in frozen fish. Certain antioxidants, however, have some value in slowing up to a degree the discoloration of certain species of fish. Even this effect is very limited.

BACTERIOLOGY OF FROZEN FISH

When fish are frozen and stored at the usual storage temperatures, the bacteria present in the fish tissue are, for the most part, inactivated. A portion of them are killed, but those surviving will, when the fish is thawed, grow once more and contribute to spoilage of the thawed fish.

When the frozen fish is held at usual storage temperatures (e. g., 0° F.) those bacteria not destroyed by the freezing process are slowly killed. Even after a year's storage, however, the fish are far from sterile since a considerable quantity of bacteria are very resistant to holding at low temperatures. In table 2 are shown some total bacterial counts for fish held in cold storage for varying periods of time.

Table 2.--Effect of freezing and storage on total bacterial counts of haddock

Time at which counts were made	Total bacterial count		
	Fresh sample	Slightly stale sample	Stale sample
	Bacteria per gram	Bacteria per gram	Bacteria per gram
Just before freezing	25,000	500,000	12,000,000
Immediately after freezing	1,500	28,000	950,000
After 1 month at 0° F.	900	16,000	430,000
After 6 months at 0° F.	700	14,000	300,000
After 12 months at 0° F.	600	11,000	270,000

Bacteria present in frozen fish normally will be killed when the fish are thoroughly cooked. If any pathogenic bacteria are present, they will all be destroyed during the cooking process so that ordinarily no danger to health exists. When precooked frozen fishery products such as crabmeat, fish sticks, or breaded shellfish are frozen, the thawed product may be eaten either without further cooking or after only inadequate heating. Under such conditions, should any pathogenic bacteria be present, they would constitute a very real health hazard. Accordingly, preparation of such precooked frozen fish products must be made under the best sanitary conditions in order to prevent their being a potential source of harmful bacteria. This handling under the best sanitary conditions is, of course, the only acceptable practice with all foods--whether they are to be eaten raw or cooked.

MINIMIZING CHANGES OCCURRING DURING STORAGE

The first prerequisite in obtaining satisfactory storage life of frozen fish is that the quality of the fish before freezing be first class. In the early days when frozen fish was a new item, a practice developed of selling iced fish on the fresh market until spoilage was imminent and then freezing what was left. Such fish, of second quality to begin with, certainly would not improve upon freezing and storage and would also have a very short storage life.

Assuming that good, first quality fish are selected for freezing, the second important step in ensuring satisfactory storage life is proper processing. This includes avoidance of contamination by metals or other substances, use of a suitable brine dip to minimize loss of drip, and use of good sanitary handling practice particularly for any precooked products and for those to which batters and breading material have been added.

The third important step is to start freezing the product almost immediately after processing. Also, an approved method of commercial freezing should be employed so that the particular product can be frozen as rapidly as is economically possible. Long time-intervals between the termination of processing and the beginning of freezing, and the use of slow unorthodoxed freezing methods will greatly affect the storage life of the product.

The next important precaution is application of satisfactory protection against desiccation and oxidation. A good ice glaze is the best protection both for dressed cuts of fish to be packaged and for whole fish. For packaged fish, the packaging materials must be moisture-vapor proof and resistant to oxygen transfer. The fish must be packaged in such a way as to avoid air pockets within the package.

One of the most important precautions is the use of as low a storage temperature as is economically feasible. This temperature should not be higher than 0° F., and still lower temperatures are desirable.

Finally, proper operation of the cold storage rooms is important. Such operation includes provision of high relative humidity, minimizing unnecessary air circulation, and keeping the temperature constant as well as low.

In table 3 is summarized the best storage practice and cold storage life for packaged fish of four categories. The various species corresponding to these various categories are shown in table 4.

Table 3.—Storage conditions and storage life for packaged frozen fish

Category number 1/	Type of fish	Brine treatment	Recommended protection	Storage life at 0°F. if optimum handling conditions are used
				Months
1	Species most difficult to store	None	Ice glazing before packaging	4 to 6
2	Oily species difficult to store	10 seconds in 6-percent brine	Ice glazing before packaging,	5 to 9
			or packaging	4 to 6
3	Non-oily species difficult to store, and oily fish relatively easy to store	20 seconds in 6-percent brine	Packaging	7 to 12
4	Fish easy to store—mostly non-oily species	20 seconds in 6-percent brine	Packaging	Over 12 months

1/ See table 4 for species corresponding to these categories.

Table 4.—Categories for different species of fish (see table 3)

Species		Category
Alewives		2
Blue pike		4
Buffalofish		3
Carp		2
Catfish and bullheads		2
Chub		1
Cod		4
Flounders		3
Haddock		4
Hake (White)		4
Halibut		3
Herring:	Lake	4
	Sea	2
Lingcod		4
Mackerel		2
Ocean perch:	Atlantic	3
	Pacific	3
Pollock		2
Rockfishes		3
Sablefish		3
Salmon:	Chinook or King	3
	Chum or Keta	2
	Pink	1
	Red or Sockeye	3
	Silver or Coho	3
Sardine, Pacific (pilchard)		2
Smelt		2
Spanish mackerel		2
Tuna		2
Whiting		4

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SECTION 3

PROTECTIVE COVERINGS FOR FROZEN FISH

By S. R. Pottinger, Chief, North Atlantic Technological Research*
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INTRODUCTION

The problems of freezing and frozen storage of fish and shellfish are, on the whole, very much like those for other frozen foods. The packaging requirements are similar (Shelor and Woodroof 1954; Woodroof and Rabak 1954), and the requirements for storage are, with some exceptions, much alike. Changes in flavor will occur in seafoods during periods of frozen storage. Most varieties of fishery products have a tendency to toughen after being held for varying periods of storage, and of major concern is the drying out of the products due to loss of moisture in the dry atmosphere of the frozen-storage room.

There is, in addition, an important problem with certain varieties of fish that is encountered with only a few other frozen products. The fat or oil that is present in the body tissues of these fish is very susceptible to oxidative rancidity, with subsequent undesirable changes in flavor. In extreme cases, the appearance of the fish will change, owing to the formation of a yellow to brown discoloration on the surface.

In order to help retard the changes that fishery products undergo during frozen storage, some form of protective coating or covering is used. In the early days of freezing and frozen storage, very little was known about ways for preventing desiccation and other undesirable changes. In fact, there were no suitable wrapping materials available. Probably the first "package" that came into general usage was the ice glaze that is formed by dipping the frozen fish in cold water. Because of the widespread practice of using the glaze in the earlier days of the industry, very little attention was given to other methods of packaging. Not until the introduction of quick-frozen foods in prepared form was any serious attempt made to improve upon protective coverings for frozen fishery products. During the past 10 years, in particular, great strides have been made in the development of these coverings, and although the perfect package is yet to be found, there are available a number of types of materials and packages that offer excellent possibilities for minimizing adverse changes in fishery products during extended periods of frozen storage. The various types of protective coverings used for fish will be discussed in the following sections.

GLAZES

Definition and Properties

Glazes may be defined as any continuous thin film or coating that adheres closely to the product. The glaze is usually applied on the frozen product by either dipping the product or by spraying it with a solution of the glazing agent and allowing the glaze to solidify. Some desirable properties of a glaze for frozen fish (Young 1935) are (1) non-cracking, (2) strength to withstand the rigors of handling and shipping, (3) low water-vapor pressure to minimize evaporation of glaze,

(4) light weight and low bulk, and (5) attractive appearance.

Several types of glazes are available for frozen fish. The following is a description of these types, with a discussion of their relative merits.

Ice Glaze

Although many types of glazes for fishery products have been introduced, the ice glaze remains the only one of commercial importance.

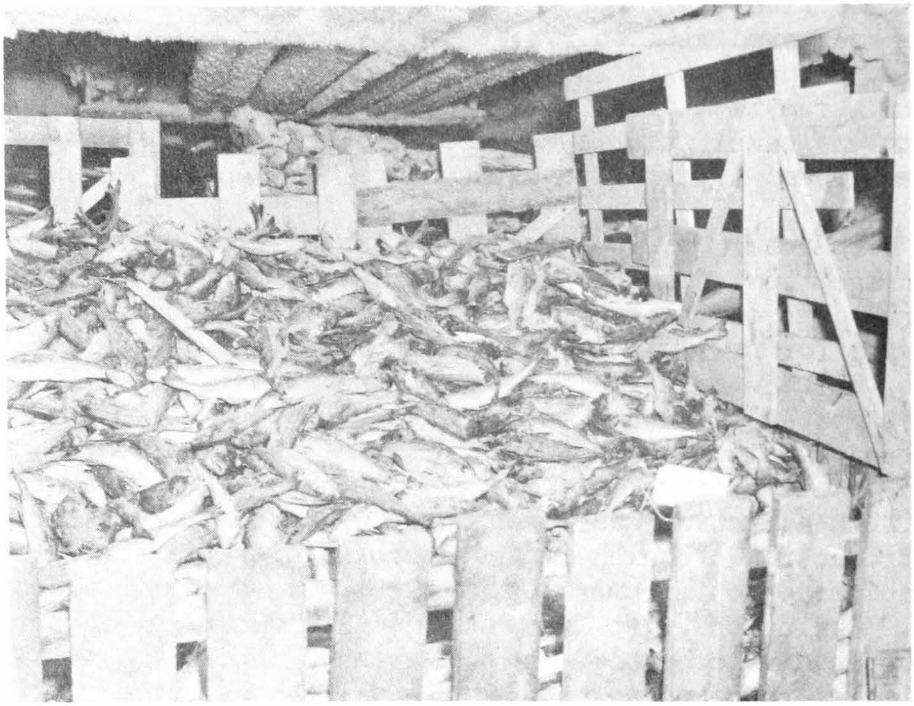


Figure 1.—Glazed fish stored without additional protective covering need to be reglazed at frequent intervals.

The ice glaze is formed when frozen fish are given a short dip in cold water or are sprayed with water, which freezes into a thin coating of ice.

Advantages and Disadvantages

The chief disadvantages of the ice glaze are its susceptibility to cracking, its brittleness, and its high vapor pressure, which necessitates reglazing if the product is stored for any length of time. Its advantages far outweigh its disadvantages, however. The ice glaze is inexpensive, easy to apply, readily adaptable to a production line, and provides a satisfactory protective covering for a variety of fishery products. When properly applied and maintained, the ice glaze is effective in preventing loss of moisture from the product and also in preventing ready access of air to the fish, thus retarding the onset of rancidity.

Recommended Procedure

In ice glazing fish, best results are obtained if (a) the fish is thoroughly frozen and is sufficiently cold, preferably at 0°F. or lower, to freeze rapidly the film of water on its surface, (b) the water used for glazing is precooled to a temperature (34° to 36° F.) slightly above the freezing point, and (c) the room in which the ice glazing is carried out is maintained at a temperature slightly above freezing to avoid warming the fish. The following is a description of the commercial methods used to apply ice glazes to whole and dressed fish, fish frozen in blocks, fish steaks, and shellfish.

Whole and dressed fish.--The ice glaze is the principal means of covering fish held in bulk storage. In some plants, conveyors are used to bring the fish from the freezer to the glazing tank and then to frozen storage. In other plants, fish carts are used to transport the frozen fish to and from the glazing room. In this room, the fish are transferred from the carts to a large metal basket, which is raised and lowered into the dipping tank with an electric hoist. The ice glaze is formed by dipping the frozen fish momentarily in the cold water and removing them to allow the film of water to freeze. This process may be repeated several times in order to secure a thicker ice glaze. In at least one plant in Alaska, the glaze is applied by conveying the frozen fish through a series of sprays. Such a system is a recent innovation in Alaska and lends itself well to mechanization, which reduces labor costs.

The thick body section of the fish, which possesses a larger capacity for refrigeration than do the thinner sections such as the tails and fins, is capable of acquiring a thick ice glaze, whereas the tails, fins, and snouts may take only a thin ice glaze. During the cold storage of the fish, it is these areas where the ice glaze is thin that must be checked and reglazed frequently in order to keep the ice glaze intact.

Fish frozen in blocks.--Small fish are often frozen in blocks in pans, and the blocks of fish are then dipped in cold water to acquire an ice glaze.

Fish steaks.--Steaks cut from frozen fish with a band saw are either dropped into the dip tank and removed on a conveyor belt or are placed on a wire-mesh conveyor belt and sent through a water sprayer to apply the glaze.

Shellfish.--Crabs may be frozen and then glazed whole, as legs in the shell, or as meat alone. On the West Coast, the meat is usually pan frozen in a block, the block of frozen meat is covered with water to fill the voids and to provide the ice glaze, and is then returned to the frozen-storage room.

Shrimp may be frozen individually or in a block in a pan and then ice glazed. Pan-frozen shrimp are also placed in a carton, covered with water, and refrozen. Another method of handling shrimp is as follows: The shrimp are packed into cartons. They are then frozen. The cartons are opened, and cold water is added by immersing or spraying. They are then returned to the freezer.

A new glazing technique for shrimp (Anonymous 1954) is to quick freeze the shrimp in a pan and then pack the frozen shrimp in the carton over a bottom layer of slush ice, with a second layer of slush ice on top. The slush ice freezes on contact and completely surrounds the shrimp. This new technique is said to provide protection equal to regular ice glazing, yet the refreezing and double handling of cartons are eliminated, and the amount of ice weight is substantially reduced.

Reglazing

In order that the glaze on unpackaged fish can be properly maintained, it is necessary to make frequent examinations in the storage room to be certain that the glaze has not disappeared. Reglazing should be done as soon as the condition of the glaze indicates that it is necessary. Quite often, the reglazing is done by spraying cold water on the fish in the frozen-storage room.

Evaporation of the glaze can be retarded by simply placing a tarpaulin over bulk-stored fish or by storing the fish in corrugated fiber boxes or in wooden boxes lined with waxed paper. With fish frozen in blocks, placing them in waxed cartons after they have been glazed will enable them to be held for longer periods without the necessity of having to renew the glaze.

No hard and fast rule can be established as to how often the reglazing should be done, as a number of factors are involved. Glazed fish stored without any additional protective covering may need to be reglazed as often as every 2 weeks. It is best to examine the fish at frequent intervals and not rely on some arbitrary time for reglazing.

Additives to Ice Glazes

One of the chief disadvantages of the ice glaze is its brittleness and its susceptibility to cracking. In order to overcome these disadvantages, various additives to the glazing water have been investigated, and patents have been taken out on additives such as salts, sugars, and alcohols. The additives, however, have not been widely used in most commercial operations, for various reasons.

Bedford (1939) has a patent to produce a substantially transparent non-cracking glaze from aqueous solutions containing approximately 0.2 to 0.3 percent alcohols, particularly edible polyhydric alcohols, aldehydic alcohols, and ketonic alcohols.

Antioxidants (section 2) may be incorporated directly into the dip solution, if desired. Experiments (Tarr, Lantz, and Carter 1950) have shown that whole fish steaks and fillets can be glazed conveniently from a solution containing 0.5 to 1.0 percent ascorbic acid. The dipping solution should contain 1 to 2 ounces of ascorbic acid per gallon of water and be kept at about 33° to 34° F. Fillets and steaks may be given a single dip of 10 to 20 seconds; whole fish may be dipped 2 or 3 times in order to give them a heavier glaze. The glaze formed is only slightly opaque and shows considerable resistance to cracking.

Glazing Fish for Locker Storage

A convenient method of glazing fish for locker storage has been demonstrated (Pottinger 1950). Unfrozen fish are wrapped in vegetable parchment. The package is then soaked in cold water for a few seconds, immediately wrapped in moisture-vapor-proof material, and frozen. Because of the excess water retained by the parchment wrapper, a heavy glaze is formed over the entire fish upon being frozen. The advantages of this method are (1) the elimination of prior freezing and extra handling involved in glazing after freezing and (2) the obtainment of a close-fitting package by having the fish in an unfrozen condition at the time the outer moisture-vapor-proof wrapping is applied.

Other Types of Glazes

Various types of glazes are discussed briefly here. Most of these types have been tried only on an experimental scale, and none have replaced ice glazing on a commercial scale for fishery products.

Pectinate Films

Pectinate has been suggested as a gel coating in place of ice glazing on frozen foods, including fish fillets (MaClay and Owens 1948). A 3-percent solution of sodium hydrogen pectinate in water, preferably in the range of pH 4 to 6, is applied on the product by dip or spray coating. Present pectinate films are not effective barriers to moisture but may find use as carriers of antioxidants.

Gelatine-base Coatings

Hall and Griffith (1933) have taken a patent for a gelatine-base protective coating that consists of 12 parts, by weight, of pure gelatine, 25 parts of cold water, 1.2 parts of potash alum, and 2.4 parts of glycerine. The solution is applied by dipping or spraying at temperatures between 135° and 140° F.

Another glazing formula consists of 7 pounds of gelatine, 10 ounces of glycerine, and 60 ounces of water.

A vegetable-gel covering for consumer items or for a "freezer wrap" is being studied by a meat processor (Anonymous 1952). Its base is a purified, vacuum-dried derivative of Irish moss that is mixed with sorbitol and water. It can be applied by the dip or the spray method and is reported to set in 30 seconds.

Combination of Chemical and Irish Moss Extractive

A combination of various chemicals and Irish moss extractive was tested as a coating solution to extend the storage life of frozen mackerel fillets (Stoloff, Puncochar, and Crowther 1948). The untreated fillets (control) were unacceptable after 3 months of storage at 0° F., whereas the fillets treated with the Irish moss extractive solution without antioxidant showed no major changes up to 5 months. Propyl gallate (0.1 percent), thiodipropionic acid (0.1 percent), lecithin (0.2 percent), nordihydroguaiaretic acid (NDGA) (0.01 percent), and lecithin (0.1 percent) plus ascorbic acid (0.1 percent) dissolved in approximately 1 percent Irish moss extractive solution were ineffective in prolonging the storage life. Gallic acid (0.1 percent) and ascorbic acid (0.2 percent) in Irish moss extractive solution, and NDGA (0.2 percent) in cottonseed oil delayed rancidity in the fillets for 7 or 8 months.

Waxes

Thermoplastic waxes appear promising for coating frozen foods. They consist of blends of various waxes combined in a number of ways with non-waxy materials to produce strong, tough, moisture-vapor-proof films. The foodstuff grades of thermoplastic waxes are odorless, tasteless, and non-toxic and may be used with frozen foods (Anonymous 1947). In application, the frozen foods are dipped in the melted, liquid thermoplastic wax. The thermoplastic wax hardens immediately into a tough and flexible wrapper that withstands ordinary rough handling at low temperature. The thermoplastic wax adheres closely to all surfaces of the food and is easily removed by stripping.

One thermoplastic wax has a dipping temperature range of 140° to 158° F., with 145° F. being the ideal dipping temperature. The manufacturer recommends it for use with non-oily fish and with shellfish, such as shrimp and crab. For oily fish, the manufacturer recommends wrapping the frozen fish in very light-weight pliofilm, saran, or waxed paper before dipping, to prevent the wax coating from cracking and separating away from the fish.

This thermoplastic wax appears to give effective protection to products that can be coated directly. For products that must be given an initial film wrap, the advantage of the form-fitting coating may be lost to varying degrees; additional handling will be involved; and the cost of the protective coating will increase.

In comparison to the ice glaze, the wax glaze is more expensive and requires more handling and a longer time to apply but is tougher, stronger, and longer lasting.

Edible Oils

With bluefish, sea trout, and butterfish, Lemon (1932) reported substituting the ice glaze with a thin coating of edible oil (cottonseed oil, corn oil, or peanut oil) by either dipping the fish into the oil or spraying them. Since the oil film does not evaporate, one coating of oil reduced the drying effect of air during the 12-week cold-storage period. All the oils tested were superior to the common ice glaze in preventing moisture evaporation; however, the use of edible oils for coating fish has never found practical application.

FILMS AND WRAPS

Films and wraps make up another class of protective covering for frozen fish. A good wrapping material for frozen fish should be strong enough to resist tearing and puncturing from handling during the packaging operation, pliable enough to make a tight wrap, easily sealable, greaseproof, and durable at low temperatures; should impart no odors or flavors; and should have a low rate of moisture-vapor and oxygen transmission.

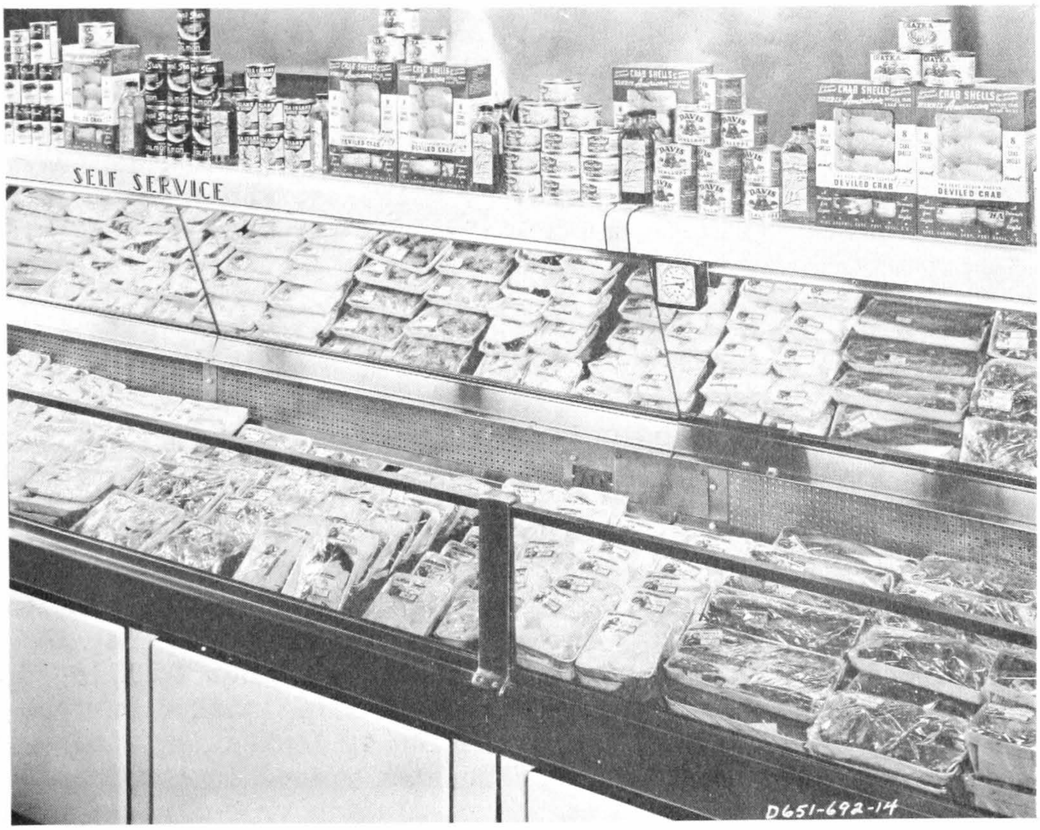


Figure 2.—Transparent films are used extensively as protective coverings for refrigerated fish.

There are a large number of films, foils, resin-coated papers, lacquered papers, waxed papers, plastic-coated papers, and various combinations of laminated papers on the market. Each has its own set of characteristics. The choice of the packaging material is governed by such factors as the protection requirement of the frozen product, the cost of the packaging material, the cost of the packaging operation, and its merchandising features.

In this section, only the more commonly used wrapping materials for frozen fish will be discussed.

Cellophane

Cellophane is transparent, greaseproof, odorless, tasteless, and flexible. It is available in about 150 different grades or types and in a large variety of colors and of printed patterns and designs. Cellophane lends itself readily for use with automatic wrapping machines.

The type of cellophane used for frozen fishery products is coated to be moisture-vapor proof, greaseproof, readily heat sealable, durable at low temperatures, and to have low oxygen permeability. The common gauges are No. 300 (0.0009 inch) and No. 450 (0.0013 inch). It is used as sheets for direct wrapping or as bags for whole fish, fillets, and steaks; it is also used as liners and overwraps for frozen-fish cartons.

Polyethylene

Polyethylene is widely accepted as a packaging film for frozen foods. It is tough, durable, flexible even at low temperatures, and chemically inert. It has a low level of taste and odor transfer, water absorbency, and moisture-vapor transmission. The disadvantages of polyethylene are that it transmits oxygen and solvent vapors and it may be penetrated and softened by many types of fats and oils. The gauges commonly used are 0.002 inch for the plain polyethylene and 0.001 inch for the laminated type. The film is heat sealable but is apt to stick to the heated surfaces of the sealer if the temperature is not carefully regulated.

Aluminum Foil

Aluminum foil is non-toxic, tasteless, odorless, pliable at low temperature, and greaseproof. It has a low degree of gas permeability, even in the lighter gauges, and minimizes oxidation and rancidification of the packaged product. The water-vapor transmission rate is negligible in foil thicknesses as low as 0.00035 inch. Aluminum foil is available with one shiny surface and one mat or satin-finished surface and may be decorated by embossing, gloss coating or laminating, and coloring or printing. Aluminum foil is also widely used in combination with other packaging materials such as paper, plastic or cellulose films, and paperboard. The aluminum foil with a thermoplastic coating is heat sealable.

Figure 3.—Bags made of transparent films are used for packaging a variety of fishery products.

Aluminum foil is one of the best wrapping materials for frozen foods (Winter 1954). For locker use, the best thickness of plain foil is 0.0015 inch, which is known as "locker foil"; for home-freezer use, a 0.001-inch gauge may be used. In addition to its excellent protective properties, aluminum foil is fully moldable and, when properly applied, hugs the product closely at every point, thus eliminating air pockets. By folding the edges of the foil twice or more until it lies flat and tight, the package requires no taping, tying, or heat sealing.

<u>Vinylidene Chloride (Saran, Cryovac)</u>

Vinylidene chloride film has the lowest water permeability of any of the plastic films. It is very strong, tough, flexible at low temperatures, completely transparent, chemically inert, heat sealable, an effective barrier to oxygen and moisture-vapor, and is resistant to common solvents, oils, and chemicals. This material has been modified to make a film

(Cryovac) that is particularly useful for packaging irregularly shaped frozen foods. In the form of bags, it can be made to shrink skin-tight over the food by the momentary application of heat after the air has been drawn from the bag.

Rubber Hydrochloride Film (Pliofilm)

Rubber hydrochloride film is manufactured in a large number of combinations of types and amounts of plasticizers. It is extremely tough and makes a strong seal. Its stability is affected by direct sunlight but is not affected by changes in relative humidity. It may be laminated to itself, to paper, or to other bases to improve its desirable characteristics. A special rubber hydrochloride film, which is plasticized by heating and stretching, can be shrunk around an object by applying moderate heat. A pliofilm particularly adapted for frozen foods (Anonymous 1946) is said to remain flexible at -20°F., is heat sealable, can be sealed closely against the frozen product, and has a negligible rate of moisture-vapor transmission. Gauges No. 120 (0.0012 inch) and No. 140 (0.0014 inch) are the most commonly used.

Figure 4.--Fishery products are sometimes wrapped in transparent films before being placed in cartons.

Coated Papers

A variety of coated papers that are suitable for frozen-food packaging are on the market. Among the most important are wax, vinyl and Saran, and polyethylene.

Waxed Paper

Waxed paper is tasteless, odorless, and non-toxic. Paraffin wax is the principal material used in most waxed-paper coatings. Polyethylene and microcrystalline waxes are used in varying quantities as additives to improve the qualities of the regular wax. The resulting coating produces greater moisture impermeability, better flexibility at low temperatures, and higher seal strength. These properties have led to the extensive use of specially prepared waxed paper in the packaging of frozen foods and other food products. It is available in various thicknesses. Opaque waxed paper lends itself to the effective use of color for brand identification of a packaged product.

Vinyl- and Saran-coated Papers

Papers coated with these plastics are quite resistant to water and water vapor and to the common gasses such as oxygen. These materials are used quite extensively for cartons that hold very wet foods and foods that contain considerable quantities of fatty materials.

Polyethylene-coated Paper

Polyethylene-coated paper (usually a 40-pound white paper with a 1/2- to 1-mil coating) is a popular locker paper for frozen foods. It gives better moisture protection than surface-waxed and wax-laminated papers, especially at creases and folds in the wrap. It has very good low-temperature flexibility and is heat sealable. It is rated as only a moderate barrier to oxygen.

Polyethylene-coated Cellophane

Cellophane with a 1- to 2-mil coating of polyethylene offers considerable promise for the packaging of seafoods. It combines the advantages of cellophane--transparency, greaseproofness, scuff resistance, gasproofness, and good printing surface--with the additional advantages of moistureproofness, low-temperature flexibility, improved film strength, and heat sealability.

Antioxidants in Papers for Food Wrappers

Antioxidants have been incorporated into paper wrappers to improve the keeping quality of fats and fatty foods. Antioxidants can easily be applied to parchment, glassine, and paperboard. The unwaxed papers are treated with an aqueous emulsion of an antioxidant during the drying stage or directly after the final drying operation of the paper manufacture. With waxed papers, the antioxidant may be dissolved directly into the molten wax before its application to the paper.

Various antioxidants may be used. Food-inhibitor-grade butylated hydroxyanisole (BHA) was found by Bentz (1953) to be effective for most paper application. He reports that good results can be obtained by treating unwaxed paper with 0.05 to 0.10 percent BHA; its effectiveness may sometimes be increased by the addition of 0.02 to 0.05 percent citric acid to complex such contaminating metals as iron and copper. Food-inhibitor-grade n-propyl gallate (0.02 to 0.03 percent) may also be used to advantage in some applications.

Carlin (1948) reports that the keeping quality of fats dispersed in cardboard was greatly improved by impregnating the cardboard with citric acid, pyrogallol, or galacetonin. Citric acid and gum guaiac, mixed with sizing on parchment, improved the keeping quality of lard wrapped with this material.

PACKAGES AND CARTONS

At the time the freezing of foods was first begun, very little was known about proper packaging; in fact, suitable packages were almost nonexistent. Along with the growth of the frozen-food industry, however, new packages have been developed so that today there are a number of suitable materials and types of packages available to the frozen-food packer. The trend has been towards the use of containers that fit into production-line procedure and yet are different in appearance from the tin can used for processed foods. As a result, the rectangular container made of waxed paperboard is by far the most widely used in the industry.

Very little has been done in standardizing containers for frozen fishery products. They vary as to types of materials, styles, shapes, and sizes, depending upon the product to be packaged and the desires of the producer. The self-locking carton is probably the most widely used container for frozen fish.

Self-locking Cartons and Trays

The development of self-locking cartons and trays has helped greatly in expanding high-speed packaging of frozen foods. These containers are available with various types of self-locking construction adaptable to the particular requirements of the processor. Frozen-food cartons are usually made of a bleached boardstock and are coated with various waterproofing materials or may be laminated with foil or moisture-vapor-resistant film. The coating material may be an improved wax formula, polyethylene, or some other plastic material.

The hinged-cover, self-locking carton is widely used in frozen-food packaging. The best self-locking carton might be said to be the one that can be set up either by hand or by machinery: much of the setting up and filling of cartons is still done manually in the fish-processing plants.

When used in conjunction with machinery that sets up the carton and then loads and closes it, this type of carton speeds up greatly the packaging operation. Being of the self-locking type, there are no glue problems.

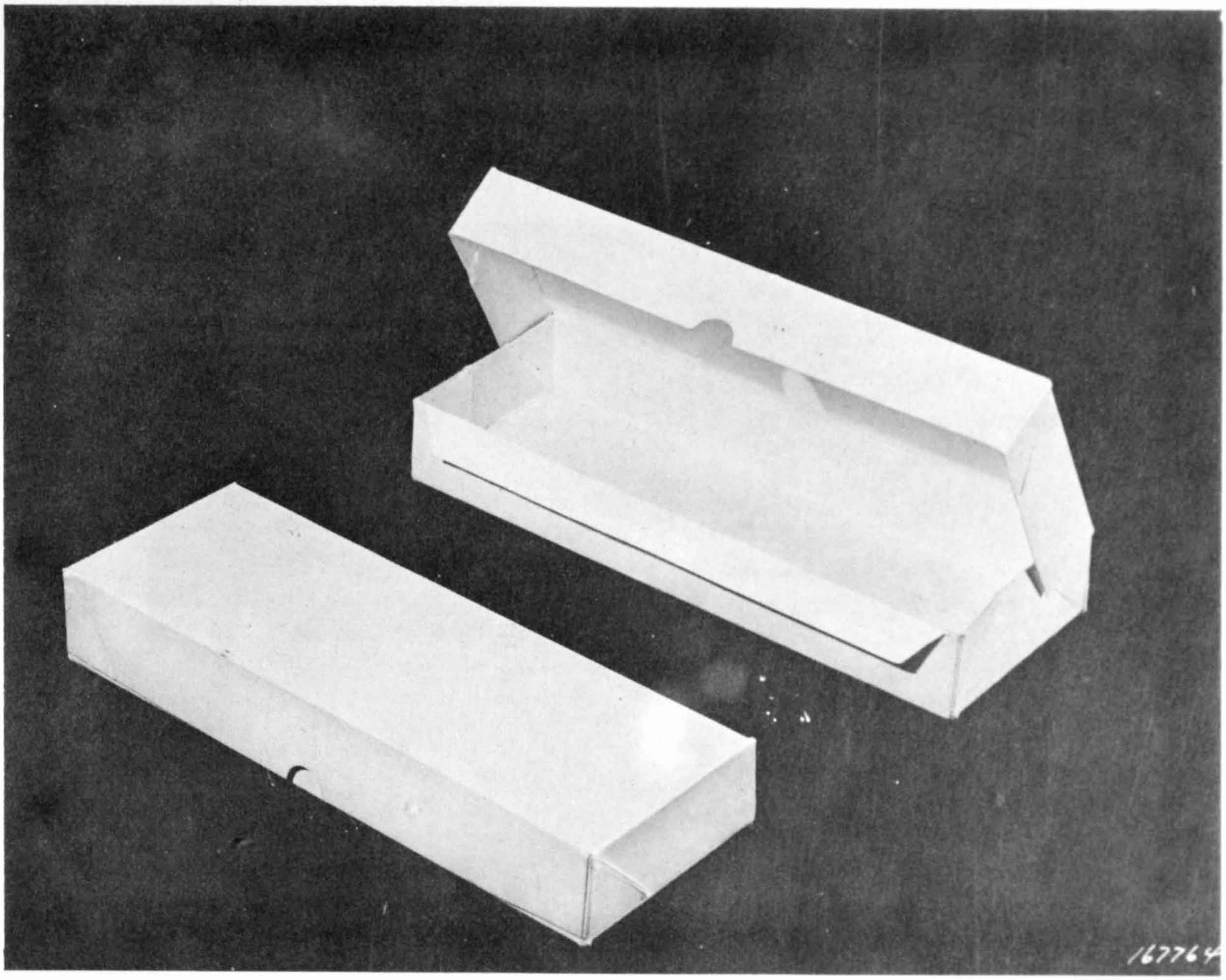


Figure 5.--The hinged-cover, self-locking carton is widely used in frozen-food packaging. (Photo courtesy Marathon Corporation.)

They are shipped and stored flat, yet they make a strong carton when folded into the box form. A moisture-vaporproof, heat-sealable overwrap is generally used with these cartons for packaging frozen foods. Some cartons have covers with a cellophane window to display the contents of the package, but the trend seems to be away from this type of package because of the relatively high incidence of breaking of the window by consumer handling.

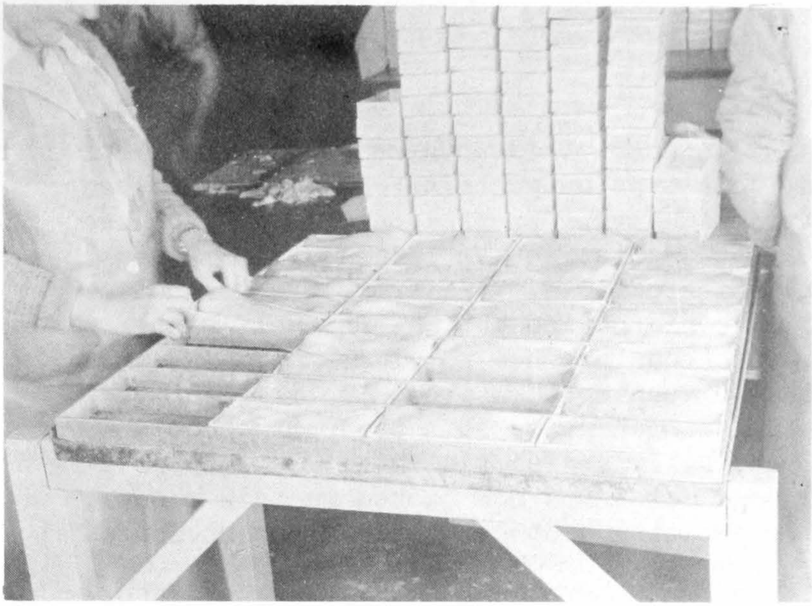
The self-locking cartons are made in two general sizes: the consumer and the institutional. The consumer sizes range from about 3 ounces to about 5 pounds. Whole fish, fillets, and fish steaks may be packed in 1-pound to 5-pound packages, whereas the more expensive products, such as shellfish meats, are generally packed in sizes ranging from 3 to 12 ounces.

A popular-size carton for shrimp and scallops is 5 1/4 x 4 x 1 3/4 inches; a popular-size carton for fillets is 8 1/2 x 3 x 1 1/8 inches. Institutional packs generally come in 5-, 7½-, 10-, and 20-pound sizes.

The cartons usually have some type of heat-sealed overwrap in order to give additional protection to the packaged product. Water-vapor transmission rate of the carton alone was found to be considerable in comparison to rates obtained with cartons used with either a liner or an overwrap, or both (Dykstra, Byrne, and Munter 1952).

Figure 6.--Formed cartons are filled on the packing table (background), and pass quality control inspection (foreground) prior to being automatically closed and wrapped (left). (Photo courtesy of Package Machinery Company.)

One form of tray consists of a sheet of paperboard with its four sides folded at right angles and fastened together at the corners. Two trays may be used to form the top and bottom of a complete telescope-type box. The protection and visibility offered the packaged product in display have been factors in the adoption of the tray for certain types of frozen fishery products. Since some form of transparent window or overwrap is used with this type of packaging, it is essential that moisture-vapor-proof material be used for this purpose and be tightly heat sealed.



Trays made of molded pulp are now widely used for prepackaged meat products and, to a smaller extent, for some fishery products, such as small fish, fish steaks, and fish sticks. The filled tray is overwrapped with a transparent film, which is heat sealed. The trays are sometimes lacquered to provide a high gloss.

Figure 7.--Filling Booth plate froster grid with 1-pound packages.

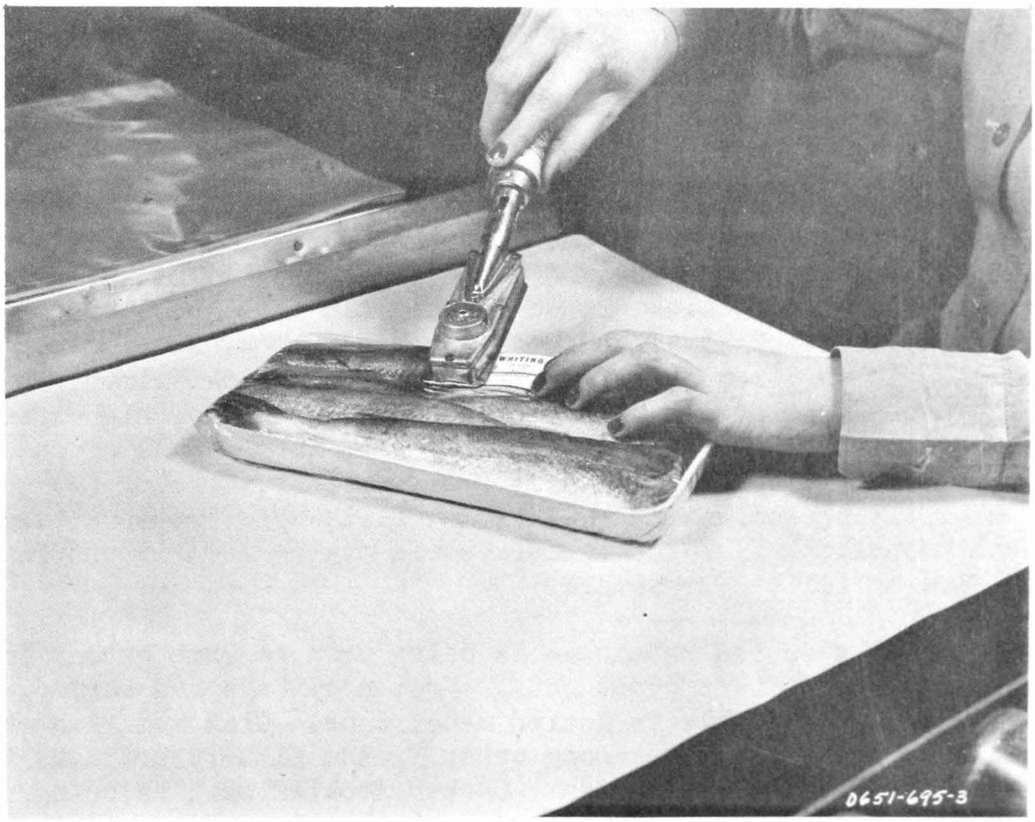


Figure 8.--Heat sealing the transparent film wrapper used with a molded pulp tray for packaging some types of fishery products.

Metal Packages

Metal Cans

Although the metal can has a number of advantages in its favor for use in the packaging of foods, this type of container has not been used to any extent by the frozen-food industry. One reason has been the need in this relatively new industry for a distinctive package which would signify without any doubt that the product was different from canned or heat-processed foods and that it could not be put on the shelf with other canned goods. Since frozen foods are now so widely used and the purchaser has become accustomed to keeping them frozen until ready to use, there has been an increasing tendency for some producers to place certain frozen products in hermetically sealed tin cans. Several varieties of frozen fruits and vegetables are now packed in this manner, and tremendous quantities of frozen citrus concentrates are distributed in metal cans.

There are several advantages in the freezing of foods in hermetically sealed metal containers. Filling operations are speeded up, and leakage problems are eliminated. Foods thus packed may be frozen by immersion-freezing methods, which are faster and more economical than methods used in the freezing of paperboard-packaged products. Transfer of air or water vapor is completely prevented. Cans, being more rugged than cartons, will withstand rough handling much better, and the frozen contents of a can may be thawed quite rapidly, if desired, by placing the can in warm water.

Tests conducted at the Seattle laboratory of the Fish and Wildlife Service have shown that fish frozen and stored in evacuated tin cans maintain their quality much better than in other packaging materials (Stansby 1955). Changes in flavor and color are almost eliminated. Among the advantages cited for packing frozen fish in tin cans are (1) higher quality fish; (2) availability in packaged frozen form of species not hitherto handled in the frozen state, as for example, pink salmon; and (3) labor saving in preparation and packaging through the use of high-speed can-handling equipment. Possible disadvantages to this method of packaging frozen fish are (1) spoilage hazards from improper storage; (2) difficulty of freezing round cans in existing plate-type freezers; and (3) the usual mechanical fish-can fillers could not be used if the fish were in the form of fillets or steaks.

The hermetically sealed metal can is being used to some extent in the packaging of frozen fishery products. Frozen oysters and shrimp, for example, are now available in sealed metal cans. Clam and fish chowders, oyster stew, and shrimp soup are among other frozen fishery products that are now distributed in the sealed can. Cooked lobster meat is being packaged in cans with transparent tops allowing visibility. Uncooked frozen salmon steaks vacuum packed in 1-pound flat salmon cans have been marketed.

Crabmeat has been distributed in 5-pound lithographed cans that were sealed under vacuum and frozen.

Cans are furnished directly to the packer fully lithographed in the desired design. It is essential, however, that some wording to the effect that the contents are frozen and that the can must be kept refrigerated be placed in a prominent position on the can in order to remind the purchaser that the can must be kept in the freezing compartment until ready for use.

Aluminum Pan Packages

The semi-rigid aluminum container or pan package is finding increased usage in the packaging of certain food products. By using aluminum pan packages, producers of prepared fish dinners (TV dinners, a la kings, fish pies) can package their products right in the retail container, which may go to the home freezer, then later to the oven, and be served atthe dinner table without being removed from the original container.

A pan package is made of a sheet of heavy aluminum foil, generally 0.003 gauge or heavier, that is stamped or folded into a pan shape, which is used as the basic container for the product. These packages--made in the form of trays, dishes, and plates--are generally tapered so that they will nest for storage. They are available with printed lids, or without lids if a transparent overwrap is to be used. When used for frozen foods, they are generally placed in individual, rectangular cartons for added protection during distribution.

OVERWRAPS

To properly close and seal paperboard containers, it is generally agreed that an outside wrapper or overwrap should be used. Tests conducted at a Fish and Wildlife Service laboratory (Pottinger 1948) and elsewhere have shown that a waxed-paperboard carton without a moisture-retardant overwrap has a considerably higher rate of watervapor loss than the one with a good overwrap (Adams, Klein, and Simerl 1953). In addition to providing added protection against desiccation of the frozen product during long periods of storage, the overwrap protects against wear and tear that normally is to be expected during distribution and against contamination during handling and storage. It tends to hold the package together and enables the package to withstand rough handling to a better degree.

Figure 9.--Modern frozen-food wrapping machines will handle trays, cartons, or metal-end fiber cans of various sizes. (Photo courtesy of Package Machinery Company.)

Requirements of Overwraps

To be of value for food packaging, a film or overwrap must be non-toxic, tasteless, and odorless, and must satisfy most of the following requirements:

1. Prevent loss of moisture.

2. Have low gas-transmission rates.

3. Be tough, flexible, and durable under conditions of shipment, storage, and marketing of the product.

4. Have adequate stiffness and slip (ability to slide freely so as to be wrinkle-free) to permit convenient and economical handling on high-speed printing and wrapping equipment.

5. Be durably printable.

6. Give an attractive package.

In choosing materials for use as overwraps for packages of frozen fish, it should always be borne in mind that the material must provide high retention of moisture within the package, as otherwise the product will lose moisture during frozen storage and become dried out and unpalatable.

Types of Overwraps

Cellophane and Waxed Paper

Probably the materials used most widely as overwraps are cellophane and waxed paper. Since cellophane is made in a large number of types, the proper one made especially for wrapping frozen foods must be selected (see under "Films and Wraps" in this section). In like manner, special waxes suitable for retarding moisture transfer are used in the preparation of waxed-paper overwraps. Therefore, when ordering cellophane or waxed-paper overwraps for frozen-fish containers, it is essential that the proper type be specified.

Aluminum Foil

Aluminum foil is becoming a popular material for use in overwraps. Eye-appeal is provided by the gloss of polished aluminum, and when the foil is printed with proper combinations of colors, the over-all effect is most pleasing. Unless used in rather thick gauges, however, aluminum foil will tear or puncture easily. Since the tearing strength of the thin foil is relatively low, it must be bonded to other material to produce a laminated product with good resistance to tear; it still retains the protective qualities (such as retarding moisture-vapor transmission) of the plain aluminum foil (Edwards and Strohm 1948). The good heat conductivity of the material may be of importance in cutting the freezing time and thereby increasing the production capacity of the freezer.

Rubber Hydrochloride

Rubber hydrochloride (Pliofilm), though made in a type that is suitable for wrapping frozen foods, has not been used very extensively as an overwrap for containers. It has a somewhat rubber-like odor and tends to become brittle during extended periods of storage.

Polyethylene

Polyethylene film, though finding increased usage in frozen-food wrapping, particularly in the home, has not been used very extensively as a material for overwrapping cartons. One improvement in frozen-food packaging, however, has been the incorporation of polyethylene resin in waxed-paper overwraps. The polyethylene helps to prevent sticking at cold temperatures, improves gloss and color, and increases the resistance of the coating to scuff and rub off.

Polyvinylidene Chloride

Polyvinylidene chloride (Saran), though offering high resistance to moisture-vapor transmission, has not been used to any extent for carton overwraps. This limited use is probably due to the higher cost of this material, as it is otherwise suitable for food packaging, being strong, tough, flexible at low temperatures, completely transparent, and heat sealable. It is, however, rapidly gaining in popularity as a wrap for food in the home.

FACTORS TO BE CONSIDERED IN THE SELECTION OF A SUITABLE PACKAGE

Very careful thought should be given in choosing a package for seafoods. When it is considered that frozen fishery products must compete with each other as well as with other products such as poultry and meat, package design is of extreme importance (Nash 1954). Because of the many kinds and forms of fishery products on the market, it is essential that the package clearly describe its contents. The package should have genuine appetite and eye appeal, and this effect can be accomplished by use of a good picture. The package should be so descriptive in word and illustration that it provides the customer with the precise information she needs. The inclusion of recipes for preparation of the product has been found a valuable aid to sales. Any legal copy that is required (see section on "Labeling") can be included without detracting from the appearance of the package.

According to a survey on consumer buying habits, almost 40 percent of all purchases are made on "impulse" at the retail cabinet and without any previous planning (Isbell 1951). This survey result shows the importance of having a package that can sell itself. A frozen-food package, as with other food packages, should therefore be colorful and clean appearing to develop an immediate interest on the part of the prospective buyer and to convey a sense of value and quality. Well-designed and colorful overwraps on a package can and do serve such a purpose, in addition to being functional. They furnish an excellent medium for attractive printing and eye-catching designs that can aid materially in giving the consumer the required incentives for purchasing. Regardless of the type of material used for the overwrap, colorful labeling is essential to help overcome some of the display limitations of freezer-cabinet storage.

Since one of the functions of an overwrap is to retard loss of moisture from the package, the material must be readily heat sealable to permit high-speed operations in automatic wrapping machinery and to maintain a tight seal under all conditions of handling during distribution. A torn or poorly sealed overwrap will allow appreciable losses in moisture from the package. Proper types of overwraps and packages are available and may be obtained if the user will specify his requirements and inform his supplier of the conditions under which the material is to be used.

LABELING

The label has a tremendous influence in selling a food product, especially in the self-service grocery store. It has been reported that more than 80 percent of grocery sales are in those stores in which purchases are taken from the shelf by the customer; labels are taking over the job of the retail salesman (Street 1955). Much thought should be put into planning a label, and it is particularly important that certain legal aspects be kept in mind. Of primary importance is the name of the product: all foods must be labeled with their common or usual name. The label must not be misleading in any way. Under certain conditions it is compulsory that specific declarations be made. Some products are "defined" and do not require a list of ingredients on the label; those "not defined," however, must list all ingredients in descending order of their proportionate part of the total contents. The presence of artificial coloring or flavoring and chemical preservatives must be stated. It is also essential that the net contents of the container be shown in uniform terms. The name and address of the manufacturer, packer, or distributor must also be shown.

The preceding paragraph gives only a general summary of some of the legal requirements in connection with labeling; for more complete details, the U. S. Food and Drug Administration should be contacted. Although this agency does not "approve" labels, it is good practice to obtain their opinions when planning a label. In addition, there are laws in various states controlling labeling and packaging, with which the manufacturer should become familiar. Since a label is so important, its selection and design should be given great consideration, Before deciding upon a label, it might therefore be advisable to obtain the services of a lawyer or consultant specializing in this field.

WRAPPING MACHINES

Various models and types of machines are available on the market for wrapping packaged frozen foods. New developments in these machines have enabled packers to increase production volume and lower production costs. Wrapping speeds of up to 150 packages per minute are obtained. A machine may generally be adjusted to accommodate packages of any one of several combinations of dimensions and is usually adaptable for the use of practically any type of wrapping material, such as cellophane, waxed paper, and laminated foil. Electric-eye-type registering devices are available that center the printed design accurately on the carton.

Several manufacturers of wrapping machines should be consulted before purchasing a machine,in order that the model best suited for the particular packaging problem under consideration may be obtained.

SHIPPING CONTAINERS

The individual packages of frozen products are placed in large master or shipping cartons for frozen storage and for shipment. These shipping containers are generally made of corrugated fiberboard, which is strong but light in weight and has good insulating qualities. Layout and color coordination between the individual cartons and the shipping containers provides better product identification and utilizes the container to advertise the product further. Certain requirements must be complied with in regard to type of construction of the shipping carton, strength (pound test) of the fiberboard, maximum weight of contents for a particular size carton, and other factors, if the carton is to be used for shipment. Corrugated fiberboard shipping containers must also comply with carrier regulations. The fiber-box industry has standards that deal with terminology, correct style names, and proper order of dimension that have been in general use. The number of cartons placed in a shipping container varies but, in general, will be 12 or 24 for the carton of a pound-or-smaller size. With larger-size cartons, such as those holding 5 or 10 pounds, the shipping container may hold a total of 50 pounds. Since many warehouse people dislike to handle square containers because of difficulties in stacking them, serious consideration should be given to the use of an oblong type of shipping container. Containers made of solid fiberboard do not furnish as good insulation as those of corrugated material and are not considered to be as suitable for shipping frozen foods.

Figure 10.—Cartons of frozen fishery products are placed in large shipping containers for storage or for shipment.

INSULATED CONTAINERS

Several types of specially insulated containers are available on the market for shipping frozen foods. Because of their cost, these containers must be returned after each shipment. (Insulated containers are discussed in more detail in section 1 in the leaflet called "Distribution and Marketing of Frozen Fishery Products" in this series on the refrigeration of fish.)

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