Vacuum Cooling and Thawing Fishery Products

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ABSTRACT—A standard pilot plant size retort was modified for purposes of developing empirical information on dehydrocooling fresh fish and vacuum/heat-thawing (VHT) frozen fishery products. Results indicated that effective multipurpose vacuum/heat-processing systems can be constructed from readily available commercial equipment. Dehydrocooling tests indicated that small fish such as whiting can be cooled to 0°C in about 1/2 hour, and VHT tests showed that frozen blocks of headed and gutted (H&G) whiting and shrimp can be thawed in from 1/2 to 1 hour. The described equipment is usable both ashore and at sea. At sea, it is proposed that enough heat energy to power the equipment can be extracted from waste stack gases.

INTRODUCTION

Several years ago, two novel processes were patented for processing fish—one for rapidly cooling and storing cooled fish (Beckmann, 1961) and the other for thawing frozen fish blocks (Bezanson et al., 1973). Though the apparent purposes of these patents appear to be diametrically opposed, the effectiveness of both described processes is dependent on the use of water to transfer heat energy under vacuum conditions.

The first of these two patents is based upon dehydrocooling and was issued to H. Beckmann (1961). Vacuum precooling, or dehydrocooling, is effectively being used today for cooling leafy vegetables. This process takes advantage of the physical penomenon wherein the boiling point of water decreases with a decrease in atmospheric or absolute pressure. At an absolute pressure of 760 mm (14.7 inches) of mercury or normal atmospheric pressure, water will boil at 100°C (212°F); at 4.5 mm (0.18 inch) of mercury, liquid water will boil at 0°C (32°F). According to Beckmann's patent, dressed fish are placed in an airtight container, and when loaded, the air is evacuated from the chamber to promote a rapid evaporation of water from the surface of the fish. Since heat energy is required to change liquid water to gaseous water, the heat necessary to cause this change of state is supplied by the fish; and, thus, the fish loses heat and is cooled. The amount of heat energy given up by evaporation is about 596 calories per kilogram lost water at 0°C or 1,073 British Thermal Units (BTU) per pound of lost water at 32°F[1]. By evacuating the chamber to an absolute pressure of about 4.5 mm of mercury, the fish within can be cooled to 0°C. Once cooled, the fish can then be stored within the chamber at 0°C by maintaining the absolute pressure at about 4.5 mm of mercury. In order to compensate for the loss of water during the cooling and storage stages, the fish are periodically sprinkled with water while under vacuum. This added water can, by dehydrocooling, freeze onto the surface of the fish. Thus, without the use of ice and refrigeration equipment, Beckmann (1961) claims that fish can be adequately cooled and stored in the fresh state. Other advantages claimed are prevention of oxidative rancidity, inactivation of aerobic spoilage bacteria, and the bleeding of the fish is enhanced which results in lighter-colored flesh.

The second patent is concerned with thawing and is known as the Vacuum Heat Thawing (VHT) process. It was specifically designed to factory-thaw large blocks of frozen foodstuffs—i.e., 100 pound (45kg) blocks of frozen dressed fish. The process can be considered to be the opposite of dehydrocooling and thus takes advantage of not only the fact that water will boil or steam condense at a lower temperature under vacuum conditions, but also that the condensation of water imparts heat. This is called the heat of condensation and is the opposite of the heat of vaporization which, again, is considerable. According to the patent, blocks of frozen fish are placed in an airtight container and the chamber is evacuated to a predetermined absolute pressure which will allow for a desired thawing temperature. For example, at an absolute pressure of 17.5 mm of mercury, a temperature of 20°C could be maintained. At the preset pressure, steam is then metered into the chamber and will condense on the surface of the fish giving up its heat of condensation. Under these conditions a kilogram of condensing steam will give up about 585 calories of heat energy (1,053 BTU per pound of steam at 68°F). By careful control of the absolute pressure and steam, it is claimed that the fish can be rapidly thawed without heat damage. Additional advantages claimed are reduction of oxidative changes, inactivation of aerobic spoilage bacteria, and reduction of weight loss due to thaw drip.

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[1]Clarke-Built (Williams), Ltd., Thetford, England. Vacuum-Heat Thawing. Personal communication.

About the time that these inventions were made known, an engineering study (Lange 1946) indicated that with the proper heat exchangers, as much as 770 kg (1,700 pounds) of 0.07 kilogram-force per square millimeter (kgf/mm^2) (100 psi)[2] steam could be generated from the heat lost in the exhaust stack of an average New England trawler. This is more than enough energy needed to power a large vacuum unit. It appears then that vacuum systems could be operated aboard the trawlers for only the cost of the proper equipment and its installation.

To the best of our knowledge, these processes are not being commercially utilized by the fishing industry. Possible reasons for this are that there is no firm information available on these vacuum processes, and the apparent costs of the equipment and manpower needed to develop the required information are beyond the means of our hard-pressed fisheries. Thus, because of these reasons and the benefits claimed by the inventors, the Northeast Utilization Research Center undertook work to obtain empirical information on the design and development of a steam-powered pilot plant vacuum processing system and on developing empirical data on the feasibility of dehydrocooling and VHT.

DESCRIPTION OF THE EQUIPMENT

The unit designed and constructed consisted of a two-stage vacuum source, a horizontal food processing retort, and a steam boiler as shown in Figure 1. All components used were readily available and usable both at sea and ashore.

A Kinney Liquid Jet[3] vacuum pump, Model KLJ-120, was chosen as the first stage in the vacuum system. This was because of the availability of water and because this type of vacuum pump is simply a large water aspirator capable of handling large volumes of water vapor as might be expected from VHT and dehydrocooling. In operation, a 10 horsepower centrifugal pump drives water under high pressure through a plate with holes to create a series of jets which cross through an air gap into a venturi tube. As the water crosses the air gap, air and other gases are entrained in the water and are carried through the venturi and expelled. For economy's sake, the water used is recirculated and stored in a tank of about 850 liters (30 cubic feet) capacity. A provision is made to add fresh cool water in the event that the stored water warms. This unit is capable of generating a vacuum equal to that of the vapor pressure of the recirculated water, i.e., about 30 mm (1.2 inches) of mercury absolute pressure at a water temperature of 21°C (69.8°F).

For the second stage vacuum, a steam jet evactor was used. In operation, the steam jet evactor operates on the same principle as a water aspirator except that this pump uses steam as a motive force. Additionally, the steam passing through the jet condenses in the water of the first stage thus helping to generate higher vacuums. The steam jet evactor is dependent upon the first stage in that it does not become efficient unless the absolute pressure at the discharge end of the steam jet is lowered to about 500 mm (19.7 inches) of mercury. With both vacuum sources in full operation, using 0.046 kgf/mm^2 (65 psi gauge) steam, this system was capable of attaining absolute pressures as low as 0.3 mm (0.012 inches) of mercury. This absolute pressure is equal to the vapor of ice at -29.5°C (-21°F) which was more than adequate for the intended work.

These vacuum sources were connected to the retort using a 101.5 mm inside diameter (ID) (4-inch) pipe. Originally, high density polyethylene pipe was used; however, when steam was allowed to escape through this pipe, the pipe distorted and caused several joints to open and leak thus causing a loss in vacuum efficiency. The plastic pipe was then replaced with iron pipe of the same size to eliminate this problem. Also, a 101.5 mm (4-inch) iron gas cock was installed in the vacuum line for quickly applying or shutting off the vacuum.

The vacuum chamber originally used consisted of a vertical retort of 670 liters (23.6 cubic feet) capacity. A retort appeared to be ideal for the purpose because its heavy walls could withstand the stresses resulting from high vacuum and because it is capable of being sealed. However, the vertical retort was awkward to load, and it was replaced by a smaller horizontal retort whose internal dimensions were 45.6 cm (18 inches) in diameter and 78.7 cm (31 inches) in length. The capacity of this retort was about 128 liters (about 4.56 cubic feet). The only modification made to the retort was to weld in along the top center line a 101.5 mm ID (4-inch) vacuum outlet containing a gate valve for opening or sealing off the vacuum to the retort. This modification in no way affected the usage of the retort for normal steam processing operations. This retort was also equipped with pneumatic controls for steam and air regulation, a steam sparger along its bottom length, and a water inlet.

Steam for VHT and for the steam jet was supplied by a 98,095-watt (10 boiler horsepower) steam boiler. Since the efficiency of the steam jet depends upon

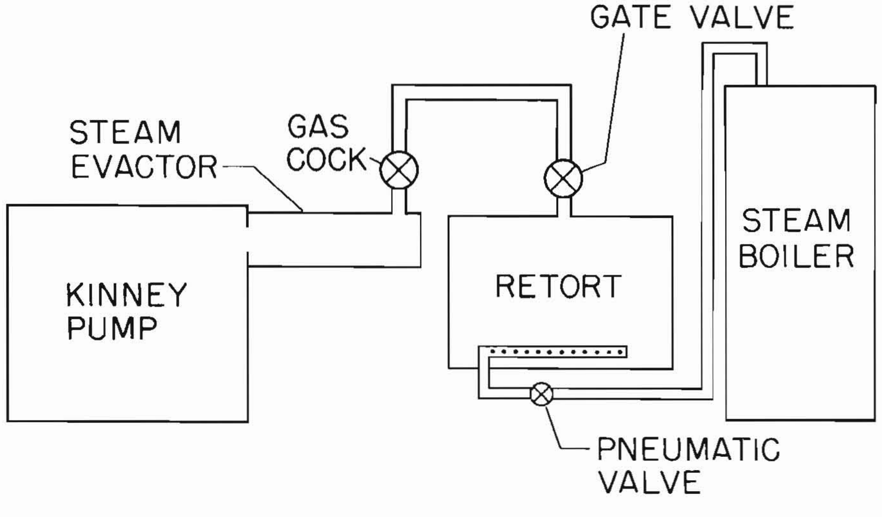

Figure 1.—Pilot plant equipment used for dehydrocooling and vacuum heat thawing tests.

[2]One psi = 7.03 × 10 [-4] kilogram-force per square millimeter.
[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

the use of dry steam, a steam separator was installed in the steam line as close to the steam jet as possible. This separator removes water condensate from steam and allows only dry steam to pass.

Once constructed, the equipment was tested for leaks and overall efficiency. Leaks were detected by filling the system with a halogenated gas to a little above atmospheric pressure and using an electronic halogen leak detector. All leaks found were sealed with silicone rubber gasket material. Some very small leaks remained as evidenced by a gradual loss of vacuum in the chamber after it was sealed off and evacuated. However, these leaks were too small to affect the outcome of the proposed tests. Subsequent tests indicated that when using only the Kinney pump with 18.3°C (65°F) water, an absolute pressure of 20 mm gauge (0.79 inches) was obtained in 32 seconds. Since the vapor pressure of water at this temperature is 15.8 mm of mercury, the Kinney pump was capable of delivering 99.4 percent of the total vacuum theoretically obtainable or (760 mm − 20 mm/760 mm − 15.8 mm) (100). When using both vacuum systems, an absolute pressure of 4 mm (0.16 inches) of mercury was obtained in 72 seconds. This corresponds to the vapor pressure of water at −1.7°C (28.9°F). When the system was tightly sealed, absolute pressures of about 1 mm of mercury (0.04 inch) were readily attainable. This vacuum would correspond to the vapor pressure of ice at −17°C (1.4°F). Some control over the degree of vacuum was achieved by closing down the gate valve, and thus the temperatures within the chamber could be roughly controlled. Typical evacuation times are shown in Figure 2 when using 0.018 to 0.070 kgf/mm² (25 to 100 psi gauge) steam pressure through the steam jet.

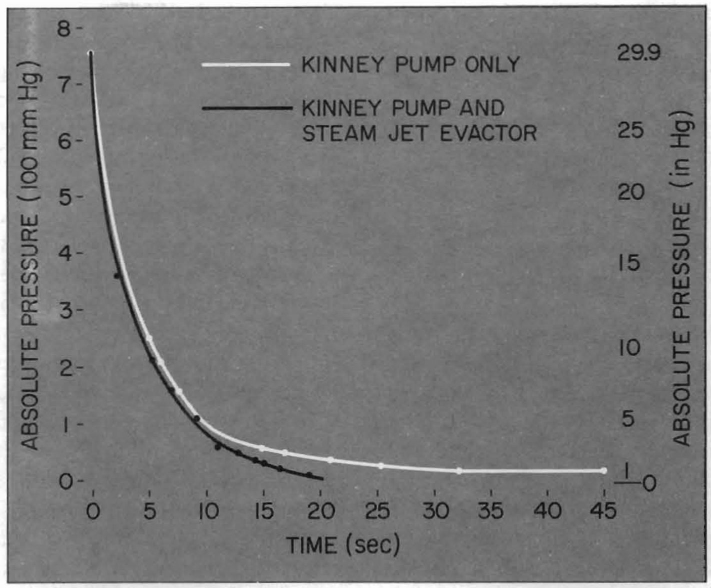

Figure 2.—Typical retort evacuation times illustrating the capability of the equipment to rapidly produce suitable vacuums for dehydrocooling and vacuum heat thawing.

DEHYDROCOOLING

Upon completion of the unit, dehydrocooling and VHT tests were conducted. For the dehydrocooling tests, fresh headed and gutted (H&G) whiting was used since this species is in good supply in this area. The individual weight of the fish used ranged from 100 to 150 grams (0.22-0.33 pound), except in one series where larger, 600-700 grams (1.3-1.5 pounds), H&G whiting were used in an effort to determine the effect of individual size on rates of dehydrocooling. Preliminary work indicated that for best results, the fish needed to be spaced apart from each other, that is, not touching each other, so that the whole surface area of the fish was available for dehydrocooling. Accordingly, fresh wet fish were spaced single layer on an expanded metal screen. In the first three series reported on, the fish were very wet so as to readily drip water; and in the last two series, the fish were wet but not dripping. Thermocouples were inserted into the fish at sites immediately below the surface of the skin and next to the backbone at the thickest portion of the fish. These latter thermocouples were about 13 mm (0.5-inch) deep in the small fish to about 25 mm (1-inch) in the larger fish. This allowed the temperatures of the fish to be continuously recorded at 5-second intervals throughout each test. The fish were then loaded into the retort, the retort closed and quickly evacuated to an absolute pressure of 2-4 mm (0.08-0.16 inch) of mercury. These pressures correspond to the vapor pressures of ice from −9.7°C to −1.6°C (14.5°F to 29.1°F). Since the vacuum system had a tendency to reduce the absolute pressure below 2 mm (0.08 inch) of mercury, attempts were made to regulate the degree of vacuum by closing down the gate valve. Results of the dehydrocooling tests are summarized in Table 1, and a typical dehydrocooling curve is shown in Figure 3.

In the first three series, the surface of the fish cooled to ice temperature in 8 minutes regardless of the size of the individual fish and regardless of the starting temperature. However, as either the

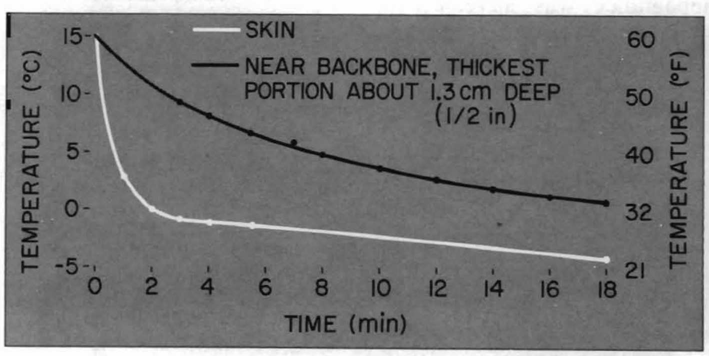

Figure 3.—Typical dehydrocooling curve showing the rapidity of the process and relationship between surface and internal temperatures during dehydrocooling.

Table 1.—Dehydrocooling headed and gutted whiting.

Total sample weight (kg)	Size of fish (g)	Starting temp. (°C)	Time needed to dehydrocool fish to 0°C (min)	
			Surface	Interior
1.5	100-150	21.0	8	15
6.8	100-150	17.0	8	28
8.0	600-700	18.5	8	33
1.0	100-150	21.0	1	14
1.0	100-150	5.0	1	7

total mass of the fish increased from 1.5 to 6.8 kg or as the size of the individual fish increased from 150 to 600 grams, the rate of interior cooling decreased. When the tray was loaded from just a few fish to a maximum number of small fish (6.8 kg), the time to cool the interior of the fish about doubled, i.e., from 15 to 28 minutes. This indicated then that the interior cooling rate is dependent upon the total number of fish, or load, being dehydrocooled. With respect to individual fish size, the interior rate of cooling decreased as the size of the fish increased. Small 100-150 gram fish were cooled to ice temperature along the backbone in 15 minutes, whereas 33 minutes were needed to cool 600-700 gram fish (about twice as thick) to this temperature along the backbone. This is to be expected inasmuch as the heat from the interior of the fish travels by conduction, and fish flesh is a poor conductor of heat.

In the last two series when no excess water was available on the surface of the fish, the surface of these fish cooled to ice temperature in about a minute. The interior temperatures of these fish cooled to 0°C in 7-14 minutes, depending upon the starting temperature. These two series illustrate the rapidity of dehydrocooling at low absolute pressures when no excess water is available. However, these fish tended to become rapidly dehydrated to a point where their appearance was adversely affected. The damage caused by dehydration could not be wholly eliminated by the later addition of water. In the first three series, dehydration was first evidenced by a slow increase in surface temperature. This was probably caused by subsurface heat warming the skin surfaces after most of the water evaporated from the surface of the fish. Further dehydration was averted by spraying the fish with water while under vacuum. For this purpose, a water spray system was built into the retort. This additional water not only prevented surface dehydration, but also aided in further dehydrocooling. Once the fish was cooled, the sprayed-on water froze to form a protective ice glaze over the nonfrozen fish. Thus, it appears that though excess water slows down the dehydrocooling process by increasing the load to be cooled and by adding some heat energy, some excess water is needed to prevent damage by dehydration.

During the dehydrocooling process, it was noted that the ambient temperature within the chamber cooled to about 3°C (37°F) and remained at this temperature even though the fish was at 0°C. The temperature of the retort shell did not change, thus indicating that there was little or no heat being exchanged through the "atmosphere" within the retort. Further, ice-glazed fish were stored in the chilled state for periods of 5-6 hours by maintaining an absolute pressure of 4-6 mm. An examination of the treated fish indicated that some of the ice glaze was lost to evaporation but there were no other adverse effects as a result of dehydrocooling and the short storage period.

These results then indicate that whiting, and probably other fish of similar size, can be rapidly cooled to 0°C by dehydrocooling under conditions that arrest oxidative changes and the outgrowth of spoilage microorganisms. There is an indication that once cooled, the fish can be stored under a vacuum without additional refrigeration. However, since this process depends upon the removal of heat by the vaporization of water, care has to be exercised to prevent dehydration damage to the fish. This can be done by the addition of water during the dehydrocooling and storage periods. The frequency and the amount of additional water would probably be dependent upon the capacity of the system and the degree to which the system is loaded.

VACUUM HEAT THAWING

Vacuum heat thawing tests were conducted on commercially prepared frozen blocks of H&G whiting and shrimp. Initial tests were conducted in the aforementioned vertical retort where larger sized samples could be handled but the process could not be easily controlled. In these tests 4.54-kg (10-pound) blocks of H&G whiting and either 2.27-kg (5-pound) or 4.54-kg (10-pound) blocks of shrimp were loaded onto an expanded metal tray within the retort. Thermocouples were inserted near the center midline and just beneath the outside surface of the blocks for continuous temperature monitoring. The retort was then closed and evacuated to an absolute pressure of about 20 mm. Once the pressure was reached the vacuum line was shut off and steam at 0.06 kgf/mm^2 (85 psi gauge) was allowed to expand into the chamber until an absolute pressure of about 50 mm (1.95 inches) of mercury was reached. At this pressure, the surface temperature of the blocks rapidly increased to about 38°C (100°F). In order to avoid overheating the samples, the vacuum was reapplied to dehydrocool the surfaces to about 22°C (72°F). Once cooled, the cycle was repeated continuously until the thermocouples along the midline of the blocks indicated that the blocks had reached a temperature of 0°C (32°F) or higher. Thereupon, the retort was opened and the samples checked for degree of thaw. If not

Table 2.—Summary of vacuum heat thawing tests on whiting and shrimp using 0.06 kgf/mm^2 steam pressure.

Sample	Block size (kg)	Total weight (kg)	Temperature		Total thawing time[1] (min)	Percent thawed
			Initial	Maximum at center line		
Glazed	4.54	18.2	−4.4	0.5	24	60
Whiting Blocks	4.54	18.2	−5.5	2.5	60	100
Glazed	[2]2.27	7.25	−6.1	6.1	1	60
Shrimp	2.27	2.27	−7.2	20.0	8	95
Blocks	4.54	9.1	−9.4	15.5	13	80
	2.27	15.9	−11.1	23.4	51	95
	2.27	9.1	−5.5	15.5	31	90
	2.27	11.1	−3.2	15.0	26	80

[1]Total time of thawing within the chamber.
[2]Loosely packed and lightly glazed.

reasonably thawed, the samples were returned to the retort and the process repeated.

Results of these initial VHT tests are given in Table 2. These results indicate that though the apparent temperature within the block was above 0°C, the blocks were not necessarily thawed. This was because though the blocks appeared to be solid, pockets of air and ice were later found among the fish and shrimp.

In the case of whiting, few enclosed pockets of air or ice were present and it was found that by increasing the temperature to a few degrees above freezing near the center of the block, the fish were thawed to the point where they could be easily separated and filleted. About 1 hour was needed to completely thaw the 4.54-kg (10-pound) blocks of whiting. With respect to shrimp, many pockets of air and ice were present throughout the blocks. The steam apparently was able to enter the air pockets and transfer its heat to the shrimp tissue. Thus, very loosely packed and lightly glazed shrimp blocks became 60 percent thawed when treated to VHT conditions for 1 minute. When the shrimp blocks were tightly packed and more heavily glazed, the VHT time was significantly increased. Under the conditions of these tests, this thaw time varied primarily because the amount of glaze and pockets of ice among the blocks varied. When the temperature of areas along the center line of these shrimp blocks reached 6-10°C, many pockets of ice and frozen shrimp still remained. However, it was noted that when the internal temperature of these shrimp blocks reached 15-23.4°C, the blocks were 80-95 percent thawed without heat damage. The thaw time for these shrimp blocks then ranged from 8 to 51 minutes, depending on the amount of glaze, the size of the blocks, and the size of the load in the chamber. It was also observed that these shrimp would probably thaw faster if some provision was made to remove the thawed shrimp on the surface of the block from the still-frozen shrimp in the interior of the block. As the outside of the blocks thawed, the thawed shrimp tended to form an insulated mat, thus obstructing the flow of heat into the block's interior.

Upon installation of the horizontal retort, more detailed VHT tests were made on H&G whiting. Since the capacity of the horizontal retort was less than that of the vertical retort, smaller sized samples were used throughout these tests. Generally, the procedure for VHT was the same as that previously described except that, as noted, in some tests the pneumatic controls on the steam lines were used to meter steam into the retort during VHT. By careful throttling of the gate valve in vacuum piping and by recalibrating the automatic pneumatic controls, temperatures of 29±1°C (85±1.8°F) could be maintained throughout the VHT test periods. Under these conditions, steam was continuously metered into the chamber.

Table 3.—Summary of vacuum heat thawing tests on whiting using various steam pressures and application of steam.

Sample size (kg)[1]	Steam pressure (kgf/mm²)[3]	Steam application	Initial temperature (°C)	Maximum temperature (°C)	Thaw time (min)
0.45	0.0175	continuous	-17.8	36.7	15
0.45	0.0352	cycled	-17.3	36.7	26
2.27	0.0175	continuous	-17.8	33.9	27
2.27	0.0175	cycled	-17.8	36.7	45
2.27	0.0352	cycled	-15.0	37.8	57
2.27	0.0703	cycled	-12.8	36.7	58
2.27	0.0175	cycled[2]	-7.8	37.3	74
0.227	0.0175	continuous	-7.8	31.1	8-9
0.227	0.0352	pulsed	-17.3	29.4	17

[1]The 0.45-kg sample (1-pound) size consisted of 3-5 H&G whiting frozen together in a block and the 2.27-kg samples (5-pound) consisted of 8-12 H&G whiting frozen in a block. The 0.227-kg sample (0.5-pound) size consisted of 6 or more H&G fish individually frozen and weighing about 0.227 kg (0.5 pound) each.
[2]Full vacuum system used. Absolute pressures of 4.5 mm were used for dehydrocooling.
[3]One psi = 7.03×10^{-4} kgf/mm².

kgf/mm² (100 psi gauge) steam. This was because when using higher pressure steam the pressure was more difficult to control, the tendency for overheating increased, and there was a need for longer dehydrocooling time. The greater efficiency of the lower steam pressures also tends to indicate that the major source of heat energy for thawing came from the heat of condensation. Lastly, when dehydrocooling with an absolute pressure of 4.5 mm (0.018 inches) of mercury, excessive cooling of the surface of the samples occurred, thus increasing the time needed to thaw the samples. For example, when using the full vacuum system for dehydrocooling at an absolute pressure of 4.5 mm (0.018 inches) of mercury between cycles of steam injection, 74 minutes were needed to VHT a 2.27-kg sample when using 0.0175 kgf/mm² steam. Under the same conditions, except that an absolute pressure of 18 mm (0.71 inches) was used, the samples were thawed in 45 minutes.

Results of these tests are given in Table 3. It is evident from these results that VHT can be accomplished much faster by a continuous application of steam than by a cycled application. This is because with the latter, the surfaces of the products heat up much faster with a full flow of steam causing a need to remove excess heat by dehydrocooling, an extra step in the procedure. Thus, with a continuous flow of steam to maintain a temperature about 36°C (97°F), the thawing times were nearly halved, i.e., 8 to 27 minutes for 0.227- to 2.27-kg samples with a continuous flow of steam as compared with 17 to 45 minutes for similar size samples using cycled steam. These data also indicate that VHT was faster with lower steam pressures than with higher steam pressures, i.e., for a sample size of 2.27 kg, 45 minutes were needed to thaw the fish when using 0.0175 kgf/mm² (25 psi gauge), as compared to 58 minutes when using 0.0703

With respect to VHT whiting at a maximum temperature without causing physical damage to the fish, it was found that the skin of the fish began to cook when exposed to temperatures of 43-46°C (110-115°F) for a few seconds. When this happened, the skin became gummy and began to slough off from the flesh below. This was also true for other thin-skinned species such as herring. Exploratory VHT tests indicated that higher maximum thawing temperatures such as 55°C (130°F) could be used on other species, such as cod and ocean perch, without causing physical damage. These latter species have thicker skins which apparently offer greater protection from the rigors of the process.

It is doubtful that this process could be used to temper fishery products, i.e., to raise the temperature of a frozen product, without thawing, in order to achieve a degree of hardness suitable for easy cutting with a saw. However, where there is a need to thaw the product prior to further processing, the data show that the process is rapid and effective. For example, experience within the laboratory indicates that 24-48 hours were needed to thaw 2.27- to 4.54-kg (5- to 10-pound) blocks of fish or shrimp in air at 2-4°C (35.6-39.2°F) and about 1-3 hours in 18.3°C (65°F) water. By the VHT process, these products can be thawed in as little as 10 minutes to 1 hour, depending upon the capacity of the equipment, the size of the load, steam pressures, the application of steam, and the presence of extra water or glaze. It should be pointed out here that by the use of microwaves[4] some hard-frozen products can be very rapidly tempered or thawed, depending upon need. For example, 50 pounds of hard-frozen shrimp were thawed per hour per kilowatt energy to the point where they could be separated and further processed.

CONCLUSIONS

These exploratory studies have shown that vacuum processes could be applied for dehydrocooling and for VHT fishery products. The components needed are simple in design and operation. Moreover, an engineering study has indicated that enough energy can be recovered from waste stack heat to power the needed equipment. Thus, the equipment could be designed for use at sea as well as ashore where power is readily available.

Good results were obtained in dehydrocooling of small fish such as H&G whiting and herring. The exterior of these fish cooled rapidly, that is, from ambient to freezing temperatures in only 8 minutes. One-half hour was needed to cool to 0°C (32°F) all the interior portions of fish of about 50 mm (2 inches) at their thickest point. However, in order to rapidly cool, it was necessary to expose the whole surface of the fish to the vacuum. This indicates fish cannot be rapidly cooled by the dehydrocooling process unless these fish are spaced apart, i.e., in layers one fish deep rather than in large masses as is now the practice. The larger the fish, the more important would be the need to separate the fish in order that the heat from the interior portions can be removed. Because the cooling process depends upon the evaporation of water, there is a danger of overly drying the surface of the fish. The danger can be readily avoided by sprinkling the surface of the fish with water while under a vacuum, and again, this is best done on layered fish. The additional water by its evaporation aids in the overall cooling effect. Once cooled, the added water that has not evaporated will freeze over the surface of the fish to form a protective ice glaze. If judiciously done, this glaze can be formed over nonfrozen fish inasmuch as the freezing point of fish flesh is about −2°C (28°F). There is no further need to keep the cooled fish spaced apart so that the fish can be stored in a massed form. If stored under a maintained absolute pressure of about 4.5 mm of mercury in an airtight container, the fish will remain cool. Only a periodic addition of water would be needed to replace that water lost by continuing evaporation. This container, if properly constructed, could also serve as a shipping container, thus also aiding in the transport of the fish.

Good results were obtained in VHT blocks of H&G whiting and shrimp. Normally 1-2 days are needed to refrigerator-thaw these products. Several hours are needed for thawing in 18°C (65°F) water. Bacterial degradation can occur during these thaw times and especially in the case of water-thawing, the bacterial contamination can be rapidly spread by the water. With VHT, these products can be completely thawed within 1 hour in a manner that does not promote the spread of bacterial contamination. The thaw times given could probably be reduced in some instances where the product is cooked during later reprocessing. For example, since some breaded shrimp are partially cooked prior to refreezing and sale, shrimp blocks for this purpose could be VHT at higher temperatures and shorter periods of time. Any cooking damages that might occur would probably be of no consequence in cooked breaded shrimp. It should be pointed out here that much has been done in developing the technology on the use of microwave energy for thawing and/or tempering frozen seafoods for further processing. For example, with one microwave unit hard-frozen shrimp were continuously thawed for further processing at the rate of about 22.7 kg (50 pounds) per hour per kilowatt energy. Where the microwave process is a continuous process, VHT is a batch-type process. Thus, to a processor who has need of rapidly thawing fishery products, VHT appears to be an attractive potential process.

Though no bacteriological work was done under the conditions of dehydrocooling and VHT, it is quite conceivable that at least during the time these processes are being applied, bacterial degradation is arrested. It is believed that most of the bacteria on fishery products are aerobic, i.e., they need air to grow and function. By the very nature of these processes, nearly all the air that sustains these bacteria is removed and thus they would cease to function.

It should be noted here that the basic equipment used for VHT is the same as that used for dehydrocooling. Thus the equipment is quite versatile since it can be used for VHT, dehydrocooling, retorting cans of food, and as a pressure cooker for such products as crabs. There are indications that this basic equipment can be used for other purposes. Some suggested uses are to briefly treat the surfaces of fishery products with high temperature steam in an effort to destroy surface spoilage bacteria. It is believed that most of these bacteria live on the surface of the fish and most are psychrophiles or cold-loving. It is further believed that these bacteria can be easily destroyed by mild heat. Another suggested use is to destroy surface bacteria by the use of sterilant gases.

Lastly, these results also indicate that these processes probably can be used for processing other foodstuffs. Since fresh fish can be dehydrocooled, other flesh foodstuffs could probably be

[4]Moore, F. F., P.O. Box 196, Rye Beach, N.H. Personal communication.

rapidly cooled. The criteria here would be that the foodstuff be wet and offer a large surface area with relation to product weight. For example, freshly defeathered and eviscerated chicken could probably be cooled quite rapidly both inside and out by this process. Moreover, the process would promote bleeding, an added benefit. With respect to VHT, this process might be of some benefit to those industries that reprocess frozen foods. An example of this would be the meat industry where meat is frozen for later processing into hamburger. As with fish, the frozen meat could probably be effectively VHT in a rapid manner which would tend to maintain the quality of the meat.

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