FREEZING FISH AT SEA--NEW ENGLAND

PART V - FREEZING AND THAWING STUDIES AND SUGGESTIONS FOR COMMERCIAL EQUIPMENT

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ABSTRACT

DATA ARE PRESENTED ON PILOT-PLANT STUDIES OF FACTORS EFFECTING THE (1) RATE OF FREEZING WHOLE ROUND FISH IN REFRIGERATED SODIUM-CHLORIDE BRINE AND (2) THE RATE OF THAWING FROZEN FISH IN FRESH WATER. RECOMMENDATIONS ARE MADE FOR THE DESIGN AND OPERATION OF COMMERCIAL-SIZE EQUIPMENT FOR FREEZING FISH ABOARD A VESSEL AND FOR THAWING THEM ASHORE.

INTRODUCTION

The feasibility of commercially freezing fish at sea for thawing and processing into fillets ashore depends considerably on the costs of installing and operating the necessary freezing equipment aboard a vessel and the thawing equipment ashore. These costs are directly related to the size and complexity of the equipment, and these, in turn, depend to a large extent on the freezing and thawing characteristics of the fish to be handled. The time required to freeze fish is a prime factor in determining the size of the freezer required to handle the fish as fast as they are caught. Data on thawing rates is also needed to determine the space requirements for thawing equipment.

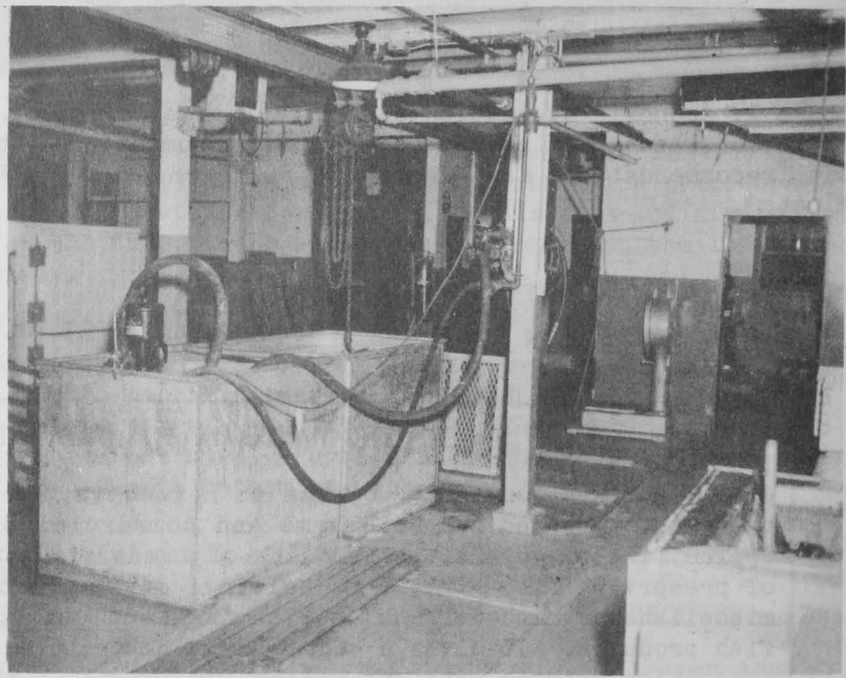

FIG. 1 - INTERIOR VIEW OF PILOT PLANT AT THE SERVICE'S BOSTON FISHERY TECHNOLOGICAL LABORATORY.

Experimental investigations to secure the necessary data on freezing and thawing rates for the commercially-important groundfish of the New England area are being carried out at the Service's Boston Fishery Technological Laboratory (figure 1). The first studies, reported in this paper, were primarily concerned with freezing whole round haddock and cod by immersion in a sodium-chloride brine (in this paper referred to simply as "brine") and thawing them in fresh water. The reasons for limiting the first studies to these freezing and thawing methods were given in detail in an earlier paper in this series (Magnusson, Pottinger, and Hartshorne 1952). After the basic conditions and characteristics of these methods are fairly well understood, it is intended that other freezing and thawing procedures will be studied in detail.

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FREEZING RATES

REVIEW OF EARLIER STUDIES: A few earlier investigators have reported on the rates of freezing fish in refrigerated brine. Plank (1917) developed formulas for calculating the time required to freeze fish of different thicknesses in brine and also in air. He made several assumptions concerning the conductivity of the meat of frozen fish and of the fatty layer near the skin, and concerning the rate of transfer of heat across a fish-brine interface. His few laboratory trials indicated the formulas were fairly satisfactory, at least under certain defined conditions. Tanaka (1949) revised Plank's formulas by using different constants for heat transfer and conductivity. He also modified the calculations slightly by considering the fish to be a conically-shaped body rather than a perfect cylinder. He found that his experimental data, obtained on freezing three fish, compared well with his calculated formulas. Dunkerley (1918) reported on experiments to determine the time required to freeze eviscerated fish in brines of different temperatures. He considered the fish as essentially frozen when a mercury-in-glass thermometer, inserted just above the backbone, read 25° F. He proposed a simple formula relating the temperature and freezing rates. In 1920 (Committee 1920) there appeared a fairly thorough but "preliminary" report on a study of the practicability of freezing fish, especially herring, in brine at a shore plant. Later Stiles (1922) made a scholarly investigation of the problem, using uniform cylinders of a 5-percent gelatin solution and noting the temperatures at several points therein with thermocouples. Taylor (1927) summarized and interpreted some of the above reports. He especially noted the advantages of freezing in refrigerated brine. These reports quite thoroughly considered the theories involved and noted the effects on the freezing rates of several factors: the brine temperature, the brine flow, the thickness and the shape of the fish, the insulating effect of the skin and the fat layers, and so forth. Unfortunately none of these workers took all these factors into account in tests on whole round groundfish. Although many valuable ideas may be gathered from their reports, it is not possible to apply their data directly to the problems of freezing trawl-caught fish aboard a vessel. Therefore, several pilot-scale brine-freezing trials were required to accumulate data on the rates of freezing of round cod and haddock (the most important commercial groundfish in New England waters).

EXPERIMENTAL STUDIES: The pilot-plant scale experiments made to determine the time required to freeze fish in refrigerated brine have been carried out in a specially-built tank, with inside dimensions of 30 by 30 by 30 inches (figure 2). The sides of this tank are encircled with freon-refrigerated coils, and the tank is well insulated. The net refrigerating capacity of the equipment is about 2,000 B.T.U. per hour; on a continuous basis about 50 pounds of fish can be frozen every three hours. For the bulk of the experiments the tank was equipped with a four-section screen-drum mechanism rotated at five revolutions per minute. Although each of the four sections of the drum could hold over 30 pounds of fish, generally less than 15 pounds were placed in each section in order to obtain complete freedom of movement of the fish.

These experiments were all performed with fish at least 24 hours out of the water. For most of the trials, whole round fish were used. It is realized that a commercial freezing-fish-at-sea operation would freeze fish that are only a few minutes, at most a few hours, out of the water. However, it is impossible to secure such fresh fish for use in shore laboratory experiments. Although no marked differences in freezing characteristics are expected, thorough freezing-rate trials with fish right out of the water are contemplated for some trips of the experimental trawler Delaware.

In the experimental pilot-plant scale trials ashore, the freezing rate was followed by periodically removing one or two fish, cutting them vertically at the point of maximum girth, and measuring the depth (from the side) of the frozen layer. On a cross section of a fish, made by cutting or sawing, the line dividing the frozen and unfrozen portion was easily distinguished. With cod and haddock of average size frozen at the lower temperatures, the "depth of freeze" could be easily measured with a precision of 1/16 inch, especially during the first few hours of a freezing operation at 10° F. or lower. Near the centers of very large fish (over 10 pounds) frozen at 0° F. to 10° F. and of smaller fish frozen at higher temperatures, the lines of demarcation between the frozen and unfrozen meat of the fish were not so distinct. A thin metal-stemmed thermometer inserted at the dividing line between the frozen and unfrozen portion regularly read between 25° F. and 28° F. After the first 30 to 45 minutes, the temperature of the unfrozen center of the fish was uniformly at about 30° F. to 32° F. At the same time, the temperature of the frozen portion near the skin approached the temperature of the brine.

In the temperature range (0° F. to 15° F.) of the brine in the experimental trials, the data indicate that the time required to freeze to a given depth is inversely proportional to the difference between the brine temperature and 30° F. Whereas a 10-pound cod in brine at 10° F. takes about 100 minutes to freeze to a depth of one inch (measured from the side), in brine at 0° F. the same depth is frozen in about 60 to 65 minutes. On the basis of this relationship between temperature and time required to freeze, all results from the pilot-plant trials were converted to the time required to freeze to the various depths in brine at 0° F. and at 10° F.; this conversion of the data to comparable bases implemented their correlation and interpretation. The results indicate that cross sections (of about the same area) of cod and haddock freeze at essentially the same rates.

FIG. 2 - EXPERIMENTAL FREEZING TANK.

Figure 3 (a cross section of a ten-pound cod near the thickest part of the fish) illustrates the freezing rate when the fish is moved at a moderate speed (5 to 10 feet per minute) through brine at 10° F. Until the depth of the frozen layer equals three-fourths of the radius of the cross section, the time (T) required to freeze to a given depth (D) is approximately proportional to the product of the depth and the depth plus one-half inch: $T = k\ (D)\ (D + \frac{1}{2})$, where k is a constant dependent on the temperature of the brine. It will be noted that the <u>rate</u> of freezing decreases as the <u>depth</u> already frozen increases. However, the last quarter of the radius was found to freeze in about half of the time predicted by this relationship. Thus, the total time to freeze completely a fish of a given radius is considerably less than the time to freeze to the same depth in a larger fish. The rates required to freeze completely (temperature throughout below 25° F.) whole round cod and haddock of various sizes moving in brine at 10° F. and at 0° F. are given in table 1 and figure 3. These rates are all conservative estimates, and therefore they are subject to later revision, probably downward, when more extensive experiments have been conducted.

If the effects of friction are disregarded, an infinitely fast movement of brine over the surface of the fish should yield the ideal condition, wherein the surface is continuously held at exactly the temperature of the brine. Stiles (1922) noted that the ideal condition was nearly approximated (at least 85 percent) with even a moderate movement (10 feet per minute) of the brine; presumably this is because of the relatively slow rate of heat transfer through the skin and the meat and the high heat capacity of the brine. In trials conducted in the pilot-plant freezing tank, when a fish was held still in brine at 5° F., and the latter was not circulated, temperatures in the brine approximately 1/8-inch from the fish rose to as high as 15° F. When the brine was circulated even mildly (e.g., 0.1 ft. per minute), the temperatures of the brine near the fish were the same as the temperature of the bulk of the brine. When brine was pumped at rates of over 25 feet per minute past a fish suspended in a cylinder, the freezing rate was not much faster than when the brine was circulated past a fish at about 0.1 foot per minute. Other tests showed that the rate of freezing was essentially the same whether a fish was in the drum rotating at 5 r.p.m. or 1 r.p.m. or was simply held under the surface of the brine with a screen and the screen rapidly raised and lowered about 10 or 15 times during the entire freezing period. Thus, there seems to be little advantage to the movement of brine past the fish surface at high velocities.

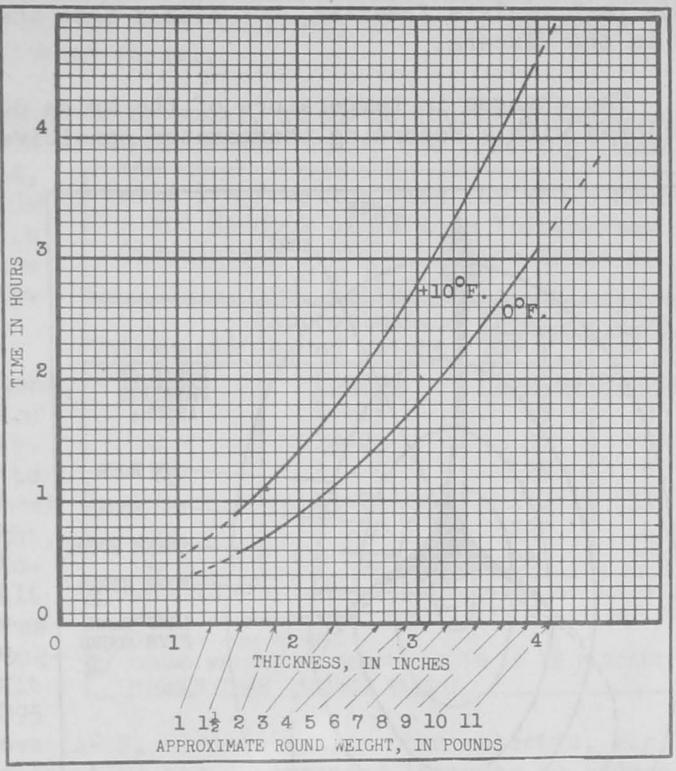

FIG. 3 - THICKNESS OF COD OR HADDOCK VS. TIME REQUIRED TO FREEZE IN BRINE AT 0° F. AND 10° F.

The shape of the cross section of a fish was found to have considerable effect on the time required to completely freeze the fish. For fish of equal weight and with approximately equal cross-sectional areas, the most elliptical (that is the least circular) froze in the least time. A flounder (lean like haddock) was completely frozen long before a haddock of equal weight or cross-sectional area. On the other hand, when fish of equal thickness are compared, the roundest freezes fastest. According to a few trials, a cross section of a flounder two inches thick (the vertical axis) with the other (horizontal) axis about ten inches, required about 25 percent more time than a haddock two inches thick.

After the elapse of only half of the total time necessary to freeze the fish completely, the depth frozen is more than three-fifths of the distance from side to the center. At this stage the unfrozen area of the cross section at the point of maximum girth is less than one-sixth of the total and, as the fish has a tapered or cone-like shape, only about one-tenth of the entire fish is not frozen.

When three-fourths of the total time has elapsed, the freezing of the fish is well over 95 percent complete. It should be noted that the last portion of the fish to freeze (see figure 4) is generally part of the viscera. It is not that this part resists freezing, but simply that the point farthest from all surfaces is in the viscera.

The changes in temperature of the brine during the freezing experiments were followed with a recording thermometer sensitive to ± 0.5° F. The temperature normally rose rapidly during the first few minutes, usually reaching a maximum in 15 to 45 minutes. The amount of the temperature rise depended primarily on the weight of fish frozen. For instance, in one trial with 50 pounds of fish, the temperature of the brine rose more than 5° F. The time of the maximum temperature depended to some extent on the weight of fish in the lot, but mainly it depended on the sizes of the individual fish. For example, with a load of scrod the highest temperature was reached in about 15 minutes; with large haddock the temperature peak came after a half hour or more. Calculations based on the temperature records, the heat capacity of the brine, and the weight of fish indicate that scrod (1½ to 3 pounds round weight) are half frozen after 12 to 15 minutes in brine at 10° F. This is about one-sixth or one-seventh of the total time required to freeze completely fish of this size. This result compares well with calculations based on the depth of freeze versus time data.

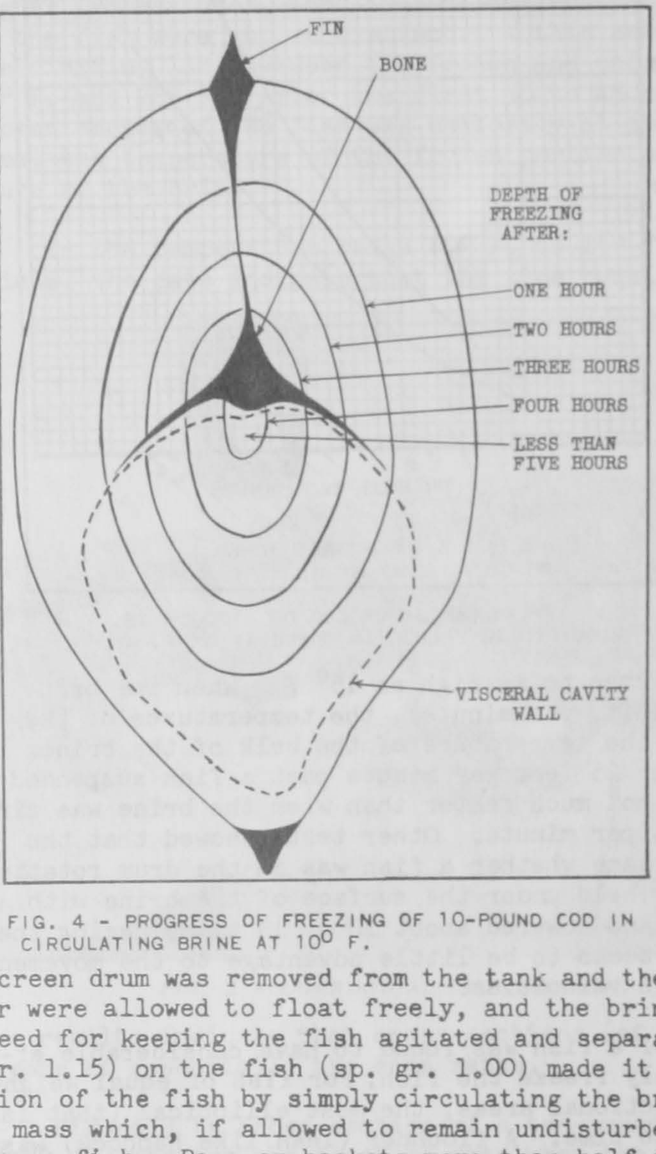

FIG. 4 - PROGRESS OF FREEZING OF 10-POUND COD IN CIRCULATING BRINE AT 10° F.

Trials in which the rotating screen drum was removed from the tank and the fish were held in a basket or a bag, or were allowed to float freely, and the brine was circulated, demonstrated the need for keeping the fish agitated and separated. The buoyancy of the brine (sp. gr. 1.15) on the fish (sp. gr. 1.00) made it difficult to secure adequate agitation of the fish by simply circulating the brine. The fish "packed" together into a mass which, if allowed to remain undisturbed, froze slowly, like a single very large fish. Bags or baskets more than half filled with fish, even though often rapidly raised and lowered and even occasionally turned over, often caused the fish to "pack" together and the freezing of all the fish was not completed in the expected time.

In freezing trials using the rotating screen drum, no "packing" was encountered when the weight of fish in a section was 25 pounds or less. However, in tests with 28 or more pounds in a section there was definite evidence of insufficient movement; on several fish there were soft spots even after they had been in the refrigerated brine at 10° F. for an hour. As the net volume of each section was 1.25 cubic feet, the critical point for this apparatus was approximately 20 pounds per cubic foot of container volume.

FREEZING EQUIPMENT SUGGESTIONS

On the basis of the pilot-plant scale experimental observations and data, several suggestions and proposals can be made concerning possible equipment for freezing fish in brine aboard a fishing vessel.

BRINE TEMPERATURE: Other things being equal, it is obviously advantageous to have the brine as cold as possible. With colder brine, the freezing times would be shorter (see table 1) and, therefore, more batches of fish could be frozen in a day. However, with sodium-chloride solutions there are very definite limitations on how low the operating temperature can be.

Table 1 - Freezing Time for Whole Round Cod and Haddock of Various Thicknesses in Circulating Sodium-Chloride Brine at 10° F. and 0° F.

Thickness 1/	Approximate 2/ Round Weight	Freezing Time	
		10° F.	0° F.
Inches	Pounds	Minutes	Minutes
1½	1 -1½	55	35
2	1½-2½	85	55
2½	3 - 5	125	80
3	4½-7½	170	110
3½	7 -10	220	145
4	9 -12	280	185

1/ SIDE TO SIDE THICKNESS (SMALLEST DIAMETER OR VERTICAL AXIS OF A CROSS SECTION) AT THE POINT OF MAXIMUM GIRTH.

2/ ROUND WEIGHT IS GENERALLY 10 TO 15 PERCENT HIGHER THAN DRESSED WEIGHT.

Several practical considerations, such as the troublesome formation of ice on the refrigerant-cooled surfaces, prevent a close approach to the limiting temperature (6° F.) where even eutectic (23.3 percent by weight, 88.3 degrees salometer) sodium-chloride solution freezes solid. Salt will crystallize out at temperatures well above -6° F. from brines stronger than eutectic. For example, salt will separate from a 25-percent (95 degrees salometer) brine at above 14° F. Brines weaker than eutectic, e.g., 21 to 22 percent (80 to 84 degrees salometer) are recommended in order to reduce the possibility of salt depositing at some critical point in the system. On the *Delaware* the planned operating temperature of the brine (21.1 percent, 80 degrees salometer) is between 5° F. and 10° F.

EQUIPMENT DESIGN: To make most effective use of whatever temperature is attained, the freezing equipment must be designed and operated to give efficient transfer of heat from the fish to the brine. According to laboratory and pilot-plant experiments, to accomplish nearly maximum efficiency it is simply necessary to maintain either a moderate movement of the brine over the surface of every fish or of the fish through the brine. Unfortunately, because of the tendency for the fish to float and "pack" at the surface of the brine, this is not easily accomplished when large quantities of fish are handled. The pilot-scale tests indicate that if the fish are to be free to move, the maximum safe load is about 20 pounds per cubic foot of useful space (the net volume of the baskets or sectors enclosing the fish).

The movement of the fish through the brine appears to be far more practical than the circulation of the brine past the fish. For example, to accomplish the same relative movement at the interface, either one part of fish must be moved a foot to the right, or 3 to 5 parts of brine must be moved a foot to the left. Furthermore, unless the brine flow rate is very high and properly directed, the moving brine will not break up the "packs" of fish. To change the direction of brine flow frequently would not be economically feasible.

On the other hand, moving the fish with a rotating, divided screen-drum immersed in a tank of brine proved simple and effective in the pilot-plant trials. At each rotation, the fish (if not too tightly packed in the enclosure) became rearranged and all surfaces were frequently bathed with new refrigerated brine. The drum must be divided lengthwise, or have baffles to keep the fish moving and turning. In order to allow for keeping the various sizes and species in separate lots, the drum recommended for the Delaware included several sections.

The advantage of using bags to hold the fish rests in a possible reduction in the labor needed to unload the freezer tank and later the vessel (the frozen fish might be left in the bags until the thawing operation was completed). The disadvantages include the extra labor of placing the fish in the bags, the problems connected with removing the fish from the bags, the reduction in the capacity of the freezing equipment (because of "lost" space between bags), and the cost of the bags. The pilot-plant trials (in which bags were used to hold the fish) were successful if the bags were only about half full. Therefore, if bags are used, the capacity of the freezing equipment would be less than if the fish are loose.

A possible alternate for the rotating drum would be a system of rectangular baskets of metal mesh fitting smoothly into a framework in a tank. The baskets would be raised and lowered in the tank to provide the necessary movement and agitation. According to the pilot-scale trial results, the baskets would not have to be moved often; once per minute would be more than sufficient if full advantage is taken of the circulation of the brine to and from the heat exchanger. The experiments indicated that the speed with which the baskets are raised is most important. The power required to raise the baskets may be excessive unless very light baskets can be employed. Possibly the cover alone could be moved to provide the necessary agitation during the freezing period. The baskets could fit closely into a tank and thus the non-working volume of brine within the freezer could be held to a minimum. In the basket-type freezing system, it might be practical to have several more or less independent small tanks. This would be advantageous because it would be possible to circulate brine in only those tanks in use. It would be practical to drain one tank at a time for cleaning or (if desirable) during an unloading operation. Furthermore, a leak or other minor trouble would often affect only one tank and the others would still be available for freezing.

EQUIPMENT SIZE: The proper size of the freezing equipment depends on the time required to freeze, the rate at which fish are caught, the distribution of species and sizes of fish, and the average fraction of the total catch to be frozen immediately after being caught. Only the first factor will be discussed in detail. For the Delaware it was planned that for experimental purposes a part of the catch would be iced in the normal manner and, therefore, the estimated desired freezing capacity was set at only 1,000 pounds of haddock or market cod (average round weight, six pounds) per hour. The chosen refrigeration machinery (an absorption-system plant) has a rated capacity of 25 tons per 24-hour day. This capacity is in excess of the present freezing and storing requirements and would therefore permit future enlargement of the freezing equipment. It is also sufficiently oversized to handle larger than average freezing loads (possibly up to 1,500 pounds per hour), such as when smaller fish predominate.

According to the pilot-plant freezer trials, haddock and market cod freeze completely at 10° F. in an average of about three hours. For a rate of 1,000 pounds per hour, the system must, therefore, have a total capacity of 3,000 pounds. At 20 pounds per cubic foot, the net volume of the containers must be 150 cubic feet. The drum mechanism on the Delaware is divided into twelve sections, each of about 12.5 cubic feet. The tank containing this drum is 5 by 5 by 10 feet, or 250 cubic feet.

If a basket system were to be used, a possible arrangement with about the same total capacity might include three separate tanks, each 4½ by 4 feet, and 4 feet deep. Each tank could have two baskets 2 by $3\frac{1}{2}$ feet, and 3-3/4 feet deep, each basket with a net volume of about 25 cubic feet and capable of holding 500 pounds.

If small scrod, weighing $1\frac{1}{2}$ pounds, are being frozen, the time required to freeze would be only about an hour and, therefore, the net capacity of the Delaware's freezing tank could be nearly 3,000 pounds of small scrod per hour, provided the heat exchanger and refrigeration machinery are adequate. When large cod (over ten pounds) are handled, and they are to be frozen completely before removal from the tank, an operation requiring about six hours, the freezing capacity of the equipment would drop to 500 pounds per hour. However, advantage could possibly be taken of the fact that even a fish four inches thick is well over 90 percent frozen after 3 hours in brine at 10° F. The freezing of these large fish could be completed during the first hours of storage mainly by the reserve refrigeration represented by the low temperatures (10° F. to 25° F.) of the already-frozen fish. Even when a variety of sizes of fish are handled simultaneously, it may prove to be most practical to leave all the fish in the brine for the same length of time. The time would be chosen so as to insure at least 90-percent freezing of the largest fish. The extra hour or two in the brine should not seriously increase the salt content or otherwise change the characteristics of the smaller fish.

THAWING RATES

LITERATURE REVIEW: Reports of studies on the thawing of frozen whole fish are far fewer than reports on freezing of whole fish. Stiles (1922) presented some information on thawing rates and problems. He noted that thawing is a relatively slower process than freezing. His data illustrate the decided advantage of thawing in water over thawing in air. More recently, Reay, Banks, and Cutting (1950) reported on a few tests on thawing whole and packaged fish in still and moving water, and air at different temperatures. They concluded that the most practical method for thawing whole fish was in well-circulated, moderately warm water. These reports are based on laboratory or small-scale experiments, generally using fish frozen in air or on plates. Additional information was necessary and, therefore, semi-commercial and pilot-plant trials thawing brine-frozen cod and haddock in water were conducted.

FIG. 5 - EXPERIMENTAL THAWING TANK.

EXPERIMENTAL STUDIES: The experimental equipment and methods used in the pilot-plant tests on thawing in water were very similar to those used in the brine-freezing studies. The bulk of the data was obtained using the same 30 by 30 by 30-inch tank with the rotating screen drum. Several semi-commercial trials were made in a tank, 8 by 3 by 3 feet (figures 5 and 6) equipped with a 1/3-hp. centrifugal pump to circulate the water. This tank was supplied with cold-water (42° F. to 65° F.) and hot-water (150° F.) inlets and with adequate overflow arrangements. Whole round haddock and cod frozen in the course of the pilot-plant freezing studies were used in most of the thawing trials. For a few of the large-scale thawing experiments, fish which had been frozen in brine aboard the Delaware were employed.

The progress of thawing was followed by occasionally cutting one or more fish with a sharp, sturdy knife and measuring the thickness of the thawed layer. The line between the thawed meat of the fish and the still frozen meat was quite clear and definite. During at least the first four hours of thawing, unless the fish were old and soft (from repeated freezing and thawing), the thickness of the thawed layer could be estimated to within 1/16 of an inch. The temperatures at various depths were determined by inserting a thin-stemmed metal thermometer at several points in cross-sectional cuts. After 30 minutes of thawing, the temperature of the center of a cod or haddock, weighing from 1 to 15 pounds, had risen to between 25° F. and 30° F. The borderline between the frozen and thawed layers was between 30° F. and 32° F. The temperature of a given point in the thawed layer depended on the location of the point and on the temperature of the thawing water. Figure 6 illustrates the rate of thawing of a 10-pound cod, near the thickest part of the fish, when it was moved through 60° F. fresh water at about 10 feet per minute. By comparing figures 3 and 6 it will be seen that thawing in water proceeds in much the same manner as does freezing in brine. However, presumably because water (thawed meat of fish) has a much lower heat conductivity than ice (frozen meat of fish), thawing at 60° F. is only about half as rapid as is freezing at 0° F. The dependence of the thawing rate on the depth of thawing and the thickness of the fish are the same as described for the freezing process. Also, in thawing, as in freezing, the rate was found to vary directly with the difference between the temperature of the thawing water and 28° F. to 30° F. Conservative estimates of the time required to thaw completely fish of various thicknesses of circulating water at 60° F. are given in table 2.

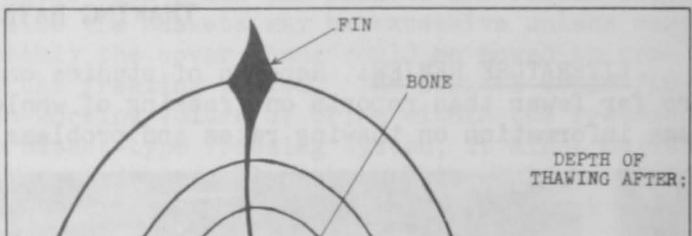

FIG. 6 - PROGRESS OF THAWING OF 10-POUND COD IN CIRCULATING WATER AT 60° F.

The effect of the shape of the cross section of the fish on the rate of thawing and the time required to completely thaw the fish was found to resemble closely the effect on freezing as described in the section in freezing rates. A flounder, which has an elliptical cross section, thawed in much less time than a round haddock of the same weight. However, the flounder took longer (about 25 percent) to thaw than a haddock of the same thickness. In whole round fish, the last portion to thaw was in the viscera. A large number of partially-thawed fish were filleted in the pilot plant to determine the effect of the degree of thawing on the ease and efficiency of filleting. In these trials it appeared to semi-experienced filleters that almost all, but not necessarily all, the fillet portion should be thawed. When the viscera, the bone, and a thin layer of meat next to the bone were frozen, the fish were easier to fillet than when the fish were completely thawed. Although it might take four hours to thaw a market cod completely in water at 60° F., the fish would be ready for filleting after three hours or less. The last column in table 2 gives a conservative estimate of the time required in water at 60° F. to thaw fish of several size groups sufficiently for filleting. The same data are also presented in figure 7. When larger quantities of fish actually frozen at sea under proper conditions are available, it will be possible to secure better data on the time required to thaw. It is anticipated that the time, especially to thaw sufficiently to permit filleting, will be revised downward from those given in table 2 and figure 7.

Table 2 - Thawing Time for Frozen (0° F.) Whole Round Cod and Haddock of Various Thicknesses in Circulating Water at 60° F.

Thickness 1/	Approximate 2/ Round Weight	Thawing Time at 60° F. Completely	For Filleting
Inches	Pounds	Minutes	Minutes
1½	1 -1½	60	50
2	1½-2½	100	85
2½	3 - 5	150	125
3	4½-7½	210	170
3½	7 -10	280	220
4	9 -12	360	285

1/ SIDE TO SIDE THICKNESS (SMALLEST DIAMETER OR VERTICAL AXIS OF A CROSS SECTION) AT THE POINT OF MAXIMUM GIRTH.
2/ ROUND WEIGHT GENERALLY 10 TO 15 PERCENT HIGHER THAN DRESSED WEIGHT.

Several experiments were carried out to determine the effect of varying the speed of the water moving past the fish on the rates of thawing. When the water was more or less undisturbed, the temperature in the water immediately next to the fish dropped to 12° F. to 15° F. below the temperature of the bulk of the water. Scrod haddock required 1½ to 2 times as long to thaw in "still" water as in moderately moving (10 feet per minute) water at the same temperature. When water (at 65° F.) was pumped past a fish at the rate of 60 feet per minute, or faster, after 15 minutes the depth of thawed meat was about 1/16 of an inch more than when water passed the fish at 1 to 5 feet per minute. After 30 minutes, the difference in the depths of thaw were less than 1/16 of an inch. Thus, circulation of water past a single fish at a moderate, practical rate resulted in thawing rates not more than 10 percent longer than the most rapid circulation possible in the pilot-plant equipment.

The pilot-plant studies demonstrated that it is far easier to agitate fish in fresh water than in brine. It was found that such positive agitation as supplied by a rotating drum was not necessary. Whereas brine has a considerable buoyant effect on the fish, a brine-frozen fish has only a slight tendency to float in fresh water. After only 15 or 20 minutes of thawing in fresh water at 60° F., all or nearly all the fish tend to sink slightly. Tendencies for the fish to float or sink were not sufficient to cause undue "packing." Large lots of loose fish were easily kept moving and separated by a well directed flow of water. After several trials, a quite satisfactory arrangement was developed for circulating water in the 8 by 3 by 3-foot tank. Water was moved by a 1/3-hp. centrifugal pump into a manifold consisting of a two-inch pipe, 7½ feet long, with six 3/16-inch holes equidistant along the length. About 30 gallons of water per minute (under a pressure of about 10 lbs. per sq. inch) were directed through these orifices in the manifold and across the bottom of the tank. This resulted in a circular movement of all the water in the tank, sufficient to keep the fish from "packing" at the bottom or the top.

In several thawing trials using the rotating drum, the maximum safe load per 1.25-cubic-foot section was found to be between 25 and 30 pounds. Thus, in this well-agitated drum mechanism it was possible to thaw 20 to 24 pounds of fish per cubic foot of enclosure. In trials with the large tank, where agitation was accomplished by means of circulating the water, the safe load was a little smaller. When the space available for use (below the water line and not including the area screened off for the pump) was about 50 cubic feet, the largest load that thawed satisfactorily was 1,000 pounds.

Whereas the lowest temperature that may be safely used in the brine-freezing process is limited by the characteristics of the brine, the temperature of the thawing process is limited by the characteristics of the fish. On the basis of reports on the effect of various temperatures on fish proteins, it was anticipated that temperatures above 65° F. might adversely affect the quality of the fish. In a preliminary experiment to consider the effects of water-thawing at elevated temperatures, several fish were thawed in water at 90° F. A semi-experienced testing group noted nothing unusual about the taste, odor, or appearance of the fillets prepared from these fish. In one trial, when the water temperature rose (accidentally) to about 110° to 115° F., the meat of the fish was partly cooked and fell apart readily. In a well-controlled pair of trials at 53° F. and 72° F., preliminary observations indicate there was no apparent difference before or after cooking between the two sets of fillets cut. It is to be emphasized that in all of the thawing trials the fish were filleted less than two hours after they were completely thawed. Undesirable enzymatic and bacterial actions are to be expected if the fish are held too long at high temperatures.

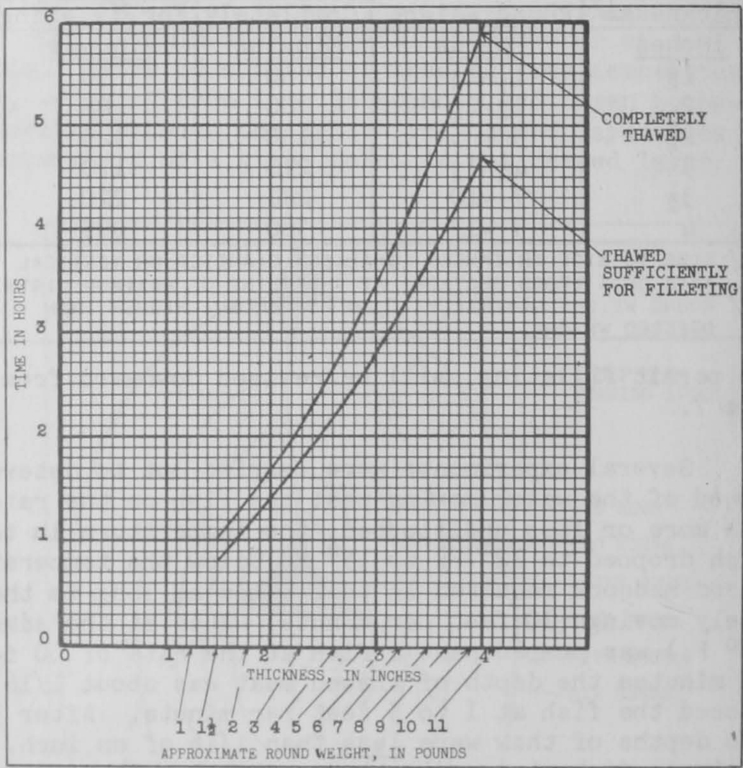

FIG. 7 - THICKNESS OF COD OR HADDOCK VS. TIME REQUIRED TO THAW COMPLETELY AND TO THAW FOR FILLETING IN WATER AT 60° F.

It was interesting to note that when fish frozen at sea were thawed, they appeared to be still in rigor mortis. Even when the fish were completely thawed as checked by knife and thermometer, they were as stiff as half-thawed fish are normally. The stiffness was not a "salt rigor" caused by the immersion in brine, for the rigor passed off after one or two hours. However, even after this rigor was gone, the fish which had been frozen at sea were firmer than the freshest dressed fish normally available ashore.

In the experimental studies, when one fish or only a few fish were being thawed, the drop in the temperature of the water was not sufficient to require adjustment. When capacity loads were thawed, some provision for keeping the water temperature up was necessary. Otherwise, the thawing process was slowed down. Except in the winter, it was possible to maintain a reasonable (higher than 55° F.) thawing temperature by simply adding a large volume of new "cold" water. (At the laboratory the "cold" water supply varied from 68° F. to 42° F.). In the semi-commercial-scale trials, even in the summer, it was found to be most practical to add a moderate quantity of hot water. The rate of addition of hot water was adjusted as nearly as possible to the demand, which was quite high during the first minute or two and gradually decreased to nothing when the fish were completely thawed.

In a commercial operation it might at times be advantageous to leave a batch of fish in the thawing tank for several hours, for instance overnight. Therefore, some tests were made to find the limitations of such a practice and, if possible, to develop a satisfactory procedure. When fish were loaded into a dry tank and left overnight, in the morning the fish touching the sides of the tank and those at the top of the load were partially or completely thawed, while some fish near the center were still completely frozen. The viscera of the former fish had deteriorated badly. When a load of fish was left overnight in a tank full of water, with no circulation of the water, the fish on the top were thawed and spoiling by morning. The fish in the center of the mass were frozen together. When a load of fish was left overnight in a tank of water with the circulating pump operating, but with no new water being added, the temperature dropped rapidly from 55° F. to about 40° F. in half an hour. The temperature probably dropped further, but by morning it was at 40° F. At that time the fish were all thawed and appeared to be in good condition. This procedure, with some modifications, possibly would be suitable when overnight thawing is desirable. It would be economical and would provide thawed fish in a satisfactory condition to produce good fillets.

A brief study was made of the possibilities of increasing the movement of the fish by injecting air into the thawing water. In a few trials, air and water were pumped into the same manifold. The mixture of air and water appeared to move the fish around more than did water alone. In a few trials, a separate small manifold for air was used. When the fish were kept off the bottom of the tank by a screen "false bottom," the rising air bubbles seemed to prevent any bunching of the fish on this screen.

THAWING EQUIPMENT SUGGESTIONS

TYPE OF EQUIPMENT: On the basis of the pilot-plant trials, a system which moves the fish through the water, such as a rotating drum, seems to be more complicated than is necessary. The most practical system for thawing frozen fish appears to involve a tank of fresh water in which the thawing fish are kept from packing together by the forced circulation of the water. The experiments indicate that the thawing fish can be handled and held satisfactorily in expanded metal baskets which fit the tank with a minimum of waste space. As the deepest tank employed in the thawing experiments was only three feet deep, the characteristics of deeper tanks cannot be safely predicted.

A batch-process thawing system would seem to be the most practical and economical for the average processing plant. A single continuous system would present difficulties every time a shift was made from one size of fish to another. If several sizes of fish were thawed simultaneously, a continuous system would necessarily be geared to the largest, slowest-thawing fish, and meanwhile the smallest, fastest-thawing fish would remain in the water a considerable time after they were completely thawed. A system made up of several small continuous thawers would eliminate some of these problems, but the cost of such a system might be excessive and in some plants it would be very difficult to arrange several thawers efficiently.

The recommended system would consist of one or more tanks equipped to circulate water at a maintained desired temperature. The fish would be handled in expanded metal or wire-mesh baskets, each holding between 200 and 500 pounds. The baskets would be transported from the delivery or loading area to the tanks and thence to the scaling equipment or tables by means of an overhead monorail and hoist. The sizes and shapes of the tanks and baskets would be adjusted to make full use of the gross volume of the tank, leaving about three inches at the bottom for a circulating-water manifold and for the unimpeded flow of the water across the bottom of the tank. In a full commercial-scale operation, it may develop that a perforated false bottom one or two inches off the tank bottom might be desirable to provide a space for sand, scales, and other debris to collect. The tank would be equipped with an overflow outlet arranged to skim the surface and remove foam and floating debris. The water could be circulated with a standard centrifugal pump attached to two holes in the side or end of the tank. The pump outlet would connect to a manifold lying along the bottom of the tank. The orifices in the manifold would direct the water across the tank; the number and size of the orifices would necessarily be adjusted to the particular pump's characteristics to secure most effective circulation.

FIG. 8 - EXPERIMENTAL THAWING TANK, SHOWING CONSTRUCTION OF BASKETS FOR HOLDING FISH. HINGED DOOR FACILITATES REMOVAL OF THAWED FISH.

THAWING-WATER TEMPERATURE: Although a few experiments indicated that considerably higher temperatures probably could be used with safety, yet at this time no recommendation will be made for using thawing water warmer than 65° F. In fact, as an extra margin of safety, all the suggestions in this section are based on a normal operating temperature of 60° F. When there is a definite need for slowing the thawing process, as when the fish are left in the thawing tank overnight, water considerably cooler than 60° F. should be used.

The desired temperature in the thawing water can be maintained in several ways. The most practical in any given situation would depend on the facilities available and the local unit costs for utilities and fuel. It is easiest to evaluate the methods on the basis of the heat requirements for thawing a definite load of fish, for example, 1,000 pounds. If this weight of fish is at 0° F. when it enters the tank and at 60° F. when it leaves, the heat absorbed by the fish would be close to 150,000 B.T.U. (British thermal units). That amount of heat must be supplied the system for each 1,000 pounds thawed. If the frozen fish were as warm as 20° F. when placed in the tank and the final product was only 90-percent thawed, the heat requirements would be about 110,000 to 120,000 B.T.U.

The simplest system for replacing the heat lost to the fish would be to add new water continuously. If water at 65° F. (occasionally available from Boston water mains) were added, and the operating (and thus overflow) temperature was 60° F., at least 30,000 pounds of water would be required for thawing 1,000 pounds of fish. This quantity of water, at $1.30 per 1,000 cubic feet, would cost 65 cents. A system similar to the one used in the pilot-plant studies, where hot water is added, usually would be less expensive, and it could operate at any desired temperature at any time of the year. To furnish 150,000 B.T.U. to a thawing tank operating at 60° F., about 1,650 pounds (including 10 percent for various losses to sources other than for thawing the fish, e.g., to air surrounding the tank) of water at 160° F. must be supplied. To heat this quantity of water (200 gallons) with manufactured gas at 11 cents per 100 cubic feet would cost about 43 cents. If coal or oil were used as fuel, this cost would be about 19 cents. In either case, the cost of the water needed, including the prorated part of the original load, would be about 5 cents. It should be noted that a moderate overflow (wastage) of water is desirable, for it would carry off floating debris, fish slime, and foam.

Heating the water directly could be done with an immersed heat exchange flue and an atmospheric gas burner, or with steam coils either in an auxiliary tank or in the main tank itself. The simplest equipment for heating would probably be electric unit heaters. At three cents a kilowatt hour, the power costs for thawing 1,000 pounds of fish would be about $1.35. In any system involving reheating the water, it would be necessary to make arrangements to clean the pipes or coils quickly and easily, for the protein from the slime and scales would precipitate and harden on the heated surfaces, thereby both reducing the efficiency of heat transfer and introducing a serious sanitation problem.

SIZE OF EQUIPMENT: The experimental studies indicated that the thawing tank baskets should not be loaded with much more than 20 pounds of frozen fish per cubic foot of free space. In the suggested type of thawing tank, about three-fourths of the gross volume of a well-designed tank would be usable (available for holding fish); thus the tank can hold 15 pounds per cubic foot of this gross volume. To handle a batch load of 1,000 pounds, a tank of 65 to 70 cubic foot is required.

The laboratory trials indicate that it is advantageous to have the water circulating at considerable pressure, ten pounds per square inch or more. For a 70-cubic-foot tank the water should be pumped at 30 gallons per minute or more. For this size tank, a 1/3-hp. and possibly even a 1/4-hp. centrifugal pump would be adequate.

The daily capacity of any thawing equipment will, of course, depend on the sizes of the fish being handled, the temperature of the water, and the number of hours per day the equipment is operated. If the water is held at 60° F., the tank would be in use for 90 minutes to thaw a batch of scrod haddock or scrod cod. A batch with fish weighing 6 to 7 pounds each, would keep the tank occupied about 3 hours. The largest haddock and market cod would require 4 or 4½ hours, while large and extra-large cod would keep the tank in use even longer. If the sizes of cod and haddock to be processed are distributed over the full range, a possible scheme for fully utilizing the equipment would be as follows: overnight (4 p.m. to 7 a.m.) thaw the largest cod at a temperature, for instance, of 45° F., chosen to assure complete thawing of all the fish by morning. Next, thaw the scrod (7:00 to 8:30 a.m.), which would be ready before the filleters have finished with the easily-handled large cod. While the time-consuming scrod are being filleted, thaw the larger haddock and market cod (8:30 a.m. to 12:30 p.m.), and finally thaw the small haddock and market cod (12:30 to 3:30 p.m.). If only scrod were handled, and the thawing was started before the filleting operations, five or six batches could be thawed in a day. Thus a 1,000-pound-batch tank would supply the filleting line with 4,000 to 6,000 pounds of whole round fish, the equivalent of 3,500 to 5,000 pounds of the dressed fish now normally handled.

SUGGESTED COMMERCIAL INSTALLATIONS: The proper design for a thawing installation at any specific processing plant would depend on several factors, especially on the size and shape of the usable floor space and on the availability of the necessary utilities. Two suggested designs for thawing tanks are detailed here. The one tank is comparatively small so that it can be moved, if necessary. It could thaw batches of 1,000 pounds of fish and compares closely with the tank in use in the pilot-plant studies. Several of these small units could be built and operated almost as economically as could a single large tank. The large tank suggested is intended for thawing approximately 30,000 pounds of fish per working day in four batches of 7,500 pounds each.

The recommended movable tank would be 8 feet long, 4 feet wide, and 2½ feet deep. It would be built of 16-gauge sheet iron reinforced with split pipe or angle irons, and galvanized. Openings would be provided in the end wall and the bottom for the drains and the water-circulating system. It might be desirable to have a perforated false bottom about one or two inches off the bottom. The circulating system could consist of a manifold with drilled holes, fed water under pressure by a centrifugal pump with a 1/4- or 1/3-hp. motor. At a "T" connection on the inlet side of the pump, hot water at 150° to 180° F. would be added. The rate of addition of hot water could be manually controlled, but an automatic control valve actuated by the tank water temperature would be better. Baskets for handling the fish would each be approximately 44 by 21 inches and 27 inches deep, so that four would fit easily into the tank. Above the tank (or tanks) and extending to the loading area and to the scaling equipment would be a monorail and hoist for moving the fish from one step of the operation to another.

A single large tank to handle 7,500 pounds of frozen whole round fish per batch might have the following dimensions: 4½ feet wide, 3½ feet deep, and 35 feet long. The water could overflow into a separate tank for heating. This tank, possibly 4½ by 3½ by 5 feet, would be fitted with steam-heated coils with a feed valve automatically controlled by the thawing-water temperature. From this separate tank the water could be circulated back to the thawing tank under considerable pressure by means of a centrifugal pump and a manifold. A simple framework would support the baskets at about four inches off the bottom. Each of 15 baskets would be of expanded metal on an angle iron frame, 4 feet by 2 feet and 3 feet deep, inside dimensions. A monorail system would move the fish from the loading areas to the tanks and from there to the scalers.1/

THAWING COST ESTIMATES: It is difficult to present any cost figures that would be generally applicable. Therefore, the following figures are simply estimates. However, it is believed they tend to be conservatively high.

A small operation designed to handle about 8,000 pounds of round fish per day would require two of the movable tanks described, a monorail and hoist, and a 130,000-B.T.U. hot-water heating system. These would cost roughly $1,500. The larger tank described, together with a monorail system, but not including the steam source, might cost in the vicinity of $2,800.

The estimated operating costs attributable to the thawing of brine-frozen fish (if coal or oil is used as fuel) for each 1,000 pounds of round fish would be approximately: water, 5 cents; fuel, 19 cents; electric power, 2 cents; labor, 15 cents--a total of 41 cents per 1,000 pounds.

1/ IT HAS BEEN IMPOSSIBLE TO CONSIDER ALL THE POSSIBLE VARIATIONS IN CONDITIONS AND REQUIREMENTS OF PROCESSING PLANTS. NOT ALL THE IDEAS NOR MANY OF THE DETAILS DEVELOPED IN THE PILOT PLANT COULD BE INCLUDED IN THIS PAPER. IT IS RECOMMENDED THAT EACH FIRM CONTEMPLATING THE INSTALLATION OF A THAWING TANK CORRESPOND DIRECTLY WITH THE BOSTON FISHERY TECHNOLOGICAL LABORATORY.

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