IMPROVED METHODS OF HANDLING FRESH FISH IN THE UNITED STATES

PART III - USE OF REFRIGERATED SEA WATER

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ABSTRACT

The chilling and storing of fresh fish in refrigerated sea water (RSW) aboard the fishing vessel eliminated several disadvantages encountered in the use of ice. These include problems of procurement of precooled ice, proper stowage of fish in ice, excessive labor, and the effects on the fish of physical handling. As compared with ice temperatures, lower temperatures (-1°C or 30°F.) of fish in RSW may be maintained. Consideration of the engineering requirements for RSW systems indicates the importance of the proper design of the heat exchanger, the selection of the compressor, the arrangement of the circulating piping, the choice of the tank construction materials, and the installation of the insulation. At present, the major commercial application of the RSW system is for cannery salmon on the Pacific Coast and menhaden on the East Coast and Gulf Coast of the United States. Research on the application of RSW to the preservation of fish has shown the need to investigate each species under commercial conditions and to determine the changes in the composition of the RSW-stored fish. These changes in the fish, as well as problems in application of RSW to specific fisheries, will be influential in the ultimate industrial use of the RSW system as a means of providing high-quality fish to the consumer.

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INTRODUCTION

Disadvantages inherent in the use of ice for the most effective preservation of fresh fish suggest the use of tanks with chilled sea water or dilute brine. As emphasized in the previous paper, the proper icing of fish requires the use of skill, experience, hard physical labor and ample ice. The labor that could be saved aboard the fishing vessel is easily visualized if the fish need only be transferred through the hatch to a tank of chilled sea water. On the assumption that mechanical refrigeration eliminates any need to use ice, the problems of stowing and mixing ice, layering fish, assuring drainage, and minimizing bruising and crushing effects presumably are solved. Furthermore, if sea water or a 3-percent salt brine is used, the temperature of the chill tank can be decreased 1 Centigrade degree below the temperature of melting ice. In accordance with the ability of lower temperatures to decrease the spoilage rate, improved keeping quality would be expected for fish in refrigerated sea water at -1°C. (30°F.) average temperature as compared with similar fish in ice at 0°C. (32°F.). In addition to these possible advantages of labor saving and improved keeping quality, the installation of a RSW system in a boat would appear to have definite advantages compared with ice in multiple use of the boat for various fisheries.

From these considerations, there appears to be some reason to expect that refrigerated sea water (RSW) would gradually displace ice for cooling and preserving fish. The use of RSW both aboard vessel and ashore has found useful application in certain fisheries; however, a closer look at the history and design of the RSW system is desirable to bring out its inherent limitations. Present commercial applications of RSW in the United States and Canada and current research on problems of applying this technique to Atlantic and Pacific Coast species will be considered in the last two sections of this report.

HISTORY OF PRESERVING FISH IN REFRIGERATED SEA WATER

In 1919, J.M. Larsen was issued a United States patent on a method of using clear, filtered sea water chilled to about 0°C. (32°F.) or lower. Larsen claimed that with his method, fish would keep from 2 to 4 weeks in a much better condition than when preserved by the usual methods.

A number of other methods that could be used either for short-term storage of fish in brine at about 0°C. (32°F.) or for freezing are described by H.F. Taylor (1927, p. 620).

Possibly the earliest practical application of RSW was in 1924 when the Marine Products Company of Reedville, Va., in-

stalled a system aboard their menhaden steamer Gloucester. With this unit (Taylor, 1926, p. 71), sea water was pumped through a cooling tank chilled to 4° to 7°C. (39° to 44°F.) and then sprayed onto the fish. The water then percolated down through the mass of fish to a sump and was recirculated.

Prior to this installation, menhaden used in the manufacture of fish meal and oil were seldom, if ever, refrigerated aboard the vessel. During the summer months, spoilage was rapid, odors were prevalent, and valuable protein and oil were lost. The 4° to 7°C. (39° to 44°F.) temperature of the fish achieved with the RSW system eliminated most of the difficulty. Taylor (1926, p. 71) also recommended that this technique be applied to the fresh-fish industry.

In the early 1940's, considerable work was done on the holding of California sardines in RSW at the canneries (Davis, Clark and Shaw, 1945; Lang, Farber and Yerman 1946). The tanks had a capacity of about 10 tons of fish and 3 tons of chilled sea water or brine. One or more cooling tanks of 24-ton capacity were used-one supplied the chilled water to the fish-storage tanks as they were filled, and the other recooled the circulating brine. Sodium chloride brines of about 3 percent were used, since the available (inshore) sea water was quite contaminated. The salt was added just before starting the circulation through the tank to take advantage of the negative heat of solution. In an efficient system, sardines could be cooled from 17° to 1.7°C. (63° to 35°F.) in about 14 hours.

At about the same time, RSW was also successfully applied to the holding of Maine sardines. Sigurdsson (1945, p. 91) reported that temperature should not exceed 0°C. (32°F.) except during very short periods and for best results, should closely approach the freezing point of the fish (initial -2°C or 28.5°F.).

In 1952, workers at the Fisheries Research Board of Canada Technological Station at Vancouver, B.C., began their investigations into the use of RSW. The work at their station has resulted in the successful application of RSW to the Pacific salmon and halibut industry both aboard the vessel and ashore. Among the numerous reports on their work is Bulletin No. 126, considered by many to be the best single reference for RSW technologists (Roach, Harrison and Tarr, 1961).

The researches at the Vancouver station emphasized the need for holding the fish as close to 0°C. (32°F.) as possible, recognizing that there is nothing magical in RSW, per se, but merely that with it, the fish can be cooled more rapidly and held at a lower temperature than is possible with ice. If these two conditions are not present, quality will be no

better and may be worse than is found with ice-stored fish.

DESIGN OF REFRIGERATED SEA WATER SYSTEMS

Many RSW installations, both on the vessel and ashore, have failed to live up to expectations, primarily because of poor design. Some of the important factors to be considered when installing RSW systems are discussed below.

Heat Exchangers

Sea water away from the immediate coast averages 3.5 percent salinity and freezes at -2°C (28.4°F.). The desired -1°C. (30°F.) temperature thus is very close to the freezing point of sea water, making the design of the heat exchanger critical. This is especially true with direct-expansion systems, where the evaporator surface will be about 6 Centigrade degrees (11 Fahrenheit degrees) below the temperature of the sea water and 5 Centigrade degrees (9 Fahrenheit degrees) below its freezing point.

Many of the older RSW installations and some of the current ones are plagued with freeze-ups in the heat exchangers, resulting in decreased efficiency and poor quality of fish. A brine chiller designed at the Vancouver station, having overcome this problem, has proved efficient and is being used in many installations at sea and ashore (Roach et al, 1961, p. 16). With a high velocity of sea water through the exchanger and a high rate of heat transfer, cooling is rapid, yet heat-exchanger freeze-ups are not a problem.

Refrigeration Compressors and Refrigerants

When compressors are sized to fit the installation, no major difficulties were experienced. For shipboard use, Refrigerant 12 (Freon-12) is the best choice in our experience. Ammonia is too dangerous aboard small vessels, but is satisfactory for shore installations.

Circulating Pumps and Piping

Open-impeller centrifugal pumps resistant to corrosion are used to circulate the sea water. A flow rate of 760 liters (200 U.S. gallons) per minute is sufficient to cool and hold 45,000 kilograms (100,000 pounds) of fish.

Plastic piping is the most suitable material, particularly aboard the vessel where repairs and replacement may be difficult. The piping should be arranged so that the sea water can be pumped either into the bottom or into the top of the tank and so that all lines can be flushed with clean sea water. All piping in the engine room or other areas exposed to heat must be arranged so there are no dead spots where bacteria can grow and contaminate the fish. Many installations of the RSW system aboard small fishing vessels during 1955 to 1960 were unsatisfactory and were discarded because of failure to design the piping for adequate circulation and sanitation and difficulties when the system was overloaded during peak fishing periods.

Fish-holding Tanks

A primary consideration in tank design is to provide for ease of cleaning. Succeeding loads of fish may spoil rapidly if the tanks cannot be completely and promptly sanitized after being unloaded.

Steel tanks are satisfactory, provided the surfaces are kept coated. Materials such as nontoxic bituminous paints and epoxy resins have been found to be suitable coatings and adhere well with proper surface preparation.

Corrosion-resistant aluminum alloys are satisfactory, but the need to use welding techniques involving inert-gas shield could present problems in vessel installation and repair. Also it is necessary to use aluminum or plastic fittings on the tanks to prevent corrosion.

Wood (including plywood) tanks are easy to construct and are satisfactory as long as the surfaces are kept covered with waterproof coatings, such as resin or plastic linings. Breaks in the coatings, however, allow bacteria to penetrate into the wood and provide a source of contamination for the next load of fish.

Concrete tanks, either of poured or of block construction, have been used for shoreside installations, but again a water-impervious coating, such as nontoxic bituminous materials, must be applied.

Insulation

The insulation of RSW tanks aboard the vessel presents problems. With wooden vessels, provision must be made for the circulation of air between the insulation and the hull structure and surface to prevent dry rot. In general, waterproof insulating materials such as foamed polystyrene, glass, and rubber are satisfactory; and in many installations, the foam-in-place insulations may be used to advantage, both for insulation efficiency and for protection of the structure in wooden hulls.

CURRENT USE OF REFRIGERATED SEA WATER

On the Pacific Coast, RSW systems aboard vessel and ashore are used commonly for salmon, halibut, and to a lesser extent, trawl fish. Roach, Harrison, and Tarr (1961, p. 24) reported that salmon packers or tenders with RSW could pick up fish in areas far from the cannery, chill them rapidly, and hold them for as long as a week. Chilling and holding large quantities of salmon for such purpose by means of ice is impractical. With halibut, it is reported (Roach, et al, 1961, p. 24) that use of RSW aboard fishing vessels produced fish of superior quality in comparison with iced fish and increased the efficiency of the crew by eliminating the laborious work of icing. The most successful use of RSW for holding bottom fish aboard trawlers

has been in Oregon and Northern California where the fishing grounds are close to port (6 to 12 hours) and the RSW system is needed to provide flexibility and efficiency for a small crew that must rapidly chill large quantities of fish. Less success has been achieved to date in several trials with trawlers operating to more distant grounds out of Puget Sound.

With the decline in the California sardine landings--from 325,000 metric tons in 1950 to 25,500 metric tons in 1960--many of the canneries have closed, and little use is made now of RSW in this area.

Menhaden vessels are the primary users of RSW on the Gulf Coast. In addition, some shrimp vessels are reported to have installed RSW systems as have some vessels fishing for the pet-food industry.

On the East Coast, menhaden vessels are the prime users of RSW. Shore installations have been tried in Newfoundland for holding cod, but since ice was the only cooling medium, temperatures were considerably higher than 0°C. (32°F.), and the results were not satisfactory. One successful shore-side installation is being used for short-term holding of fish that are to be canned for pet food.

RSW is not presently being used with Maine sardines, although many of the processors do hold the fish in a refrigerated 30°-salinometer (30 percent saturated) brine prior to canning.

RESEARCH ON REFRIGERATED SEA WATER

Current research on the application of RSW is emphasizing the determination of storage life of various species of fish and shellfish and the effect on the acceptability of the end product. Inasmuch as the commercial handling and individual characteristics of each species affect its keeping quality in RSW as well as in ice, systematic testing is essential before any application may be forcast. These tests should include a consideration of the effect of the sea-water storage on the chemistry of the flesh as well as on the progress of microbiological spoilage. A small portable tank used in conjunction with either refrigerated immersion coils or an external heat exchanger to provide chilled water is convenient for such tests.

Northwestern Atlantic Species

Since little work had been done on the storage of Northwestern Atlantic species of fish in RSW, research was undertaken at the Bureau of Commercial Fisheries Gloucester Technological Laboratory to determine whether this technique could be applied to the fisheries in this region. The preliminary results of storage tests both aboard the vessel and ashore are given in the following sections.

Preliminary studies.--A small tank, capable of holding 180 kg. (400 lbs.) of fish at

a packing density of about 720 kg./cu.m. (45 lb cu.ft.) and at a temperature of -1° ± 0.3°C. (30° ± 0.5°F.), was used in tests on ocean perch and whiting.

With ocean perch, the researchers found that the fish stored in RSW were of edible quality for about 7 days longer than were those stored in ice (Cohen and Peters, 1962, p. 46). They found that whiting kept 2 to 3 days longer in RSW than in ice (Cohen and Peters, 1963, p. 27).

They also found that there was no loss of amino acids or protein from whiting held in RSW (Cohen and Peters, 1963, p. 10) and that during subsequent frozen storage, fish that had been held in RSW lost quality at a slower rate than did fish that had been held in ice (Cohen, Peters, and King, 1963, p. 109).

With the cooperation of the captain of an ocean perch vessel, RSW equipment was installed, and several shipboard tests were conducted. These tests were moderately successful but not as successful as the laboratory tests. A specific problem that arose was the development, in the recirculating sea water, of off odors that penetrated into the fish flesh. Since the odors were bacterial in origin, efforts were directed toward finding methods of inhibiting bacterial growth in the sea water by use of ultraviolet radiation.

Ultraviolet radiation of refrigerated sea water.--Ultraviolet radiation has been used for many years in various bactericidal applications. Boyd and Southcott (1964, p. 43) concluded that ultraviolet radiation of refrigerated brines was very effective in preventing bacterial development in the brine but did not improve the bacterial quality of the fish stored in the brine.

Penetration of ultraviolet rays into solutions is greatly affected by turbidity, and after only a few hours of circulation during the cooling of fish, the RSW is highly turbid. Available commercial ultraviolet units designed for sterilizing relatively clear water, such as municipal water supplies or swimming pools, did not appear suitable for our use.

An ultraviolet unit designed and built at the U.S. Public Health Service Laboratory in Purdy, Washington, appeared to be suitable (Kelly, 1961). A modification of this unit, built by the Maine Department of Sea and Shore Fisheries, was made available to us for tests. During a 2-hours period of recirculating a simulated RSW solution, bacteria counts were reduced from 12 million to 3 thousand per ml.

A similar unit was built at the Gloucester Technological Laboratory and connected into the experimental RSW system. Tests showed that with the ultraviolet unit operating, bacteria counts seldom exceeded 100,000 per ml., but when the unit was cut out of the system, counts approached 8 million per ml. Odor in the sea water was

reduced somewhat, and fish quality was slightly improved when this unit was in operation.

Changes in the fat.--Further tests with whiting and pollock, however, have indicated undesirable changes in the fat during RSW storage. In current studies, seasonal changes in fat composition as they relate to the storage of these species in RSW and in ice are being investigated.

Northeastern Pacific Species

The comprehensive studies and commercial-scale trials summarized by Roach, Harrison and Tarr (1961, pp. 23-28) clearly indicated the advantages of the RSW system for a wide group of species of Pacific fish and shellfish. Both these studies and the early commercial applications in the salmon, halibut, trawl-fish, and shrimp industries indicated the need for continuing research into problems resulting from the interchange of components in the fish-RSW system.

The storage of eviserated pink salmon (*Oncorhynchus gorbuscha*) for 8 days in a 3-percent solution of sodium chloride at 1°C. (32°F.) was shown by Thurston and Groninger (1959, p. 284) to result in a ninefold increase in the sodium content and a decrease, by more than half, in the potassium content of the flesh. They concluded that the differences in quality between iced and brine-chilled salmon were small but that the high level of sodium absorption might affect the use of such salmon in "dietetic" (low-sodium) products. In a recent study of changes in steelhead trout (*Salmo gairdneri*) passing through rigor mortis while in RSW, Tomlinson (1964, p. 3) observed that an increase in the sodium content of the ordinary muscle became evident earlier in the exhausted than in the unexercised fish. He also concluded (Ibid., p. 4) that metabolic processes cause some of the weight changes observed in trout and sockeye salmon (*Oncorhynchus nerka*) stored in RSW.

With small fish and crustacea, one might expect that storage in RSW would result in a significant loss of soluble components. Limited tests at the Bureau of Commercial Fisheries Technological Laboratory in Seattle during 1958 showed that the total solids content of raw shrimp meat declined from 18.2 percent to 14.8 percent during storage for 7 days in a 3-percent sodium chloride solution at -1°C. (30°F.). In later studies at the Ketchikan Technological Laboratory, Collins (1960, p. 14) showed that the loss in solids content of pink shrimp stored in RSW was reflected in the lesser yield of precooked meats. He estimated that if shrimp were held longer than 2 days prior to machine peeling, there would be a loss in yield of two cases per 100 cases (one case is 24 cans of 128 grams or 4.5 ounces drained weight) of canned shrimp produced.

It is evident from both the U.S. commercial developments and continuing research in the application of RSW to the fisheries that careful investigations of the species and of other industry factors should be conducted before the RSW system is used to replace other preservation techniques. The final judgement must reflect the factors of keeping quality, production efficiency, and changes in the composition of the product.

CONCLUSION

Refrigerated sea water as a storage medium for fish has been applied successfully in several U.S. fisheries, and because of the advantages of (1) rapid cooling, (2) low storage temperature, (3) greatly simplified stow-age, (4) no bruising or pitting of the fish, and (5) slower spoilage rate, its use will undoubtedly be extended to other fisheries.

Before such applications are attempted, however, thorough investigations must be made of each species throughout the catching season to determine its keeping quality in RSW under commercial conditions and the changes in the composition of the RSW-stored fish as they acceptability.

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