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Chilled Seawater System for Bulkholding Sea Herring

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INTRODUCTION

The sea herring, *Clupea harengus harengus*, is one of the most intensely harvested stocks in the northwest Atlantic. The herring has traditionally been a highly prized species for food and a number of industrial products such as oil, fish meal, and pearl essence. The harvesting of juvenile herring for canned sardines supports some 16 plants in the state of Maine alone. Tht total annual catch of sea herring in the northwest Atlantic by all nations has averaged 295,400 metric tons (650 million pounds) from 1972-74[1]. Of this, U.S. fishermen landed 32,680 metric tons (71.9 million pounds) in 1974 valued at $2.6 million (Statistics and Market News Division, 1975).

Much of the U.S.-landed herring is presently used for industrial fish rather than food fish primarily because of quality. Lack of adequate storage techniques for herring being transported from the fishing grounds and inadequate means of holding herring once landed add to the reduction in herring quality.

Extremely large catch performances make it virtually impossible to preserve them by traditional icing practices; therefore, fish must be returned to port as quickly as possible to avoid excessive spoilage. During the summer months, deterioration of the fish is so rapid that travel time from the fishing grounds is reduced to a maximum of 5-6 hours to ensure fish of food quality.

Another consideration is that of overland transport. Large quantities of herring are transported considerable distances to processors in order to maintain operation during herring migrations. Presently, the method of transport is an open dump truck or tank truck with no means of icing used during transportation. The time lapse between catching and final processing may be as long as 12 hours, depending on the distance traveled and quantity of fish.

Considering the unusually rapid spoilage rate of herring, it is ideal to chill the product rapidly before the onset of bacterial degradation and autolysis. In a study by Merritt (1974) on the stability of herring in relation to treatment before freezing, the immediate chilling at 0°C (32°F) for 32 hours before freezing produces 75 percent first class fish as compared to 33 percent for herring unchilled for 8 hours on the catcher vessel.

Spoilage rates are directly related to storage temperature. Banks (1966), comparing spoilage rates of herring stored at 0°C (32°F) with spoilage rates at various temperatures, observed that fish spoiled 2.5 times faster at 6°C (42°F) and 5.5 times faster at 11°C (52°F). The relationship between temperature and spoilage rate indicated the importance of rapid chilling on the maintenance of quality.

Estimates made by the New England Fisheries Development Program (NEFDP) have shown that increased herring utilization for food could benefit the U.S. fishery greatly. Earl[2] estimated an added value of $1.6 million if all of the 1974 U.S. herring quota for the northwest Atlantic was processed as food.

One potential area for improvement of fish quality aboard ship as well as on land is the use of chilled seawater (CSW), a mixture of ice and seawater for holding the fish. Sea trials carried out by the National Marine Fisheries Service's Northeast Utilization Research Center (NURC) using CSW for mixed species indicated that several species including herring could be held for several days while maintaining excellent quality (Baker and Hulme, 1977). Extensive work has also been carried out in Great Britain on CSW holding of herring (White Fish Authority, 1972; Karsti and Blockhus, 1966; Merritt, 1974; and Hewitt and McDonald, 1972). This holding method requires limited mechanical equipment and is adaptable to both bulk systems and containerization.

[1]Gordon, W. G. 1975. Outcome of ICNAF meetings, Edinburgh, Scotland. Unpublished.

[2]Earl, P. M. 1975. New England Fisheries Development Program Progress Report. Unpublished. 16 p.

PREPARATIONS FOR TESTING

Bulk Tank System

In the spring of 1975, the *Lady Esther III*, a 35-m (115-foot) vessel previously used as a carrier for herring seiners, was outfitted with a prefabricated, insulated afterhold and a CSW circulation system.

The bulk tank is a single unit, subdivided longitudinally to form two separate holds, each approximately 39.6 m^3 (1,400 feet^3), capable of carrying 27,200 kg (60,000 pounds) of herring with ice and seawater. The tanks are constructed of plate steel, insulated outside by 7.62 cm (3 inches) of spray-on polyurethane foam and overcoated with two 0.635 mm (25 mil) thick layers of butyl elastomer. The interior is sandblasted, primed, and coated with vinyl.

The circulation system, constructed of 7.62-cm (3-inch) polyvinyl chloride (PVC) pipe connected to two diesel-powered, self-priming pumps, allows adequate flexibility in operations. Water from the seacock is routed through a perforated lower return line for initial filling with seawater. A perforated high suction line located around the top border of each tank allows the CSW to be drawn off and recirculated through the lower return line during circulating operation. Each tank is also equipped with a low

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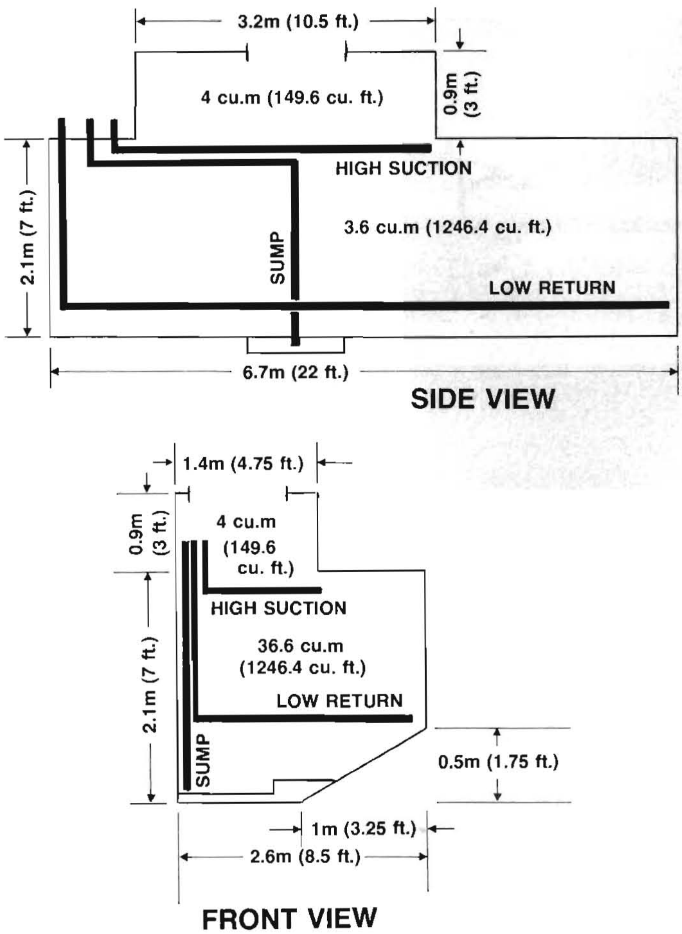
The *Lady Esther III* herring carrier steaming out of port for an all-night seining operation.

Figure 1.—Bulk tank dimensions and piping diagrams.



suction (sump) to be used in draining the tanks or as an aid to circulation of CSW. A separate hatch cover is provided for each hold permitting adequate access for loading and unloading of ice and fish. Figure 1 shows the diagram of the bulk-tank system.

A multipoint strip chart recorder was mounted in the wheelhouse for recording temperature data during sea trials. This was connected to two 9-element copper constantan, thermocouple cables, each located in separate holds (starboard and port). The elements were located in various places within the hold (to give an accurate record of the temperature distribution). Flow meters installed on the output side of each pump indicated the approximate flow rate during circulating operation. The quantity of seawater added to the ice in each hold was critical for the evaluation of the system. For this reason, a water meter was installed on a bypass line located on the output side of the starboard pump. The valve system allowed filling of either hold section through the meter.

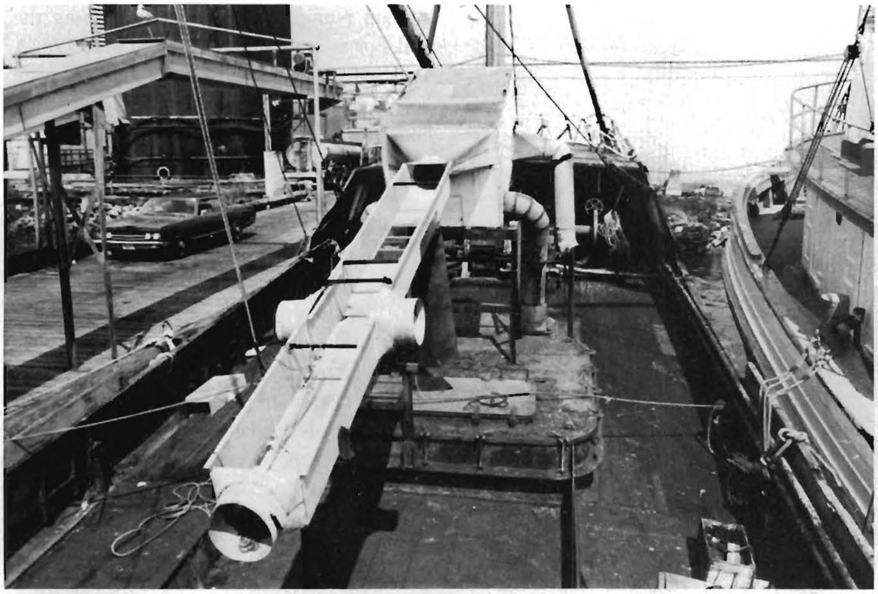
Containerization

For the containerization studies, four Tote System[3] containers measuring 2.3 m (7.5 feet) in height and 1.2 m (4 feet) by 1.1 m (3.5 feet) in width were obtained commercially. These containers were aluminum-skinned with one container insulated by 7.62 cm (3 inches) of polyurethane and the other three with 5.08 cm (2 inches) of polyurethane and a capacity of 1.91 m^3 (67.6 $feet^3$) and 2.12 m^3 (74.7 $feet^3$), respectively. Each container was provided with a hinged hatch cover and a drain plug for cleaning. During testing, circulation in the container was provided by compressed air at 5 psi forced through a 0.64-cm (0.25-inch) diameter outlet located in the bottom of each container. The air flow rate was about 1.6×10^{-3} cm^3/second (3.35 cfm). The containers were held on the deck of the vessel during the trials and loaded and offloaded by means of a crane.

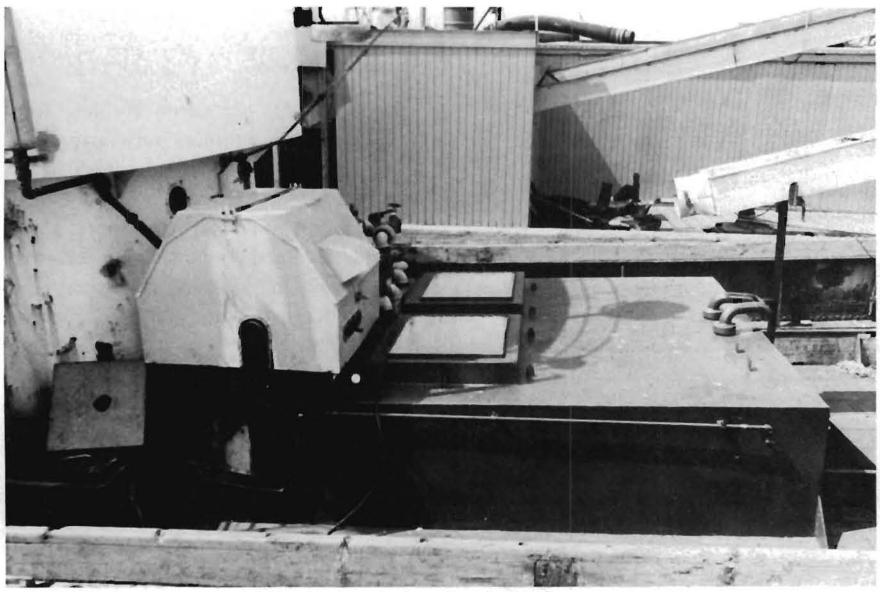
PROCEDURE

The optimum amount of seawater was determined for the bulk tanks before starting the investigations. Before each test, crushed

[3]Mention of a commercial company or product does not constitute an endorsement by the National Marine Fisheries Service, NOAA.



Dewatering box and chute system on the *Lady Esther III* used in typical New England herring seining operations.



Another (starboard) view of the bulkholding system.

block ice was loaded in each hold. Quantities of ice were varied using 3.6, 4.5, 5.4, 6.4, and 8.2 metric tons (4, 5, 6, 7, and 9 tons) of ice in separate tests. Seawater was added to the tanks after reaching the fishing grounds and 3,785 liters (1,000 gallons) of seawater was constant for all ice quantities in the bulk tank system. Seawater drawn through the seacock was pumped through the water meter which accurately measured the amount of water added to each hold.

The containers, located in the mid-deck area, were loaded with ice at the same time as the bulk tanks. Ice quantities used were varied while the seawater quantity remained constant at approximately 189 liters (50 gallons) per container. Temperature of the seawater added to the CSW systems and the ambient temperature were recorded.

No further operations were necessary from this point until the fish were caught and loaded. The fish were pumped out of the seine to a dewatering box located on the vessel. A chute system conveyed the fish directly into each hold. Fish were alternately loaded into both bulk tanks and containers to permit adequate mixing of the fish in the ice mixture. When each tank was filled to capacity, the fish were given a short time to settle within the slush. The remaining portion of the catch was loaded into the forward hold which was held in the traditional manner without ice. Internal temperatures of the fish and temperatures of the CSW at various points were recorded immediately after loading with fish. Once the fish had settled within the tanks, circulation at a rate of about 120 gpm was started. The temperature of the water at various points in the tanks was taken at half-hour intervals until it stabilized. Once the temperature stabilized throughout the tanks, circulation was turned off and checked periodically until offloading. Temperature data were taken at intervals during the trial to observe the maintenance capabilities of the system.

Fish were offloaded from the bulk tanks in the usual manner with a centrifugal suction pump and on one occasion with a pneumatic Temco pump. Samples from the CSW were removed and placed on ice along with control samples from the forward hold for extended shelf-life studies, organoleptic evaluation, and bacteriological plate counts carried out at the NURC. The containers were lifted off the vessel by means of a crane and placed on a truck for transport to a Maine canning company. After arrival, the fish remained in the containers for 60 hours, and fish temperatures were recorded periodically until unloading. Control samples were shipped in saturated brine for comparison of quality.

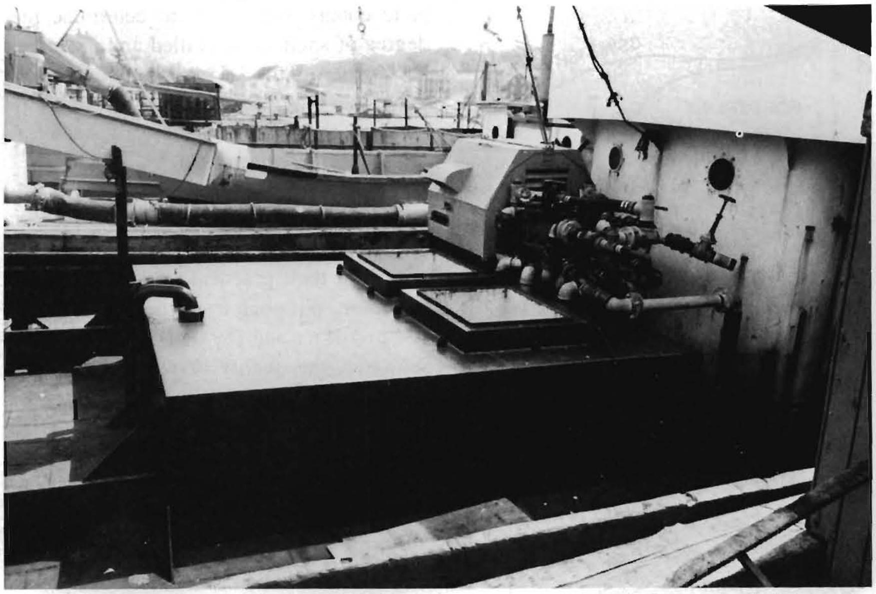
RESULTS AND DISCUSSION

Several problems with the CSW system were encountered during the sea trials. The first difficulty involved the slush preparation. On the first tests, ice was loaded into the tanks and addition of seawater was delayed until the fish were actually being drawn up in the seine. The slush preparation was adequate as long as the fish were caught and loaded shortly after the ice was loaded, but occasionally 2 or 3 days elapsed before the fish were located. During that time, the ice within the tanks began to fuse, forming agglomerated ice masses which complicated the loading, offloading, and circulation procedure. It was found that agglomeration of the ice could be significantly reduced if seawater was added as soon as possible after the loading of ice. Maintenance of the slush was quite effective using this method; in fact, on one occasion the slush was maintained for 3 weeks before the fish were finally loaded.

The design of the bulk tank allowed adequate circulation provided the herring settled in the tank water and ice. Occasionally, the fish did not settle within the slush upon loading, rendering circulation impossible because of clogging at the high suction line. This problem was remedied by attaching a rubber fire hose to the pump discharge and drawing water from the bottom of the tank (sump) and redirecting it through the fire hose through the hatch opening which initiated settling within a matter of minutes. Occasionally, when water was pumped from the sump with a full load of fish in the hold, the fish tended to compact around the sump grate and stop the flow of water to the sump. To increase the area of drainage and provide a more continuous flow of water to the sump, a standpipe leading from the sump grate to the top of the tank was constructed of 7.62-cm (3-inch) PVC with a random series of slit-type openings throughout its length. This provided an additional flow of water to the sump area and prevented clogging of the grate.

After these difficulties were overcome, the system was capable of stabilizing temperatures in the tanks within a 4- to 6-hour period. Temperatures of fish taken from various parts of the tank were within 1-2°C (1.8-3.6°F) of the temperature of the CSW mixture indicating effective heat transfer. In subsequent testing of the CSW system, stabilization temperatures were plotted against quantities of ice (Fig. 2). These are based on the average CSW temperatures recorded—average seawater temperature of 17°C (62°F) and air temperature of 24°C (75°F)—versus the time of holding.

Temperature maintenance of the system was a key factor in the overall efficiency of the system. Fish were held for a maximum of 32 hours before unloading and examining their quality. Upon examination, the quality of CSW herring was visually better than the quality of those taken from the forward hold without ice. Lack of bleeding or autolysis and firmness of the fish itself were evident.



Port view of chute, hatch openings, and pump and piping arrangements of the bulkholding system. Only the upper portion of the bulk tanks is shown; the remainder is below deck.

The efficiency of the bulk tank system is largely due to the configuration of the tank. The smaller upper portion of the tanks made it possible to limit the amount of excess water required for circulation. In British experiments with the CSW system adapted for containers, the ratio of seawater to ice to fish was 1:1:3. Because we were dealing with a bulk system, making maximum use of the space available, the proportion was approximately 1:2:7 for attaining a stabilization temperature of 0°C (32°F).

Optimum temperatures of −1°C to 0°C were reached using a mixture of 6.4 metric tons (7 tons) of ice and 3,785 liters (1,000 gallons) of seawater at 17°C (62°F), although lesser quantities of ice were used for extended holding periods. However, adequate holding temperatures can be achieved with lesser quantities of ice for relatively short, one-night fishing trips, as is the practice with many New England herring boats.

All of the herring caught on these sea trials was processed in commercial plants. Comparisons made on consecutive days between CSW fish and traditionally held fish indicated an increase in the overall yield (Table 1) for the CSW fish. Most noticeable was the condition of the fish upon entering the plant. As there were no plant facilities for storing the catch after the fish were unloaded, all fish, both non-iced and CSW-treated fish, underwent the same process. The CSW fish, unlike those held without ice, did not appear to show any signs of

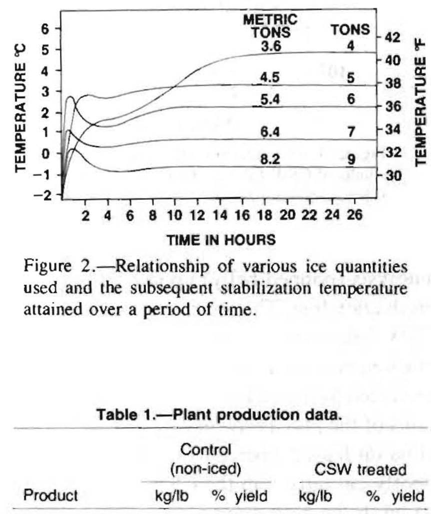


Figure 2.—Relationship of various ice quantities used and the subsequent stabilization temperature attained over a period of time.

Table 1.—Plant production data.

Product	Control (non-iced)		CSW treated	
	kg/lb	% yield	kg/lb	% yield
Gross input				
Herring	63,518 140,000	—	39,164 86,340	—
Fillets	26,762 59,000	42.13	17,962 39,520	45.77
Roe	177 390	0.28	204 450	0.52
Milt	195 430	0.31	168 370	0.43
Discards	36,383 80,210	57.28	20,866 46,000	53.28

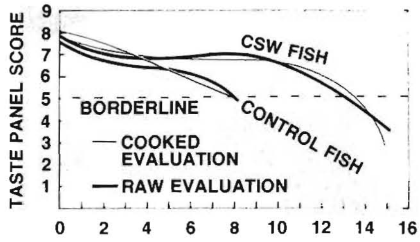


Figure 3.—Average taste panel scores (9-point hedonic) vs. subsequent iced storage time.

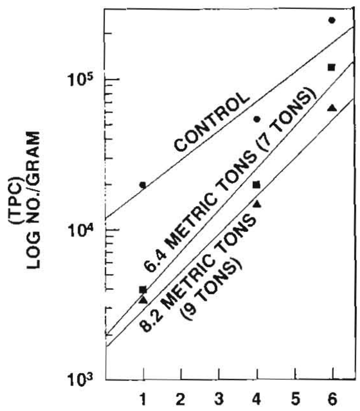


Figure 4.—Comparison of total aerobic counts of CSW fish vs. control fish during subsequent iced storage.

autolysis (popped belly) upon reaching the production line. The relative firmness of the CSW held fish upon reaching the filleting machinery reduced the number of discards produced by the cutting machines. Observations of the process revealed a dramatic decline (at least 50 percent) in the number of poorly cut tails with the CSW fish as compared to the softer non-iced fish. Firmness of the fish also had a direct effect on the increased number of whole, unbroken milt and roe sacks, which accounts for the lower yield obtained from non-iced control fish in which autolysis occurred.

CSW held fish and control samples from the forward hold were boxed and iced upon return to the NURC. Every 2-3 days, a number of specimens in the raw and cooked state from each lot were examined by a taste panel.

Results (Fig. 3) indicate the initial quality of the fish before being placed on ice to have an effect on the shelf life by 5 days when compared to the non-iced fish. Total aerobic plate counts were made to determine the degree of spoilage in chilled and unchilled herring during the 4-5 hour holding time on board the vessel. Results shown in Figure 4 indicate the advanced state of bacterial growth in the control fish.

Container System

The containers for holding herring were tested for their practical value in overland transport. With one test using 299 kg (660 pounds) of ice and 189 liters (50 gallons) of seawater, the quality of fish unloaded 60 hours later was excellent compared to the herring shipped in brine which was spoiled in 24 hours. The circulation system of compressed air for the containers did manage to keep the temperature within the tanks fairly uniform, within 2-4°C (3.6-8°F), although not as well as in the bulk tanks where water circulation was used and the temperature variation was lower.

A preparation of ice and seawater for the storage of herring on the vessel proved effective for overall quality maintenance and in increasing the percentage yield of food-quality sea herring. In general, the CSW system was simple to use and was extremely dependable.

Previous studies performed with herring held in mechanically refrigerated seawater (Meyboom and Van Pel, 1965) showed a permanent red discoloration of the tissues around the belly cavity and the backbone after 5 days. The discoloration was obviously caused by blood or blood components and could not be removed by washing. It was found through further investigation that the salt content of the storage medium influenced the red discoloration in that the higher the salt content, the higher the intensity of the discoloration. Our results indicate that the lowered salt content in CSW could delay this phenomenon.

The design of the bulk tank system was quite effective for use with CSW. The bulk tank is capable of holding sufficient quantities of fish for several days. There is, of course, some reduction in holding capacity but the marketability of the product more than compensates for this loss.

Piping diagrams as shown in Figure 1 indicate the arrangement used throughout the testing procedure—at completion, only one modification was necessary. Raising of the high suction line into the upper portion of the tank could facilitate more rapid circulation of CSW with a decrease in obstruction by unsettled fish. This would also place the high suction line in closer proximity to the ice and seawater consolidated at the top of the tank.

Sufficient testing could not be done with the containers to determine economic specifics, although the overall design of the containers tested was adequately suited to storage and transport procedures. Success of the container system lay primarily in the fact that fish are chilled more rapidly and with less effort than in ordinary icing procedures. Other advantages include: 1) Ease in offloading and transport; 2) Maintenance of quality storage for overland transport; and 3) Less overall handling.

The major drawbacks of containerization are the additional space requirements and reduction in vessel capacity, as well as the cost of large numbers of containers and complete handling systems at dockside and in processing plants. These factors have to be weighed against the improved handling which could bring a higher market value.

The sea herring industry involves a dual system. Those fish considered good are used for food purposes and command the highest market value; the remaining fish are used for industrial purposes. Many times, perfectly good quality fish will be diverted to fish meal because of a surplus and inadequate means of storage.

On a number of occasions, observations were made of the quality of fish waiting to be processed. Unchilled fish often arrive in an advanced state of autolysis. By the end of an 8-hour working day, the fish have become progressively worse, leading to reduction in the filet quality. Even chilled herring can begin to lose their firmness approximately 5 hours after unloading when ambient temperatures are about 18-21°C (65-70°F). After such time, the belly linings begin to soften and break open and the fish quickly lose their firmness.

Currently, there is a lack of adequate equipment for the handling of fish during the processing procedure. It may be advisable that holding tanks prepared with ice and seawater be established in the receiving process. This would allow continual chilling of the herring until such time as they are ready to be cut. Also, a waterless pump could be used in the unloading process to eliminate the use of warm water to remove the fish from the vessel. Such a pump was demonstrated with very good results not only in unloading capacity but in the handling of the fish without physical damage. The CSW could be reused for dockside holding or overland transport with the added benefit of a reduction in waste water volume.

SUMMARY

The results of the tests on bulkholding of herring in CSW indicate several advantages over normal industry practices. Benefits to the fishermen would include: 1) The ability to take advantage of herring stocks further from port; and 2) Increased revenues by landing food-quality fish at higher prices.

Potential benefits to the processing sector would be: 1) Increased production yields; 2) The ability to transport fish long distances without quality loss; and 3) More efficient use of plant facilities by holding surplus fish for longer periods, leveling production, and maintaining operations during periods of inclement weather.

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