FREEZING FISH AT SEA--NEW ENGLAND

Part 2 - Experimental Procedures and Equipment

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ABSTRACT

IN VIEW OF THE FAVORABLE RESULTS OF THE PRELIMINARY TESTS ON FREEZING-FISH-AT-SEA, FURTHER LABORATORY AND PILOT-PLANT STUDIES WERE CARRIED OUT TO SECURE DATA IN PREPARATION FOR A COMMERCIAL-SCALE INVESTIGATION. FOR FREEZING FISH AT SEA ABOARD THE SERVICE'S EXPERIMENTAL TRAWLER DELAWARE, THE METHOD OF FREEZING FISH BY IMMERSION IN COLD BRINE WAS ADOPTED FOR THE INITIAL TESTS. SALT PENETRATION INTO THE FISH MEAT DOES NOT SEEM TO BE A SERIOUS PROBLEM. THAWING THE FROZEN WHOLE FISH IN WATER (SO THAT THEY CAN BE FILLETED) SEEMS TO BE THE MOST PRACTICAL METHOD. ORGANOLEPTIC, PHYSICAL, AND CHEMICAL TEST PROCEDURES FOR JUDGING THE QUALITY OF THE FROZEN FILLETS ARE DESCRIBED.

INTRODUCTION

Small-scale experiments conducted by the Service's technological laboratories on the Pacific and Atlantic Coasts (Puncochar, 1949) indicated that uniformly good-quality fillets could be prepared from fish frozen aboard fishing vessels and then defrosted in shore plants. These preliminary trials were followed by a laboratory study which compared fillets prepared from fish frozen "in the round" aboard a vessel at sea, with fillets prepared from fish preserved at sea by the usual icing procedures (see Part 1). In these tests, which included five species of groundfish commercially important to the New England Area, the fillets from fish frozen at sea were found to be as good as, or better than, the fillets from corresponding lots of iced fish.

These highly encouraging experiments were, of course, on too small a scale to warrant their direct application to any proposed commercial operation. Therefore, the various possibilities and problems connected with freezing fish aboard a standard New England trawler and thawing them at a shore processing plant were reviewed in considerable detail. Pilot-plant and laboratory studies were conducted to secure data on which to plan the course of a commercial-scale investigation, taking into account the economic aspects of this method of preserving and processing fish.

In the preliminary experiments the fish were frozen individually on coils in still air; in most of the subsequent trials a more rapid freezing method, immersing the fish in refrigerated brine, was used. Fairly-large-scale brine-freezing tests suggested the design for a possible refrigeration system for a commercial vessel. These pilot-scale freezing studies are being continued to develop improvements and simplifications.

Studies of methods for thawing the fish have favored the use of water. After several tests employing single fish, the scale of the experiments was increased until semicommercial trial lots of several hundred pounds each were thawed. Pilot-plant-scale thawing trials are being continued to develop commercially-practical systems. Simultaneously, the scaling and filleting characteristics of the thawed fish

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are being studied to determine whether any changes in the normal procedures are necessary or desirable.

All freezing and thawing methods are being evaluated on the basis of chemical, physical, and organoleptic tests in the laboratory. These tests should aid in providing the best estimate of the consumer acceptability of the final products.

FREEZING ROUND FISH

Choice of Freezing Method: A review of the literature, both technical and trade, indicated no specific information on satisfactory methods for freezing fish aboard a trawler at sea. However, there was considerable related information on which a choice for pilot-plant and vessel experiments could be made. Taylor (1927) presented a useful review of the advantages and disadvantages of several freezing methods. On the basis of this and miscellaneous other reports, four standard freezing methods were considered: (1) direct contact with a refrigerated liquid by immersion or spraying, (2) refrigerated coils or plates, (3) refrigerated air blast, and (4) refrigerated molds or plates.

After considering several variations of each of these four methods, it was decided first to concentrate research on studies of freezing fish by immersion in a refrigerated sodium-chloride solution. This system has several basic advantages for its use aboard a fishing vessel, where space and manpower are at a premium. Freezing in brine is rapid and the equipment required occupies comparatively little space. Because of the buoyant effect of the brine, the manpower and equipment needed to keep the fish separated during the freezing period are at a minimum. Also there are, at least theoretically, some advantages to freezing fish as rapidly as possible. Media other than solutions of sodium chloride, such as mixtures containing calcium chloride, alcohol, glycerol, or sugars, will be studied later. Sodium-chloride brine is being considered first, because it is known that the penetration of sodium chloride into the meat of the fish is only moderate and the penetration of sodium chloride could possibly be reduced to a negligible quantity with the optimum freezing conditions to be employed. The system of freezing with a spray of refrigerated liquid was not considered practical on a vessel because of the excessive space and the special equipment required and the labor needed to handle each fish individually.

Freezing on refrigerated coils or plates, one of the oldest and most common methods, has proved quite satisfactory for land installations. Even aboard a floating freezership it might be a highly satisfactory system, but on a standard commercial trawler the following disadvantages are important considerations: (1) the space required for the freezing room and the weight of the coils or plates would be objectionable; (2) the freezing rate is comparatively slow; (3) the fish must be stacked individually or in thin layers, requiring much space and manpower. It should be noted, however, that this system has one definite advantage: there is no machinery in the freezing room requiring attention.

Freezing in a blast of cold air is faster than on coils or plates, but not so rapid as in refrigerated brine. The space required is also intermediate between the other two. However, considerable manpower is needed to stack the fish individually and to transfer them from the freezer into the cold storage. Also more insulation would be required for a blast-freezer room than for a brine-freezer tank.

Refrigerated molds and compressing plates have been used successfully for packaged cut fish and for blocks of small whole fish. The main difficulty encountered in using this system for large fish is that the block is necessarily thick and therefore requires a long time to freeze. Also, the large heads of the fish make it

difficult to obtain direct contact of the thin tail portion of the fish with the frozen plates. In addition, an excessively long time is required to thaw these large blocks of fish. It is possible that a vertical-loading mold freezer could be designed which would require a minimum of handling, but the equipment would probably be quite costly and complicated.

Although it was determined to start the experimental studies on freezing by immersion in brine, the other methods are not considered impossible or impractical. The pilot equipment and the vessel installations were constructed so that modifications would be possible to permit a variety of studies.

Factors Affecting Salt Penetration: The penetration of salt into the fish is probably the principal reason that brine freezing is not more commonly practiced. The extent of salt penetration and its effect on the final product is being given thorough consideration in the present project. Because the absorption of salt is comparatively high at a cut surface or through the wall of the visceral cavity, it seems obviously desirable to freeze the fish whole. So long as there is no unusual spoilage attributable to the presence of viscera, this freezing method is evidently advantageous, for it should mean less work for the fishermen and delivery at port of potentially-valuable viscera in excellent condition. Preliminary trials demonstrated that the degree of salt penetration depended on the length of time the fish were in the brine, and on the strength and temperature of the brine. When fairly fresh haddock were frozen in brine at 5° F., the absorption of brine by the fish was not serious. In fact, after these brine-frozen haddock were thawed in fresh water, the final salt content of the meat of the fish was very nearly the same as in samples from fresh, unfrozen fish. Although the preliminary tests are encouraging, the problem is being considered in more detail as large lots of fish are frozen and thawed in the course of this project.

Rates of Freezing: In order to attain most efficient operation aboard the vessel and to keep salt penetration to a minimum, information on the factors affecting the rates of freezing in brine is required. Pilot-scale freezing trials are being performed in a specially-built, refrigerated, and insulated tank, with inside dimensions of 30 by 30 by 30 inches and a capacity of about 110 gallons. With brine at 5° F., the brine-freezing tank has a maintained freezing capacity of about 50 pounds per three hours.

As had been expected, the freezing trials demonstrated that circulation of brine around each fish was an absolute necessity; if the fish "packed" together the mass of fish acted more or less like a tremendously large fish, and froze very slowly. Therefore, for some trials, the tank was equipped with a rotating drum mechanism consisting of four sections, each having a radius of 12 inches and length of 24 inches. The rotator is adjustable to operate at several speeds. When the rotator is not used, the brine is circulated with a small water pump of 4-gallons-per-minute capacity. Circulation of the water with this pump did not adequately agitate the fish, which floated and "packed" because of the considerable difference in the specific gravities of fish and brine.

Although the need to keep the fish separated was demonstrated, the trials revealed no significant advantage to very high rates of flow of the refrigerated brine. When the rotator revolved at 5 r.p.m., the fish did not freeze noticeably faster than when the rotator operated at 1 r.p.m. On the basis of this information it was recommended that the rotator in the brine freezer on the experimental vessel need not be operated faster than 3 or 4 r.p.m. A slower rate was not recommended because of the resultant longer time required to shift from one sector to another during loading and unloading operations.

The effect of brine temperature and salt concentration on the rate of freezing is being determined in the experimental brine tank, with and without the rotator. The depth of freeze in the fish is experimentally determined, with an accuracy of 1/16 inch or better by simply cutting or sawing a cross section of the fish and measuring the width of the frozen portion. The line dividing frozen from unfrozen flesh is easily determined by sight and by touch. In preliminary trials, it was found that at 0° F. a depth of freeze of one inch on the side of a large fish required approximately one hour. Whenever the cross section was nearly circular, the width of the frozen portion was nearly the same at all points. On narrow fish, the depth of freeze was greater at the back and at the belly than on the sides. In circulating brine at +10° F. it required nearly 1½ hours to freeze the sides of a large fish to a depth of one inch.

The first freezing trials indicated that the rate of freezing varies with the depth already frozen, and the total time required to freeze to a given depth was roughly proportional to the square of the depth. On a large fish in circulating brine at 0° F., the first quarter inch was frozen in about four or five minutes; a half inch was solid after about fifteen minutes; while a full inch was frozen after about an hour. Data on the times required to freeze the usual sizes of cod and haddock are being determined under various conditions of brine concentration and temperature, movement of the fish, and so forth. The pilot-plant freezing tank and the vessel's brine tank will both be used in securing freezing-rate data.

THAWING FROZEN FISH

Methods: Of importance equal to the choice of satisfactory freezing methods is the determination of practical thawing methods. Three methods and their variations appear worthy of consideration as commercially useful for thawing fish which has been frozen at sea: (1) immersion in water; (2) exposure to the air; and (3) by dielectric heaters.

After reviewing the possible variations of these methods, it was concluded that first consideration should be given to thawing in circulating water, since (1) the rate of thawing would be moderately fast, (2) the operation in a commercial plant could be largely mechanized, (3) the cost of equipment and operation would be moderate, and (4) some of the salt introduced into the fish during freezing in brine would probably be removed.

Thawing in still air at room temperature requires little equipment, but the floor space involved is tremendous, the hand labor needed to spread the fish is costly, and the rate of thawing is slow. Use of an air blast would hasten thawing and consequently reduce the floor space needed; but the labor required would not be reduced, the fish would be more difficult to handle, and the moisture on the surfaces of the fish would evaporate more rapidly. If the air is heated the fish will thaw more rapidly, of course. However, there is the danger of changing the characteristics of the final product if too high temperatures are used. Complete data on air-thawing methods, and combination water-and-air-thawing methods will be obtained as a part of this phase of the study.

Thawing by use of dielectric heaters or other possible electronic systems might prove practical if the cost of suitable equipment is not excessive. Some difficulty may be encountered because of the wide variation of physical characteristics of the parts of fish: bone, flesh, oil-rich liver, etc. If these heaters are as efficient as some reports indicate, the electric power costs would not be unreasonable.

Rates of Thawing: In the experimental studies of thawing in water, the simplest equipment used was a sink or a pan, with water added from the tap. Tests with

50-pound lots of fish were carried out in the 110-gallon tank of the experimental brine freezer. Water was circulated by a 3- to 4-gallon-per minute pump, by operation of the rotator, or by manual operation of a wooden paddle. Large-scale pilot plant operations are being conducted in a reinforced galvanized iron tank, which is 74 inches long, 34 inches wide, and 36 inches deep, with a bottom drain and an adjustable level skimmer. A 1/3 hp. centrifugal pump circulates water through six 3/8-inch holes in a manifold located along one side of the tank. With the tank full, about 32 gallons of water per minute are circulated at a pressure of about 10 pounds per square inch. This provides positive but moderate movement of the water.

Experimental trials for thawing single fish indicated the need for circulation of the water. In still water the temperature of the water within 1/8 inch of the fish dropped as much as 10° or 15° F. below the temperature of the mass of water. These drastic differences were eliminated by even, mild circulation of the water. Further increases in the circulation did not seem to increase the thawing rate markedly.

Thawing proceeds in a manner very similar to that described for freezing; however, the rates are comparatively slower. At 65° F. the first inch on the side of a large fish is thawed in approximately two hours. At 45° F. it required about five hours to thaw to the same depth. As with freezing, the rate of thawing decreases as the depth of thaw increases. A thawing temperature of 65° F. is being used as a base for further studies, since organoleptic tests had indicated no detrimental effects on the fillets of fish thawed at this temperature.

During the first few minutes of thawing, most of the fish tend slightly to float; after about 20 minutes, with few exceptions, the fish tend to sink. Because the fish are so nearly free floating, they are moved about by a minimum of circulation of water, providing there are not so many fish as to prevent movement. In the 400-gallon thawing tank, using the water circulation system earlier described, it is possible to thaw over 1,000 pounds in each batch. This is believed to be a sufficiently large lot to give data directly applicable to full-scale commercial operations.

FILLETING AND PACKAGING

Although a pilot-plant scale cutting and packaging room is being used for some studies, it is planned to conduct the principal processing trials in standard commercial plants. The fish will be thawed at the pilot plant and transported to one or more cooperating fish-filleting plants. Under this arrangement thawing will be conducted under controlled conditions and the further processing will be carried out by the fishing industry's experienced personnel using existing commercial equipment.

TESTING PROCEDURES

General: Preliminary reviews of the literature indicate a lack of entirely satisfactory methods for indicating quality and measuring certain changes that might occur in fish as a result of freezing or refreezing. It is known that freezing and storage, except in some cases where the storage period is very short, cause unavoidable deterioration in fishery products. This deterioration may be so slight as to be almost imperceptible or so pronounced that the products are unacceptable as food.

Insofar as related to this project, at least in the initial phases, the tests will be made on fish immediately after being frozen and after being held in frozen storage for varying periods of time. Any deterioration, if perceptible at all, will

probably be very slight. In view of the lack of entirely accurate and sensitive tests for distinguishing between small differences in quality of the meat of fish, the choice of testing methods is very limited.

Organoleptic Examination: Organoleptic-test procedures are to be used in this project as a basis for judging consumer acceptability of the various lots of fish. Such methods of testing are considered of basic importance since in the final analysis, appearance, flavor, and texture are the deciding factors as to whether a product is acceptable to the consumer. Such factors cannot be ascertained by objective tests alone. Organoleptic measurement of the quality of fish has been, and may continue to be, the first test applied for the determination of its grade. Although chemical and physical methods are often used, the primary standard of comparison goes back to the organoleptic tests.

Organoleptic tests are being conducted on lots of fillets prepared experimentally in the laboratory and those prepared under commercial conditions from fish brought in by the Service's experimental vessel Delaware. The results so far have shown only negligible differences in acceptability between fish frozen once and those thawed and refrozen. These results were obtained from tests conducted with a taste panel composed of laboratory personnel. Large-scale consumer acceptability tests are planned as the project progresses.

Physical and Chemical Methods: It is advisable to use, where possible, other indices of quality in conjunction with the organoleptic tests. Various attempts have been made by investigators at devising chemical and physical yardsticks for measuring quality changes in fish. While some such methods are reasonably satisfactory, they still serve merely as a check and as supplemental data to organoleptic measurements. In this connection, chemical and physical tests which appear to be applicable to the problem and which might correlate well with the organoleptic tests are being studied. The tests being considered first are press drip, free drip, dry matter in press drip, degree of toughening, salt content, trimethylamine content, and extractable actomyosin.

Press Drip: The quantity of liquid or "drip" that separates upon thawing frozen fish is often determined in connection with quality evaluation, especially for experimentally prepared fish. In a sense, it is a measure of the degree of breakdown of the cells of the meat of fish as a result of freezing and other processing. The determination of drip may be of value in showing differences in the quality of the fish as related to method of freezing, storage temperature, rate of thawing, and other factors.

Many methods of determining drip have been reported and it is doubtful if any two of them will give the same results. Since drip is generally determined for purposes of comparison, it is felt that as long as any one method is used for a given series of tests, the results should at least be comparable among themselves.

In this project, press drip (the liquid that separates from the fish during thawing when pressure is applied) is determined in a special piece of equipment designed, in part, in this laboratory. It consists essentially of a cylinder having an internal cross-sectional area of one square inch. A snug fitting plunger, with a detachable weight on top, fits into the cylinder. The combined weight of the plunger and weight is 10 pounds. In making a press drip determination, a plug of frozen fish meat, approximately one inch in thickness and of the same diameter as that of the inside of the cylinder, is weighed and placed in the cylinder. The plunger and weight are set in place and allowed to remain for fifteen minutes at a temperature of approximately 75° F. The fish thaws during this time. The liquid that separates from the fish runs off into a container. The plug of fish is then again weighed,

the loss in weight due to pressing respresenting the quantity of press drip obtained.

Free Drip: The determination of free drip (the liquid that separates from the fish during thawing without applying pressure) is made by placing a portion of frozen fish fillet, previously weighed, on a wire screen in a closed container and allowing the fillet to thaw at approximately 75° F. over a period of 3½ hours. The difference in weight between the frozen and thawed product represents the free drip. This method obviously gives lower values than are obtained by the press-drip method. The combined values for drip by the two methods will also be considered in attempting to correlate the findings with the results of other tests. The differences in drip between lots have so far been too small to be of any consequence.

Dry Matter in Press Drip: It is thought that the quantity of soluble (dry) matter in the press drip may possibly vary as a result of the freezing and processing of the fish. The content of solids or dry matter in the press drip is being determined in order to ascertain whether this value might give some indication of the effect of refreezing on cellular breakdown in the fish flesh. The determination is being done in two parts, namely, the percentage of total solids and the percentage of salt in the drip. Only negligible differences in the total solids and salt content of the drip for different lots of fillets have been obtained.

Texture: In addition to determining texture of the samples by organoleptic means, this quality factor is being determined objectively. The measurement is made in a "tenderometer," a machine which exerts a shearing action on a sample of fish meat by means of a series of metal plates. A force applied to the plates causes them to shear or be forced through the sample of fish. A scale, reading in pounds, indicates the force required for the plates to shear the sample, this force being proportional to the degree of tenderness of the fish.

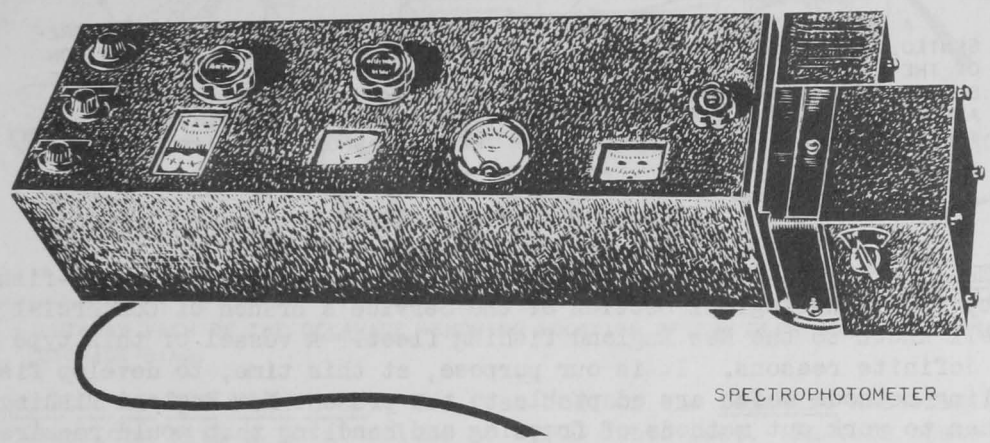
The tenderometer readings have shown very little difference between lots of fillets during the test period. There is some indication, however, that the readings as a whole are increasing as the storage period for the fillets increases. Further tests should indicate whether such a trend exists.

Salt Content: Freezing the fish in brine and thawing in fresh water make possible wide variations in the salt content of the resulting product. Through osmotic action there is a passage of salt from the brine to the meat of the fish. Likewise, the frozen fish containing this increased salt content will most likely lose some of this salt upon being thawed in fresh water. The extent to which the salt content of the fish increases or decreases as a result of these two operations is being determined by chemical analysis, using the method of the Association of Official Agricultural Chemists (1950) for salt in fishery products.

Samples of brine-frozen fish thawed in fresh water have indicated that the salt content of the fish meat will be reduced to approximately that of the meat prior to contact with the brine.

Trimethylamine Content: The muscle of marine fish contains trimethylamine oxide which, upon reduction by certain types of spoilage bacteria, is changed to trimethylamine. The muscle from very fresh fish contains practically no trimethylamine, but as freshness decreases there is a gradual rise in the content of this substance, reaching a concentration of about 15 milligrams per 100 grams of fish meat at the time the fish is considered unmarketable. The application of this determination to this project will be for the purpose of making a comparison of the trimethylamine content of frozen fillets prepared from the fish held in ice, with that of frozen fillets from the fish frozen immediately after being caught. These tests may give an

indication of the relative freshness of the products before the final freezing and storage. Although preliminary tests have indicated that trimethylamine values change very slowly in fish that have been frozen, this determination will also be made periodically on the fillets held in frozen storage. The determinations are being made by the spectrophotometric method.



SPECTROPHOTOMETER

Extractable Actomyosin: The amount of actomyosin (so-called "myosin"), a protein fraction of fish meat, which can be extracted by salt solution at room temperature, decreases as a result of freezing and frozen storage. This decrease in solubility is due to denaturation or internal changes in the protein brought about by the low temperature. By following the changes in solubility of myosin, an indication of the degree of denaturation of the fish protein may be obtained. It is thought that this determination may be of some value in this project in showing possible effects of refreezing on protein denaturation. Due to a delay in obtaining suitable equipment for large-scale separation of liquid and colloidal phases required in this determination, the work so far has been only preliminary and the accuracy has not been such as to permit close comparison of results.

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