NOAA TECHNICAL MEMORANDUM NMFS-SEFC-102

ENGINEERING AND ECONOMICS OF REFRIGERATED AND CHILLED SEA WATER SYSTEMS FOR SEMI-TROPICAL WATERS, INCLUDING AN ANNOTATED BIBLIOGRAPHY

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ABSTRACT

An overview of work done with RSW and CSW systems and the potential for the use of their combinations is presented. Particular attention is given to the problems arising from the use of these systems in the tropical and semi-tropical waters found off the Southeastern United States. Brief estimates of both first costs and operating costs are given for four hypothetical systems; however, no attempt is made to specify a least-cost system due to the number of controlling variables that must be considered in any specific application. An annotated bibliography of most of the relevant literature is provided in an appendix.

INTRODUCTION

Refrigerated Sea Water (RSW), Chilled Sea Water (CSW), and their combinations are chilling and holding systems for bulk storage of finfish and some types of shellfish. They are used on board harvesting and transport vessels and on shore after the fish are landed. The common factor among these systems is the use of sea water as a heat exchange and holding medium. Usually these systems utilize total immersion, although some types are spray brine systems which hold the fish in bulk and only pass the sea water over the fish to chill them. The terms RSW and CSW derive from the cooling method used in the system. An RSW system uses mechanical refrigeration, while a CSW system uses ice as the source of cooling. A combination system uses both mechanical cooling and ice.

There are many variations on the basic theme of a fluid based heat exchange medium. Brine freezing, whether it is a spray as is used in the Northwest shrimp fisheries or an immersion system as is used on tuna vessels, is one variation. In the Southeast, some shrimp vessels may use a sugar-salt solution to freeze and glaze the catch before storage. More exotic examples may eliminate the water completely in favor of other liquid heat exchangers such as glycerin or liquid freon.

This report will be limited in its discussions to those systems in which water is both the heat transfer medium and the flotation medium. Also excluded from this report will be those systems designed to freeze the product instead of providing a temporary holding mechanism for fresh fish.

The purpose of this report is to act primarily as a guide to the users, owners, or potential investors, who have the need for more information so that they can better understand their needs and the capabilities of such systems.

This report should assist such persons to better convey their demands to the engineers and designers of the systems, and to develop a confidence in their evaluation of the system's ability to perform the specified job. It should also serve to assist designers and engineers in providing them with additional information as to the more critical aspects of the systems. For those who are not familiar with the literature on fish handling in RSW-CSW systems, these areas are covered in some detail. Much of the material in this report is from other sources, while some small part is from first-hand experimentation. However, this document is not intended in any way to serve as a do-it-yourself guide, and it is strongly recommended that professional engineering and design help be obtained as early in the design process as is feasible.

RSW and CSW systems have a number of advantages and disadvantages primarily resulting from the use of the sea water medium. Primary among the advantages is the system's potential ability to chill relatively larger volumes of fish in a shorter time as compared with icing by hand. Circulating chilled water offers much faster heat transfer from the fish than does the contacts and air pockets of icing. However, the chilling of fish using direct contact with ice, if properly done can hardly be faulted. It is an excellent method as it provides a low temperature. It is a visible, reliable source of cooling and it washes the fish as it chills them. Ice is normally safe, sanitary, readily available, and it has a high cooling capacity. When large quantities of fish are handled, ice must be evenly distributed among the fish and often this is not possible because of the large amounts of labor involved. Too often the choice is one between cooling the fish in RSW or CSW systems, or icing the fish poorly, if at all.

The second advantage of RSW and CSW systems is that the sea water offers some physical support for the fish. Thus, larger depths of fish can be stored without the weight of the fish and ice crushing those fish towards the bottom of the pile. This eliminates the need to shelf or to box the fish as when they are iced. A third advantage of these systems is the potential for faster chilling to a lower temperature than is obtainable from ice. The use of full strength sea water in RSW systems allows the fish to be held at 29^{0} F instead of the 32^{0} F possible with ice. This slight difference in temperature may mean a slightly longer shelf-life for the fish.

Other advantages offered by the RSW-CSW system are a washing action; the storage is non-drying to the fish; and the media is a less supportive environment for bacterial growth. The fluid medium means that the storage temperature can be adjusted, fluidized unloading can be used, and offers the unproven possibility of using additives for bacterial control or control of oxidation.

The disadvantages of RSW-CSW systems also stem largely from the use of the salt water storage medium. Primary among the disadvantages is the uptake of salt in fish from the sea water. Full strength sea water is 3.5 percent salt by weight. In time, this salt will penetrate the fish stored in the salt water. The longer the period of storage the greater will be the salt uptake into the fish flesh. CSW systems which use fresh water ice and no added salt have less of a problem with salt uptake because the melt-water dilutes the salinity. When 88^{0} F sea water is added to enough ice to chill the water to 30^{0}F the melting of the ice will dilute the salinity from 3.5 to about 2.5 percent almost immediately. When additional ice melts to chill the fish, the salinity will become even more dilute. Salt uptake is not normally a problem where the fish will be processed with salt as for canning, but it can limit the length of time that RSW-CSW systems can hold fish destined for fresh markets.

While the holding of fish in water prevents compression damage, it can produce other types of physical changes. The motion of the water and fish can remove scales from fish that have naturally loose scales. The water medium can bleach some of the color out of the fish, so that they may be less attractive in the market place. The fish can absorb the water itself, and thus gain weight and lose firmness.

Another disadvantage of the liquid storage medium is that it can transport bacteria from one part of the hold to other parts, and it can transport bacteria from a bad fish to the rest. Thus RSW-CSW systems demand careful sanitation for good quality fish: the holds and piping must be easy to clean and sanitize, and the operator of the system must make the effort to keep it clean.

Other potential limitations of the RSW-CSW systems are that: they require good circulation of the water to achieve adequate heat transfer and prevent areas of warm water within the holds; they require monitoring during operation and more maintenance of the mechanical systems than icing; and they are more expensive to purchase and install initially. While these additional considerations are not reasons to avoid RSW-CSW systems, the potential user of these holding methods should be aware of the constraints involved.

The literature on RSW-CSW systems covers many of these constraints in a somewhat fragmentary manner. The bibliography included as an appendix covers most of the major sources of information on RSW-CSW systems and related studies. Some related articles are included to assist the reader in reviewing the basic principles of refrigeration, fish handling and testing procedures. Many of the articles are research articles based on laboratory or small scale experiments. Most of the articles dealing with commercial scale tests and operations are either review articles, or are items which are often deficient in detailed information. Roach et al. (1961, 1967, 1973), Gibbard and Roach (1976), Hulme and Baker (1977) are exceptions in that they provide broad sources of information. The ASHRAE handbooks (American Society of Heating, Refrigeration and Air Conditioning Engineers) are comprehensive in their coverage of refrigeration fundamentals and systems, and of food handling. A good practical lay guide to refrigeration is the Audel Handbook (Anderson and Palmquist, 1977). Several books are good sources of information on marine refrigeration and fish handling. Merritt (1969) addresses RSW and CSW systems, while Mead (1980) only mentions them but addresses marine refrigeration and fish handling.

While Merritt provides some details on RSW systems, the most detailed coverage of RSW systems and design is found in Roach, et al. (1961); however CSW systems were not covered in that paper. The work on RSW was extended in several additional publications including Roach (1973), and Gibbard and Roach (1976). A good summary of both RSW and CSW systems is provided by Kelman (1977). Kelman particularly addresses the problem of heat transfer into the system through the walls of the tanks. Hansen (1981a and Hansen et al. 1976) provides a review of past British, Danish, and Chilean boat trails using CSW systems; advantages and disadvantages are discussed. Kolbe (1979a, 1979b, 1979c, 1981a, and 1981b) has published extensively on RSW spray systems for northern shrimp vessels, and there is much useful design information to be found in this series.

The Kolbe series also provides field trial information on the system he discusses. The series of articles by Roach also provides information and actual results from commercial systems. Some of the news articles detailing commercial systems are: Anon (1964) deals with systems for tuna boats; Anon

(1973a, 1973b) deal with containerization of CSW systems; Hulme and Baker (1977) report on shipboard CSW work with herring in holds and containers; Anon (1973c) deals with the CSW containerization research of Hewitt and McDonald at the Tory Research Station; and Eddie and Hopper (1977) report on CSW container systems for herring. Other articles on CSW container systems are Hansen et al. (1977a), Hansen (1981a), and Dagbjartsson (1981). Articles dealing with the use and manufacture of sea water ice in field trails are Brinch (1973), Eddie (1961), Kelley and Little (1968) and Hansen (1956).

The majority of the articles published on RSW-CSW systems are the result of laboratory testing and evaluation of the food quality of fish and shellfish held in these systems. A recent FAO document (Santos and Tentscher, 1981), "Guidelines for Chilled Fish Storage Experiments," offers numerous suggestions about conducting this type of work.

The earliest work on RSW-CSW systems appears to have been done by Le Danois who in 1920 was issued a French patent for holding fish in sea water or brine. Huntsman in 1931 showed that fish could be held in circulating sea water cooled by large blocks of ice, and Hess in 1933 determined that fish flesh held at 30^{o} F kept twice as well as when it was held at 36^{o} F. Roach (1961) gives an excellent overview of the above early history of the field.

The next major period of work was done with RSW in shore tanks for the California sardine industry during World War II by Davis and Clark in 1944. Osterhaug (1957) published a bibliography of the early work, 1944-1957, on RSW-CSW systems. One of the earliest continuous research programs was conducted by the Fisheries Research Board of Canada initially working with RSW systems for salmon (Harrison and Roach, 1955; Steiner and Tarr, 1955; Barker and Idler, 1955; and McBride et al., 1955). From these early beginnings the work on RSW-CSW systems has been expanded to a nearly world-wide basis.

THE CHILLING OF FISH AND HOLD DESIGNS FOR RSW-CSW SYSTEMS

RSW-CSW systems are principally a means for removing heat from fish, and for holding the fish at as low a temperature as possible without freezing them. Without defining heat in a rigorous manner, some of the aspects of heat and its transfer between materials need to be discussed before the design and engineering of RSW-CSW system can be developed. First, heat will flow from the warmer to the cooler object. The rate at which the heat flows between the two objects ($\frac{\Delta Q}{\Delta t}$) is proportional to the temperature difference between the two objects (ΔT), to the surface area between the two objects (A) and to the overall heat transfer coefficient of the substances separating the two objects (U). That is $\frac{\Delta Q}{\Delta t} = UA\ \Delta T$.

The second aspect of heat is that relatively large amounts of it are normally required for phase changes such as going from a solid to a liquid or from a liquid to a gas. When a pound of ice at 32^{o} F melts, it absorbs from its surroundings 144 British Thermal Units (BTU's) of heat. This is enough to lower 144 pounds of water from 63 to 62^{o} F. The boiling of the refrigerant in the chiller of a refrigeration system is another phase change that absorbs heat from its surroundings. The precise amount of heat absorbed by this phase change depends upon the pressure at which it occurs and the properties of the particular refrigerant.

The third aspect of heat is that it is interchangeable with mechanical energy. Pumping water will add heat to the water that the cooling system will have to remove. One horsepower for one hour completely converted to heat will add 2545 BTU's to the system, however in reality a one horsepower pump will not add this amount of heat. This is not a particularly large amount of heat. The melting of 18 pounds of ice will roughly counter-balance it. These and other concepts will be developed as needed in this section.

The purpose of removing heat from fish is to slow the rate of spoilage, which begins immediately upon death. After the fish is removed from the sea, a race begins to deliver it to the consumer in the best condition possible.

Three factors play a major part in the spoilage of fish: enzymes, bacteria and oxidation. There are digestive enzymes present in the stomach and intestines and other enzymes in the muscle of all fish. To some degree the amount and activity of the digestive enzymes depends upon the recent feeding history of the fish. A second major factor in the spoilage of fish is bacterial action. On live fish bacteria are largely confined to the skin, gills and intestines. After death of the fish, bacteria will penetrate the flesh both from the inside and from the outside. The third factor is oxidation, especially of the fish oils. Fish normally have oils that are much more reactive (unsaturated) than vegetable fats and oils. When the unsaturated fish oils react with oxygen, the process produces the rancid odors and flavors of a "fatty" fish gone bad. This factor becomes more important in the spoilage process the "fattier" the fish. (Merritt, 1969.)

All three factors are slowed by chilling, but not to the same degree. Bacterial growth is significantly reduced below 32° F. Enzyme activity is slowed by chilling but can continue even after some of the water is frozen in the fish. Oxidative rancidity is slowed by cooling or freezing, but it is not stopped. The best way to prevent it is to eliminate the oxygen in the system. The use of antioxidants can greatly retard oxidation.

The proper chilling of fish with ice requires that each fish be in intimate contact with the ice. Much of the heat transfer is achieved by contact with ice and by the cold melt water running over the fish. Even given proper packing, ice may not chill fish as fast as contact with circulating cold water.

Croaker (Micropogon undulatus) of about 2 pounds each were chilled from 81^{o} F to 33^{o} F in 1 3/4 hours by icing, while an experimental RSW system took slightly less than one hour to chill the same fish. It was also shown that the initial temperature had less effect on the length of the chilling period in fluid based RSW-CSW systems than it did for iced fish (Ernst, 1981).

The length of time it takes to chill a fish is largely dependent upon the thermal conductivity of the fish, the thickness of the fish, the temperature difference between the fish and the cooling media, and what is referred to as a film coefficient of heat transfer. The thermal conductivity of the fish which may differ with composition and species is natural to the fish and cannot be changed. The thickness of the fish is also an uncontrollable factor. A thick fish will require more time to chill than a thin one. The temperature difference is the driving force behind the heat transfer. This changes as the temperature of the fish drops and becomes very small as the inside temperature of the fish closely approaches the temperature of the chilling water. Finally there is a film resistance which can be thought of as a thin layer of water contacting the surface of the fish and serving to insulate it from the chilling water. The more rapidly the water is moved past the surface of the fish the less will be the film resistance --to a limit. While it is not practical to totally minimize this film resistance, it can be significantly lowered by increasing the velocity of water past the surface of the fish and rapidly replacing the surrounding water with colder water. Thus, while the thermal conductivity and thickness of the fish cannot be changed the temperature difference and film resistance can by keeping the temperature of the surrounding water as low as possible and moving the water past the fish as rapidly as reasonable.

The use of seawater as the chilling media permits the chiller to be operated at a lower temperature (29 to 30°F) than fresh water or fresh water ice because of the lower freezing point of seawater. Fish, however, will begin to freeze about 29°F. This slow freezing may be detrimental to the fish although it is sometimes utilized in the super chilling of fish (Merritt, 1969 and Scarlatti, 1967).

The storage and chilling of the fish takes place in the hold of the vessel. A water-tight hold and some method of chilling and pumping or stirring the water are common to all types of RSW-CSW systems and their combinations. Therefore the design of the vessel holds and their circulation systems are the logical starting point for a detailed analysis of the sub-systems of the overall RSW-CSW design. The design and construction of hold tanks for liquid based systems involves a number of important considerations: size, structure, vessel stability, materials (including insulation), cleanability and sanitation, water piping, and access to and from the hold.

The size of the hold will depend upon the expected size of the catches, the length of the fishing trips, and the size of the vessel. It would not make sense to put the largest size hold possible into a vessel whose fishing trips are expected to be limited by the length of time the fish can be held, nor would it make sense to limit the length of the trips by undersizing the hold. When the installation of a RSW-CSW system is contemplated, two factors should be initially counterbalanced. These are the physical size of the vessel, and its expected catch rates. The calculation of the hold capacity for RSW systems is relatively straightforward. The total hold volume multiplied by the desirable bulk storage density for the species of fish to be stored will give the hold capacity in pounds. A number of bulk densities have been found in the literature and they are presented in Table 1. The capacity of a 2000 cf RSW tank holding fish at a loading density of 45 pounds per cf is 90,000 pounds. Care must be taken to use a loading density which will permit adequate water circulation. Loading densities are normally lower than dry bulk densities and probably should not exceed 45 pounds per cf for most fish.

The calculation of hold capacity for CSW or combination systems is complicated by the presence of the ice in the water. A safe but rough approximation of the capacity of the hold for fish can be made by subtracting the volume occupied by the ice in the hold from the total hold volume, and then proceeding as above. The volume occupied by the ice can be calculated by dividing the weight of ice by the bulk density of the ice. The bulk density of the ice will vary with the type of ice used (Table 1).

The same 2000 cf hold as above with 10 tons of 40 lb/cf ice would have 1500 cf of useable space remaining and a capacity of 67,500 pounds of fish. The capacity of CSW systems for fish will increase as the ice melts. One of the more difficult operational aspects of CSW systems is to ensure that enough ice remains in the hold to properly refrigerate the fish, and yet reduce the amount of ice which must be discarded at the end of the trip so that the hold capacity is not unduly limited by the excess ice.

After the total volume of the hold has been determined, the design and compartmentization of the hold must be considered. Two factors enter the design at this point, vessel stability and overflows among the compartments. The fluid nature of the fish/ice/water mixture in the hold can lend itself to easy and rapid shifts in the vessel center of gravity, if proper care is not taken. For this reason one should depend upon a competent marine architect to aid in the development of a safe and stable vessel design.

TABLE 1

Densities of Materials

MATERIAL	DENSITY (lb/cf)	TYPE	SOURCE
Fresh water	62.4	True	
Sea water	64	True	
Block ice	57.2	True	Myers, 1981
Crushed ice	41 to 44	Bulk	Myers, 1981
Flake ice	27 to 28	Bulk	Myers, 1981
Sardines-anchovies	54.5	Bulk	Hagen, 1981
Large Shrimp	32	Bulk	Hagen, 1981
Lobster Tails	32	Bulk	Hagen, 1981
Small shrimp	40 to 60	Bulk	Kolbe, 1979
Salmon	45	1/	Roach, 1973

1/ Recommended loading density for RSW systems.

One solution that has been recommended and used is to use a narrow throat at the top of the hold and to fill the hold until the water surface is in the throat. This will eliminate the majority of the free water surface in the hold and will also prevent the fish floating at the top from being damaged by the motion of the vessel (Merritt, 1969).

The second factor to be considered is the dividing of the hold into compartments so that overflow of water is minimized when the fish are loaded into the hold. When fish are added to a hold full of water, an amount of water equal in weight to the fish will be displaced out of the hold. A hold completely full of sea water will have about 70 percent of the water displaced when it is filled with fish at 45 lbs/cf ($\frac{45}{64}$ = .703). The problem with discarding this overflow is that considerable investment will have been made in chilling the water as it is recommended that the water be pre-chilled to 30-32^{0} F before the fish are loaded. For a 1000 cf hold and a sea water temperature of 88^{0} F, the investment in cooling the 700 cf of overflow would approximate 17,500 pounds of ice or equivalent refrigeration when the hold was fully loaded.

Several solutions have been offered to the problem. The first is to only fill the hold 30 percent full, or to compartmentize the hold and to fill each compartment 30 percent full as needed. This solution may not be satisfactory in rough weather or in high seas. A second solution offered by Hagen (1981) is to size the compartments so that the overflow from the first compartment fills the second compartment, and the overflow from the second compartment fills the third, and so forth. For three compartments in the series the ratios are: 2.04 : 1.43 : 1, and for a 1000 cf hold the volumes are 457, 319 and 224 cf. This would reduce the overflow discarded from seventy to 15.6 percent and the discarded investment in cooling power in the earlier example to 3,900 pounds of ice or its equivalent. A third solution is to size the compartments so some full compartments of sea water will hold the exact amount of chilled water for the total maximum catch. Water will then be available if a total load is harvested. The fallacy of any of these solutions is that neither the exact amount of fish nor water will ever be available to just totally fill some tanks and keep the remainder empty. The use of several different size compartments will however, offer the opportunities to better stabilize the vessel with two reasonable size compartments full for the initial sea water load. Reasonable adjustments can then be made as fish are loaded.

The use of RSW-CSW systems places a number of requirements upon the materials and the design of the hold compartments. They must be watertight, corrosion resistant, and well insulated. They also must be free of obstructions which would make the tanks difficult to load or unload, to clean and sanitize, or would tend to damage the fish in the hold. Almost all writers on RSW-CSW systems stress sanitation and cleanability pointing out the absolute necessity for including cleanability as part of the design considerations, and for including the sanitizing of the system as part of the physical operation and maintenance of the equipment. Sanitation should be considered second only to temperature, and it becomes even more important once low temperatures are achieved. One or two degrees F are probably not as important as a clean system is once the fish have been chilled. However, neither can be neglected.

Wood is not recommended as a construction material for the hold because of sanitary considerations. If wood is used, then it must be thoroughly isolated from the fish by the use of plastic laminates such as fiberglass. Steel can also present considerable problems as a hold construction material unless it is also continuously protected. The physical stresses and strains and thermal expansions and contractions can create difficulties in maintaining the integrity of the protective coating.

TABLE 2

Typical Values of Thermal Resistance and Conductance

SUBSTANCE	THICKNESS (inches)	RESISTANCE $\left(\frac{ft^2\ h\ ^oF}{BTU}\right)$	CONDUCTANCE $\left(\frac{BTU}{ft^2\ h\ ^oF}\right)$
Aluminum	0.4	0.00028	3571
Steel	0.4	0.0014	714
Surface, Water	*	0.014	71.4
Surface, Air	*	0.56	1.78
Air Space	2.5	0.96	1.04
Wet Wood	2.0	1.02	0.98
Dry Wood	2.0	1.87	0.53
Fresh Fish	2.0	5.67	0.18
Fiberglass	4.0	15.38	0.065
Polystyrene	4.0	17.39	0.057
Foamed in place Urethane	4.0	33.90	0.029

To calculate the heat flow through a series of materials the resistances are added:

$$\frac{\Delta Q}{\Delta t} = \Delta T \cdot A \cdot \left(\frac{1}{R_1 + R_2 \ldots + R_n}\right)$$

where $\frac{\Delta Q}{\Delta t}$ = heat flow in BTU/h

ΔT = Temperature difference in ^{o} F.

A = Area in ft^2

$R_1 \ldots R_n$ = Thermal Resistance in $\frac{ft^2\ h\ ^oF}{BTU}$

If metalic materials are used in the hold construction, then their inherently high thermal conductivities must be considered in the vessel design. Kelman (1977) points out in his discussion of RSW-CSW tank insulation that when steel tanks are built with the support members penetrating the insulation, the insulation is much less effective than when the tanks are fully isolated. Kelman also presents a method for calculating the total heat load from the environment through the hold walls. The basic process is to take the area (A) for each section of the hold walls and to multiply it by the overall heat transfer coefficient (U) and the temperature difference between the inside of the tank and the environment outside the area (Δ T). The sum of the heat leaks for all of these sections of the walls is then the total heat load from the environment through the walls. An example of the calculations are shown in Table 2, and the heat transfer coefficients for a number of materials are given. Another source of environmental heat load is the air entering the hold through the access ways. Merritt (1969) presents a good discussion of the heat gains from air changes in a fish hold.

Warm winds blowing into the hold will add an appreciable heat load. Sun shining on an open or uninsulated hold will also add significantly to the heat load. White rather than colored surfaces will significantly reduce the heat load from sunshine.

The last hold design factor that will be discussed is the circulation system. Circulation of the sea water is absolutely necessary to move heat in the RSW systems from the fish to the chiller and from the fish to the ice in CSW systems. High flow rates are necessary to speed the removal of heat from the fish by raising the heat transfer coefficient at the surface of the fish and rapidly replacing the warmed water with cold water. Larger flows also tend to improve the distribution of cooling water within the tank in either RSW or CSW systems.

Circulation of chilled water within the hold may be achieved by several means. In CSW systems or in combination systems, while the ice is still present, air from a compressor can be used for agitation, but warm air will add to the heat load. Foaming will occur with the use of air. Some writers say to live with it, but the use of food grade silicone antifoaming agents has been proven effective. Once the fish are chilled, the circulation can be greatly decreased or intermittant.

Some RSW systems use a spray-deluge system in which the chilled seawater is sprayed over the mass of fish and drained off a sump in the bottom of the hold. Immersion type RSW systems use two basic patterns of water flow either up or down. Both of these have proven effective in our laboratory tests. No matter which flow system is chosen, it is important to ensure that there is no channeling of the flow through the fish. Channeling can result in local hot spots and consequent spoilage and contamination of the rest of the fish. Up-flow systems generally result in better distribution of the flow than down-flow systems and are much less subject to blockage of the flow. While apparently few of the older systems are of the upward flow configuration, this method is highly recommended.

The design of the up-flow system is complicated by the need to allow for the recycling of water in a partially filled tank. One tank design that deserves careful consideration is the up-flowing tank with vertical screens to allow the return of the sea water to the pumps at varying levels of water. Details of this type of system are given in Gibbard and Roach (1976), Kelman (1977), and Hagen (1981). The vertical strainer appears to allow some short circuiting of the sea water flow, but this is presumably blocked by the pressing of the fish against the screen.

The question of how much sea water circulation needs to be provided is not well addressed in the literature. The only firm recommendation found is by Hagen (1981); who recommends a rate of 0.5 gallon per minute (gpm) per cf of hold volume. For a hold of 2000 cf, this would mean a pumping capacity of 1000 gpm. Roach et al. (1961) makes reference to a 200 gpm pump for a hold of 100,000 pound capacity in six separate tanks. This would be approximately 2220 cf of hold volume at 45 lb/cf of bulk density, and calculates to be only 0.09 gpm per cf of hold space. This is less than 1/5 of Hagen's recommended flow rates. Hagen's flow rates at 45 lb/cf bulk density would result in the recirculation of the sea water in the tank every 4 1/2 minutes. We can add that the higher circulation rates are highly desirable from our experience in the laboratory. In a RSW System for a given hold size and refrigeration system capacity the pumping rates should at least take full advantage of the chiller capacities in order to chill the fish as rapidly as possible. The calculation of heat loads, refrigeration system capacities and chiller capacities will be covered in the next section.

REFRIGERATION SYSTEMS AND OTHER MECHANICAL SYSTEMS

The basic refrigeration cycle (see Figure 1) can be viewed as beginning at the expansion valve. The expansion valve separates the high pressure side from the low pressure side and controls the flow of refrigerant between the two sides. As liquid refrigerant passes through the expansion valve it enters the evaporator (chiller) where it begins to boil. The low pressure side is controlled by a pressure sensor and controller which controls the opening of the expansion valve. The pressure is controlled to control the temperature at which the refrigerant boils (around $+20^{0}$ F for R-22 at 43 psi). The phase change (boiling) in going from a liquid to a gas requires heat (Q_1), which is absorbed through the chiller tube walls from the circulating sea water from the fish hold tank. This is the refrigerating part of the cycle of operation which extracts heat from, in this case, the sea water used to chill the fish.

Once the refrigerant has evaporated it flows as a low pressure gas through the suction line to the compressor. The compressor, which is driven by an outside power source, compresses the low pressure gas into a high pressure gas. The work of compression from the outside power source results in adding even more heat (Q_2) to the gas as it increases the pressure. This increased pressure permits the refrigerant gas to be condensed at the higher temperature of the condenser water (about 90 to 110^{0} F). Sea water directly from the ocean removes heat from the high pressure gas through the condenser tubes thus condensing it to a liquid under pressure. The total heat (Q_3) removed in the condenser is equal to both the heat absorbed by the chiller and the heat added by the work of compression. Once the refrigerant is condensed to a liquid it is stored in the receiver ready to enter the expansion valve and repeat the cycle.

Examining Figure 1, three things may be observed. First, the compressor and the expansion valve separate the high pressure side of the system from the low-pressure side. Second, the condenser and the evaporator (chiller) separate the liquid phase of the refrigerant from the gas phase. Third, the heat out of the system (Q_3) must equal the heat into the refrigeration system for the refrigeration system to be in balance.

The capacity of a refrigeration system and the power required to drive the compressor are related to the displacement of the compressor (bore and stroke), the speed at which it is driven, the type of refrigerant used (R-12, R-22, R-502, etc.), and the temperatures of the refrigerant as it leaves the evaporator (saturated suction temperature - SST) and as it leaves the compressor (saturated discharge temperature - SDT). The temperature of the evaporator (SST) is usually selected on the basis of how low a temperature one needs for extracting heat from the object to be cooled. In this case, the sea water in the hold is to be held at about 30° F, and thus, the refrigerant in the evaporator needs to be 5-10° F cooler. The temperature in the condenser (SDT) is determined by the need to discharge heat into the cooling water. In tropical and subtropical waters the cooling water will be relatively warm (80-90° F) much of the time, so that a SDT of about 105° F is required.

The capacity of a refrigeration system may be expressed in BTU's per hour or refrigeration tons (RT). A refrigeration ton is the equivalent of one ton of ice melting over a 24-hour period or 12,000 BTU's per hour. The capacity ratings of a compressor and refrigerant combination are normally specified for a given SST and SDT. Conditions relevant to a RSW system operated in semi-tropical waters would normally be in the range of a SST of 20° F and a SDT of 105° F or higher. A series of compressor ratings for a commercial line of compressors (Carrier)* are shown in Table 3, using refrigerant R-22 at 1750 rpm, SST - 20° F, and SDT - 105° F.

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* Use of trade names does not imply endorsement by the U.S. Department of Commerce.

FIGURE I.

Diagram of a Basic Refrigeration System

$(Q_1 + Q_2 = Q_3)$

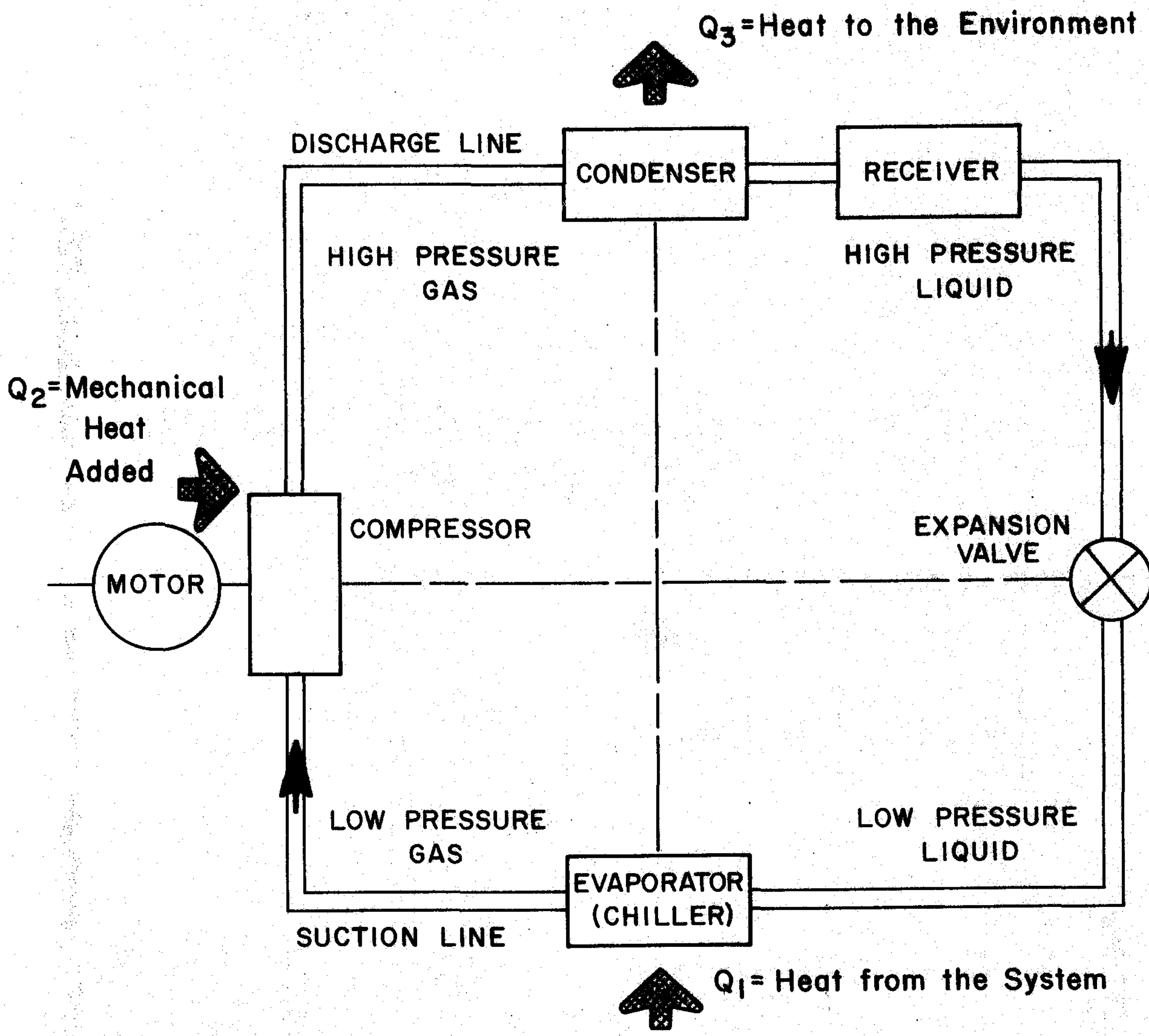


TABLE 3

Compressor capacities for a commercial line of refrigeration compressors[1/]

Compressor	Refrigeration Ton Capacity (RT)[2/]	Brake HP	Total Heat Rejection (THR) (RT)[2/]
5F20	5.6	7.6	7.1
5F30	8.5	11.3	10.6
5F40	11.2	14.9	14.1
5F60	16.9	22.4	21.2
5F40	26.9	34.4	33.5
5H60	40.2	51.3	50.1
5H80	53.6	68.1	66.8
5H120	80.5	101.8	100.2

1/ Specified at

1. 1750 RPM
2. R-22
3. SST - $20^{O}F$
4. SDT - $105^{O}F$

2/ 1 RT = 12,000 BTU/hr

A compressor's capacity increases as the SST increases, decreases as the SDT increases, and increases with increases in the RPM at which it is driven. The horsepower required to drive the compressor increases with the SDT and SST. The relationship between both capacity and horsepower required to drive a compressor and the SST are shown in Figure 2. The relationships between both capacity and horsepower and variations in SDT are shown in Figure 3. The relationships shown are examples of specific performance curves and will vary with compressor design from different manufacturers.

Two factors in sizing the compressor(s) for a RSW system are the peak cooling load and the maintenance (or minimum) load. The maintenance or minimum load is primarily relevant because of efficiency considerations. The compressor should be able to maintain the minimum load efficiently while still being able to handle the peak loads. One solution is the use of an unloading type compressor. The peak load is determined either by the amount of sea water, its temperature and the time allowance to chill it, or by the amount of fish expected to be caught, their temperature, and the time allowance set to chill them. To calculate the peak cooling loads the weight of water or fish multiplied by the specific heat and the temperature difference will give the total BTU's to be removed. Dividing by the time allowance will convert this to an average cooling load. For example, the first compartment of the 1000 cf hold described in the previous section contains 456 cf of sea water which is 29,184 lbs. A specific heat of 1.0 and a temperature difference of 56^{o} F gives a total of 1,630,000 BTU to be removed. A time allowance of 2 hours means that 817,000 BTU's per hour must be removed. This would require an average cooling rate of 68 R.T.

The same compartment will hold 20,520 pounds of fish which at 56^{o} F temperature difference and a 0.86 specific heat, contains 988,000 BTU's of

FIGURE 2.

Capacity and Horsepower vs. SST

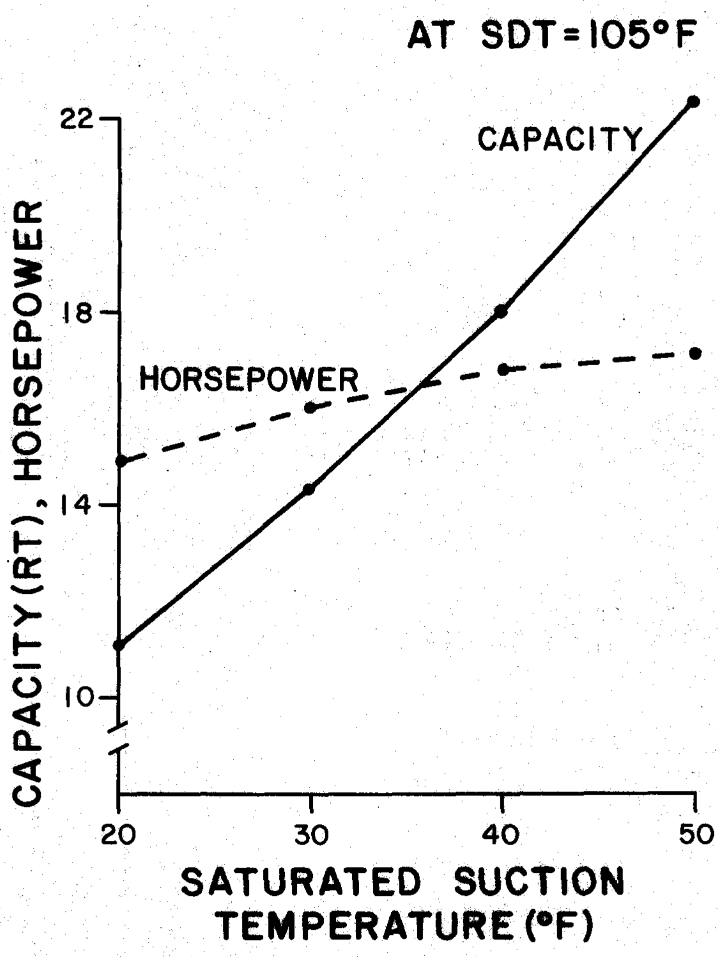
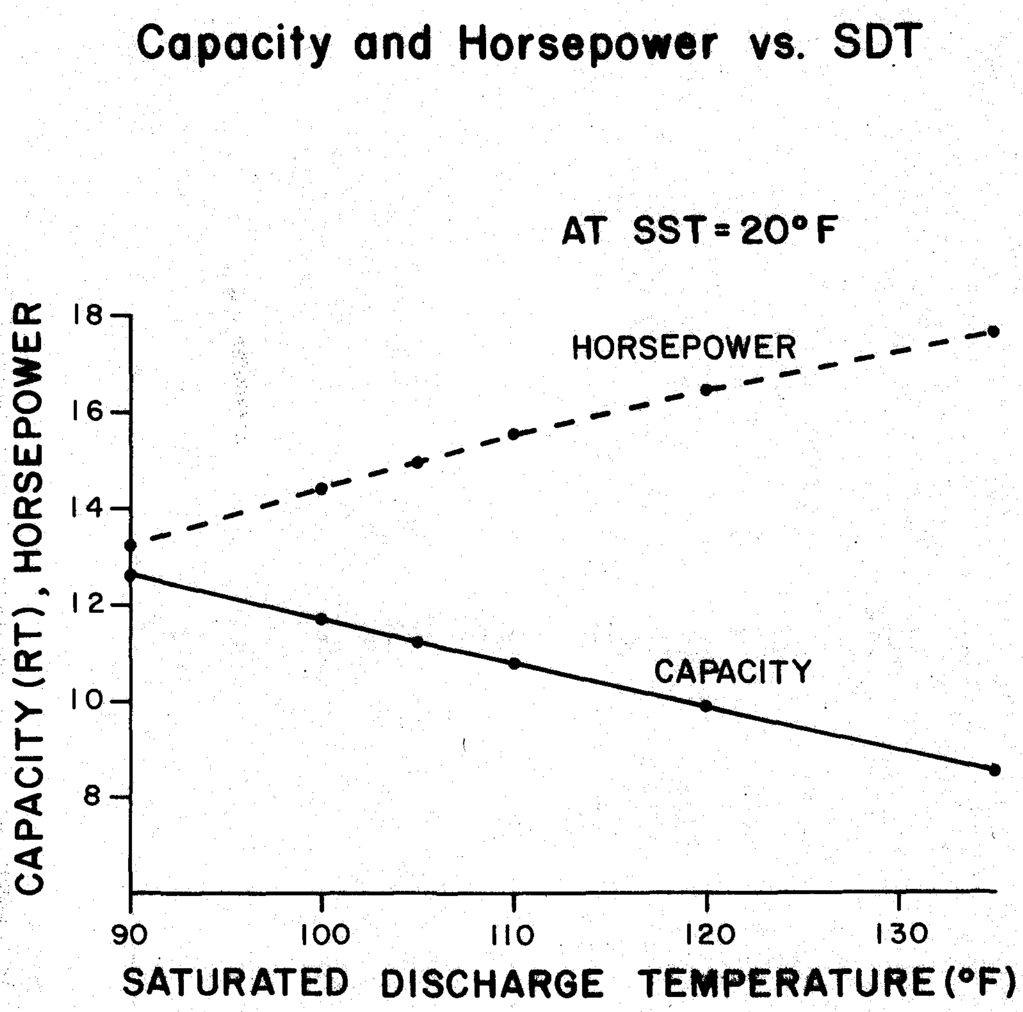


FIGURE 3.


Capacity and Horsepower vs. SDT
AT SST = 20° F
HORSEPOWER
CAPACITY
CAPACITY (RT), HORSEPOWER
18
16
14
12
10
8
90
100
110
120
130
SATURATED DISCHARGE TEMPERATURE (°F)

heat to be removed. The rate at which the fish can be chilled depends not only on the refrigeration capacity of the system, but also on the size of the fish. At the same RSW driving temperature, a smaller fish can be chilled more rapidly than a large one as was pointed out in the last section. The amount of refrigeration capacity required to chill the fish in 3 hours would only be 27.5 RT average capacity. Thus, the size of the refrigeration system is determined by the 68 RT of average capacity needed to prechill the sea water, and the specification of chilling the fish in 3 hours is redundant. If the specification that the hold water be chilled in 2 hours is relaxed and the requirement that both the heat from the sea water (1,634,300 BTU's) and the heat from the fish (988,243 BTU's) be extracted in 5 hours is substituted, then the size of the refrigeration system needed is reduced to 43.7 RT of average capacity from the 68 RT in the first example.

However, this will produce a slightly different cooling curve for the fish. The fish will not drop in temperature as rapidly in the second system as it will in the first. This is because the hold water would be warmer than the 30-32^{o} F for the first example system if fish were added after only two hours of pre-chilling the water.

The term average refrigeration capacity was used in the above examples because the capacity of the compressor varies with the hold water temperature passing through the chillers which will alter the SST and thus the compressor ratings. Roach (1973) gives a method to calculate the time requirements for a system by breaking the cooling period down into temperature intervals and then using the average compressor capacity for each temperature interval to calculate the time of the interval and then summing the times together. This method allows the estimation of the total chilling time for a given load once a compressor is specified.

Once a compressor-refrigerant combination has been chosen, a condenser unit(s) must be matched to the system to allow adequate heat removal by the condenser cooling water. Because sea water temperatures of up to 90° F can be expected, the condensers for semitropical waters must be larger or use higher flow rates for the cooling waters than comparable systems in more northerly waters. However, higher flow rates mean higher water velocities in the condensers and shorter life spans because of erosion of the condenser components. The pump for the condenser cooling water must be adequate to move the required amounts of water against the pressure drop from the condenser. During the initial cooling period the total heat rejection will be greater and thus the amount of condensing water required will be larger than during the low demand (maintenance) period of cooling. It may be necessary to pipe the pumps and the condensers so that minimum sea water velocities can be maintained in the condensers during the maintenance period.

The chillers are opposite in performance from the condensers. They remove heat from the surroundings and add it to the refrigerant. This is done by vaporizing the refrigerant in a sealed compartment or tube and passing the hold water across the surface. In many of the earlier vessels using RSW, the evaporating coils simply lined the hold walls. This produced problems of fish freezing onto the coils. Later modifications used baffles to keep the fish off the coils, but this introduced extra cleaning problems.

Most current RSW designs use heat exchangers external to the hold compartment for chilling the hold water. These have the advantage of permitting much higher water velocities and increased heat transfer coefficients. The use of these external chillers have greatly simplified installations and maintenance, however, the design of the system can be critical from the standpoint of cleaning, maintenance and fouling. The chillers must be designed and installed in such a manner they can be serviced when necessary. Tubes or chilling surfaces must be kept clean and free from accumulation of debris from the RSW to permit good heat transfer and prevent contamination of water. Some chillers are built such that the outer shell can be removed, others so the tube bundle can be removed from the shell and others have removable panels for access. All require an adequate filter strainer to keep debris from plugging the chillers and pumps. The design of chillers must also take into account the results of occasional freezing of the water. Sooner or later this will happen and the chiller must be able to withstand this without damage.

The chiller must satisfy two requirements. It must be able to handle the heat transfer requirements imposed by the compressor and the water flow required by the hold size. Chillers are normally arranged in banks if more than one is required. The chiller should be protected from the solids in the hold water by a screening mechanism, and piped so that it can be back-flushed for cleaning.

The final set of components in a refrigeration system is the expansion valve and other mechanisms for controlling the flow of refrigerant in the system. The choice of the expansion valve is determined by the refrigerant used in the system, the size and type of chiller, and the capacity of the system. The expansion valve is controlled by either the temperature or the pressure of the refrigerant in the evaporator. Its principal function is to match the flow of refrigerant to the heat load on the evaporator and to prevent liquid refrigerant from reaching the compressor.

A suction line throttle valve can be used to limit the demands made by the compressor upon its power source during start-up or at high operating suction temperatures or pressures. The throttle valve is installed in the suction line between the evaporator and the compressor and serves to limit the amount of refrigerant flowing to the compressor. Thus, it lowers the horsepower required to drive the compressor.

During time of light loads, some mechanism must be employed to limit the minimum temperature of the refrigeration system. Some compressors come equipped with automatic unloading where one or more cylinders are disengaged from service. Reducing the compressor speed, or cycling the system on and off, and hot gas by-passing are other methods of accomplishing the same purpose.

A combination RSW-CSW system will have all of the same components as a pure RSW system except that the refrigeration units need not carry the total capacity and will not need to be as large. An initial load of ice taken on board at the dock will pre-chill the sea water almost as soon as it is pumped into the hold. The initial charge of ice could also be large enough to provide most if not all of the initial chilling of the catch. This would allow the size of the refrigeration system to be limited to the size necessary to maintain the hold temperature against heat gains from leakages, pumping gains, and other environmental heat sources.

A pure CSW system would eliminate all of the refrigeration equipment except the filter screen (which could be coarser without the need to protect the chillers) and the recirculation pumps. However, a CSW system requires that enough ice be remaining in the holds to prevent the temperature from rising again after the fish have been chilled. Both the RSW-CSW combination system and a pure CSW system requires that all the ice that is expected to be used be purchased and loaded on board before the fishing trip begins. An economic analysis of these factors will be presented in the next section.

COMPARATIVE ECONOMICS OF RSW-CSW AND COMBINATION SYSTEMS

This section will compare the additional capital and operating costs of four RSW-CSW and combination systems. The systems will be compared for a vessel with 2,000 cubic feet of water-tight hold space divided into two sets of compartments, one set on each side of the vessel. Each set of compartments will be assumed to be sub-divided into compartments of 456, 318 and 223 cf as in the earlier example. Since the basic cost of the vessel's construction along with the cost of construction of the hold space and its primary piping systems will not vary between the four systems being compared, these costs will not enter the comparative analysis.

The four systems are defined as follows:

1) Pure RSW - no ice used.
2) Combination RSW-CSW-ice used to pre-chill the sea water.
3) Combination RSW-CSW-ice used to pre-chill the sea water and to initially chill the catch.
4) Pure CSW - no mechanical refrigeration used.

The basic fishing trip for which the four systems will be compared will be of 36 hours duration with an average total catch of 60,000 pounds divided into four 15,000 pound lots. It will also be assumed that the vessel routinely leaves port with enough cooling capacity to chill a capacity load of up to 90,000 pounds. Only two hours are available for pre-chilling water.

The size of the refrigeration system required for the pure RSW system is determined by the need to chill 456 cf of sea water from 88^{0} to 32^{0} F in two hours. This will require the removal of 1,634,300 BTU of heat from the sea water during the two hours. Following the method of Roach (1973) a compressor of 40.2 RT capacity - rated at 20^{0} F SST and 105^{0} F SDT - will suffice to do the job in slightly over two hours. The maximum refrigeration capacity for this compressor would occur during the initial cooling period and would equal 78.6 RT or 943,000 BTU per hour. During this initial period the refrigeration system would require that the drive motor provide approximately 60 brake horsepower, that the condensers handle a maximum of roughly 1,082,000 BTU/hr of rejected heat, and that the chillers be able to transfer a maximum of 943,000 BTU/hr of heat extracted from the hold.

The costs for such a system might approximate very roughly:

Compressor/condenser	$24,000
Chillers	22,500
Pumps	11,000
Drive	16,300
Installation @ 25% of above	18,400
Total First Costs	$92,200

The size of the refrigeration system for the first RSW-CSW combination system (system number 2), which uses ice to provide the initial chilling of the sea water loaded into the hold, is determined by the need to chill 15,000 pounds of catch in two hours. This requires the removal of 361,000 BTU per hour or 30.1 RT average capacity during the chilling of the fish. Assuming that the hold water temperature rises to 40^{0} F soon after the loading of the fish, and again using Roach's (1973) method of time calculation a refrigeration system of 26.9 RT capacity at 20^{0} F SST and 105^{0} F SDT would meet the performance specifications. The chillers could be smaller in proportion to the refrigeration system because the higher capacities of the compressor during the initial chilling of the sea water would not be a consideration.

The cost for such a system might approximate very roughly:

Compressor/condenser	$ 17,500
Chillers	11,200
Pumps	6,600
Drive	12,800
Installation @ 25% of above	12,000
Total first cost	$ 60,100

The second RSW-CSW combination system (system number 3) would use mechanical refrigeration only to maintain the hold temperatures at the required operating temperatures. Both the initial chilling of the sea water and of the fish would be done with ice. The two principal loads that the mechanical refrigeration system will have to carry are the heat gains from the pumps recirculating the sea water in the hold and the environmental heat leakages. A refrigeration system of about 5.6 RT capacity at 20^{0} F SST and 105^{0} F SDT should meet these requirements. However, a slightly larger system of about 8.5 RT will be used in order to provide some surplus capacity in case the ice runs out or the heat loads are greater than expected.

The cost for such a system might approximate very roughly:

Compressor/condenser	$ 11,000
Chillers	4,500
Pumps	5,500
Drive	8,500
Installation @ 25% of above	7,400
Total first costs	$ 36,900

The pure CSW system (system number 4) uses only ice for cooling. There is no mechanical refrigeration provided. The only physical item of equipment comparable to those included in the costs for the other three systems would be the circulation pump and a power system to operate it. The pump would be required to move 1000 gpm through the holds. This could be done with a 10 hp pump electrically driven from the vessels primary generator. The additional cost of such a system might approximate $5000 with installation. The pure CSW system would not have the same maximum capacity as the RSW or combination systems because of the bulk storage space required by the ice needed to maintain the hold temperatures. The amount of hold capacity lost to the ice storage would depend upon the length of the trips, type of ice used, and the nature of the holds. When ice of a bulk density of 40 lb/cf and the fish are loaded at a bulk density of 45 lb/cf, the hold capacity is reduced by 1.125 lbs of fish for every pound of ice in the hold at the time the holds are topped out. This is based on the assumption that the bulk volumes of the fish and ice are mutually exclusive. Given the length of fishing trip as 36 hours and an ambient temperature of 88^{0} F, the fishing vessel specified in this analysis would have a maximum capacity of about 78,000 pounds of fish. This assumed that the last of the fish are loaded 30 hours after the sea water is added, that the vessel returns with 7100 pounds of ice in the hold, and that the hold walls have an overall heat transfer coefficient of 0.6 BTU/ft^2-hr.

The total amount of ice required for the fishing trip would be approximately 27 tons or 54,000 lbs. Of this quanity of ice, 7,600 pounds would be required to initially cool the sea water and the hold walls, 26,100 pounds would be needed to chill the fish, and 13,100 would be needed to cover the environmental and pumping heat loads with 7,200 pounds of ice remaining in hold when the vessel returns to port. The pumps would place an additional load on the generator that would require the burning of 29 gallons of diesel fuel. If the vessel caught the specified 60,000 pounds of catch the amount of ice remaining in the hold would have been 13,200 pounds. The remaining figures would remain the same. The cost of the ice for the trip would be $900 at $5.00 per 300 pound block of ice blown into the hold. The cost of the additional diesel fuel would be $34.80 at $1.20 per gallon with a total cost of $935.

System number 3 would use its mechanical refrigeration to eliminate the ice used for the environmental and pumping heat loads, and to eliminate the need for ice in the hold upon the vessels return to port. The system would require about 18.2 tons of ice to be loaded before departing. This would be 28,800 pounds for the chilling of up to 86,000 pounds of fish and 7,600 pounds for the chilling of the sea water and the hold walls. The operation of the refrigeration system would require about 70 gallons of diesel fuel. The total trip cost for ice and refrigeration would then be $607 for ice and $84 for fuel or $691 altogether.

System number 2 would use mechanical refrigeration to eliminate the ice used to chill the fish in addition to the ice used to cover the environmental heat loads. Because there would be less melt water, about 27,500 pounds of sea water would be needed along with the melt water from the 10,500 pounds of ice required to chill it in order to cover the fish in the hold. The refrigeration system would be required to operate with an average capacity of 11 RT over the course of the trip. This would require the consumption of about 112 gallons of diesel fuel. The trip costs would be about $175 for ice and $134 for fuel or $309 total.

System number 1 is a pure RSW system and uses no ice for cooling. The system is sized so as to be able to chill 456 cf of sea water in 2 hours. This results in considerable overcapacity for the rest of its requirements. Over the 36 hour fishing trip the system might consume approximately 185 gallons of diesel fuel. This would cost $222.00 at $1.20 a gallon.

The trip operating costs have been estimated for the warmest season of the year, and cooler temperatures will mean lower operating costs for all four of the systems. However, the reduction in operating costs will be larger for the ice component of each system's operating cost than it will be for the fuel component, because while the amount of ice required will vary in linear proportion to the difference in temperatures, the amount of fuel required will not. This is because the lighter the loads are, the less efficiently the mechanical systems will operate.

While admittedly the estimates of both the equipment costs and the operating costs are rough approximations, they are sufficient to point out some of the trade-offs between the four systems (see Table 4 for a summary of the costs). First among the trade-offs is first costs versus operating costs. The pure RSW system is far more expensive to purchase and install, but cheapest to run, especially in hot weather. The combination RSW-CSW systems are intermediate in both first costs and in operating costs with the system that is more dependent on ice being cheaper to purchase and more costly to operate. The pure CSW system is by far the least expensive set of equipment to purchase and install, but it has the highest operating costs.

The second set of trade-offs can be expressed in terms of reliability. The CSW system cannot lose its refrigeration capacity because of mechanical breakdown. If the pump does break down, then there may be a problem with

Table 4

A Comparison of First and Operating
Cost for Four Hypothetical Systems

		First Costs	Operating Costs*
System 1	Pure-RSW	$ 92,200	222
System 2	Combination	60,100	309
System 3	Combination	36,900	691
System 4	Pure-CSW	5,000	935

* For a 36 hour trip as defined in the text.

thermal stratification and hot-spots. However, the CSW system can run out of ice if the fishing trip takes longer than expected or if the catches are greater than expected. There must be ice in the hold to keep the fish cooled. The mechanical refrigeration will not disappear at the end of a trip. Another trade-off is that additional insulation of the hold will lower the operating costs of the more ice dependent systems more than it will lower the cost of the mechanical systems.

There are also trade-offs that are not directly economic in nature. The less ice that a system uses, the lower the temperature it can operate at, because the less diluted the salt content will be by the melt water. The other side of this trade-off is that the more diluted the sea water is by melt water, the less salt uptake there will be in the fish. This trade-off can be negotiated by either adding some fresh water to the hold for the pure RSW systems or by adding salt to the hold water for the CSW systems.

The final trade-off is in the area of ease of operations and personal preferences. A mechanical system takes more maintenance and tending than the simpler ice based system. However, the ice based system requires a steady reliable source of ice, and a stop at the ice-house each trip. Ice may have to be moved between hold compartments if one of the compartments runs out and the plumbing of the system does not allow the movement of water and/or ice from compartment to compartment.

We have not tried to make recommendations between the choices of systems, because the operating costs will depend upon other factors such as: the length of the individual fishing trips, the number and timing of the trip over the year, the expected catch rates at different times of the year, and interest rates and tax situations.

In closing this section, we would like to point out the importance of setting necessary requirements. The pure RSW system was sized to be able to chill the first compartment of water in 2 hours, and the first RSW-CSW combination system uses ice in order to meet this same requirement. If this requirement can be relaxed, then it is possible to use a smaller size refrigeration system for the RSW vessel with a savings in both first costs and in operating costs. The first RSW-CSW combination system would need no ice if four or five hours were available for pre-chilling the water and this would save on its operating costs. The other two systems would not be affected. The addition of ice to an RSW system will first serve to shorten the pre-chilling time for the seawater. Only an excess of ice above this amount will contribute to chilling the fish. If the refrigeration system is sized larger than necessary to chill fish at their maximum catch rate the requirements should be carefully re-examined.

SUMMARY AND CONCLUSIONS

The higher temperatures encountered off the coasts of the Southeastern United States place a much larger demand upon the chilling systems of RSW-CSW vessels than northern vessels have been traditionally designed to handle. The wintertime temperatures found in southern waters can be as warm as the summer temperatures for which northern systems have been designed to operate and the summer temperatures can be higher by 20° F or more. This places a greater challenge upon the vessel's designers to properly size the system, and even in some cases to fit a refrigeration system into a vessel.

There are a number of types of fisheries where these systems could prove useful. Potentially, RSW-CSW systems can find their best applications in those fisheries with high catch rates, and especially where icing has not been done as well as possible, if at all. Traditionally, RSW systems have been used by menhaden vessels in the Southeast to chill their very large catches only to about 50°F. Other purse seine fisheries should also find RSW-CSW systems useful. Drum and long-haul seine fisheries where the catch rates are large, should also be good candidates for the use of these systems. Recently a few individuals in the southeast have been adapting these systems, and in general, they have been pleased with the results.

It should be pointed out that there is a need for more data collection with full sized systems under actual fishing conditions. This will provide information in many areas in which it is sorely lacking. In addition laboratory research is needed to help define how fast various species must be chilled in order to provide the final consumer with a quality product. The effects of the initial chilling rates of fish upon the eventual shelf-life has not been clearly documented in the literature of RSW-CSW systems that we could find. However, it is an important design parameter, especially for mechanical systems.

The information provided in this report has been provided to give the reader insight into the nature of RSW and CSW systems and their operations. The discussion of the trade-offs between the various systems has been provided to allow a more informed choice between the many options available in the adoption of these systems to the Southeast. Attached is an annotated bibliography for those who are interested in pursuing any of the aspects of the matter in greater detail.

ACKNOWLEDGEMENT

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APPENDIX

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A ratio of one part ice to three parts fish was used to hold whiting and red hake in water tight pens aboard a trawler. Fish were more readily unloaded and economically separated when compared to coventional bulk loading.

BAKER, E.G., B.A. SOUTHCOTT, and H.L.A. TARR.
1958. Effect of chlortetracycline (CTC) antibotic on the keeping quality of Lingcod stored in refrigerated water. Fish. Res. Board Can. Pac. Progr. Rep. No. 112:15-18.

Eviscerated Lingcod were placed in chilled seawater tanks and subjected to a 10 p.p.m. of CTC. The untreated fish remained acceptable after 11 days while the treated samples remained palatable after 20 days.

BARHOWNI, M., A. ABDOULAYE FAYE, F. TEUTSCHER, C. DOS SANTOS, and E. VIKE.
1981. Storage characteristics of sardine (Sardina pilchardus) held in ice and chilled seawater. I.I.F.-I.I.R. Boston 1981.

Sardines were stored in ice and CSW to be tested for pH., TBA, TVA, and sensory tests. Initial quality of fish remained the same for both methods after two days. CSW retained acceptability up to 7 days.

BARKER, R., and IDLER, D.R..
1955. Transport and storage of fish in refrigerated sea water: IV Prelimary report on nitrogen loss, weight changes, and proteolysis (bellyburn). Fish. Res. Board Can. Progr. Rep. No. 104:16-18.

Gutted salmon stored in polyethylene bags containing seawater lost less protein and maintained more body weight than those salmon stored in ice.

BARNETT, HAROLD J., RICHARD W. NELSON, PATRICK J. HUNTER, and HERMAN GRONINGER
1978. Use of carbon dioxide dissolved in refrigerated brine for the preservation of Pink Shrimp (Pandalus spp.). Mar. Fish. Rev. 40(9):24-28.

A study which discussed the bacterial inhibition and extended keeping quality, up to 6 days, of pink shrimp in a brine-CO_2 mixture. Dissolved CO_2 and lower pH of the brine slowed bacterial activity.

BARNETT, HAROLD J., RICHARD W. NELSON, PATRICK J. HUNTER, STEVEN BAUER, and HERMAN GRONINGER
1971. Studies on the use of carbon dioxide dissolved in refrigerated brine for the preservation of whole fish. Fish. Bull. 69(2):433-442.

Storing rockfish in brine-CO_2 mixture increased storage life for at least one week. Untreated fish became unacceptable after 5 days while treated fish remained palatable for 17 days.

BILINSKI E., R.E.E. JONES, and Y.C. LAU.
1978. Chill stowage and development of rancidity in frozen pacific herring (Clupea harengus pallasi). J. Fish. Res. Board Can. 35:473-477.

A study of the stability of pacific herring stored in ice or in RSW at $0.8^{0}C$ and then filleted and frozen at $-28^{0}C$. Fillets were then vacuum packed which prevented rancidity developed when held in RSW alone.

BINGHAM, WILLIAM.
1982. Cooling the catch: cut costs and boost prices with mechanical refrigeration. Fish. News Int. 21(5):64-65.

A brief report on the economics of various mechanical refrigeration systems for shrimp boat owners. Also discussed are temperature effects on shrimp quality.

BINGHAM, WILLIAM.
1979. Technology brings changes to fish boat refrigeration. Fish Boat, Feb. p. 48-49.

The final section of a series of reports on various methods of mechanical refrigeration for commercial fishing boats. Sea water spray, blast freezing, and cold plate systems are discussed.

BOYD, J.W., and B.A. SOUTHCOTT
1964. Ultraviolet irradiation of circulating refrigerated fish storage brines. J. Fish. Res. Board Canada. 21(1):37-43.

A discussion of the irradiation of refrigerated brine for controlling bacterial development in ling cod. The process proved successful for preventing bacterial growth but unsuccessful for killing bacteria present in stored fish.

BOYD, N.S., and N.D.C. WILSON
1975. A comparison of chilling methods on NZ fishing boat. Food Technol. New Zealand. 10.(7):48-49, 51.

Bulk icing of fish at sea was found to be the most effective method of preserving fish. Time taken to cool fish was stated as low as 3 hours for iced fish and up to 60 hours for air chilled fish.

BRINCH, J.
1973. Seawater ice manufacturing and use. Proc. Inter. Congr. Refrig. (13th) Wash. (4):563-570.

A discussion of the chemical properties of saltwater ice as related to the current design of various ice machines. Structure and phase change of seawater ice is covered.

BULLARD, F.A. and J. COLLINS.
1978. Physical and chemical changes of pink shrimp (Pandalus borealis), held in CO_2 modified refrigerated seawater compared with pink shrimp held in ice. Fish. Bull. 76(1):73-77.

Chemical tests for spoilage were preformed on pink shrimp which had been held in a CO_2-seawater mixture for 12.5 days and in ice for 11.5 days. The CO_2-seawater mixture kept shrimp acceptable for 9.5 days as compared to 6.5 days for ice held shrimp.

CASTELL, C.H., JILL MACLEAN and BARBARA MOORE.
1965. Rancidity in lean fish muscle. IV Effect of sodium chloride and other salts. J. Fish. Res. Board Can. 22(4):929.

Sodium chloride accelerated rancidity in blended cod flesh. According to the researchers, relationships between TBA values and type of odors varied for sodium chloride-induced rancidity as compared to copper-induced rancidity.

CHARM, S. E.
1963. The fundamentals of food engineering. Avi Publishing Co., Inc., Westport, Conn. 523p.

A summary of the relationship and compatability between basic engineering principles and the fundamentals of food processing. Information is provided for the freezing, thawing, evaporation, dehydration, freeze drying, and filtration of food stuffs.

COHEN, EDWARD H., and JOHN A. PETERS
1963a. Effect of storage in refrigerated sea water on amino acids and other components of whiting (Merluccius bilinearis). Fish. Ind. Res. 2(2):5-11.

Samples of whiting flesh were analyzed for their proximate composition; amino acid, sodium, potassium and chloride contents, after storage in RSW and ice. The storage life of RSW held fish was extended for up to 3 days longer but a marked sodium content increase was observed which could affect acceptability.

COHEN, EDWARD H., and PETERS, JOHN A.
1963b. Storage of fish in refrigerated sea water 2-quality changes in whiting as determined by organoleptic and chemical analyses. Fish. Ind. Res. 2(2):21-27.

A study of the acceptability of whole whiting stored in ice as compared to storage in 30°F RSW. Sensory tests selected RSW held fish for greater palatability.

COHEN, E.H., and PETERS, J.A.
1962. Storage of fish in refrigerated sea water 1 - quality changes in ocean perch as determined by organoleptic and chemical analyses. Fish. Ind. Res. 2(1):41-47.

The correlation of sensory and chemical tests was poor for ocean perch held in RSW. Storage in RSW proved to extend edible quality for 7 days longer than ice held fish.

COLLINS, J.
1960a. Processing and quality studies of shrimp held in refrigerated seawater and ice. Commer. Fish. Rev. 22(3):1-5.

Pink shrimp were mechanically-peeled after 40 hours in RSW containing 3 or 6 percent brine. Also discussed is the leaching action of water and discoloration prevention through the addition of citric acid.

COLLINS, J.
1960b. Processing and quality studies of shrimp held in refrigerated sea water and ice. Commer. Fish. Rev. 22(7):Part II:10-14.

A report which dealt with the holding of whole pink shrimp in 3 percent brine at 30°F for 11 days. The holding process was broken down into various components (whole shrimp, peeling waste, brine, peeled meats and precooked meats) where each component could be analyzed.

CONNELL, J. J. (ed.).
1980. Advances in fish science and technology. Fishing News Books Ltd., Farnham, Surrey, England.

Seminar by Torry Research Station, Jubilee Conference, Aberdeen, Scotland. Sessions: Past, present and future of fish science, minced fish, process and new product investigations, smoking, chilled and frozen storage, krill, by-products, seasonal changes, quality assessment, protein studies and microbiology.

CORNICK, J.W. and J.E. STEWART.
1977. Survival of American lobsters (_Homarus americanus_) stored in a recirculating refrigerated seawater system. J. Fish. Res. Board Can. 34:688-692.

American lobsters experienced a 10 percent mortality rate when placed in a RSW system at 5°C, when activated carbon was used in the filter. Without the carbon, they placed mortality at more than 20%.

CRAWFORD, L. and R. FINCH.
1968. Quality changes in albacore tuna during storage on ice and in refrigerated sea water. Food Technol. 28(2):1289-1292.

Albacore displayed an increased hypoxanthine concentration when stored in brine at 30°F or on ice at 32°F. Changes in organoleptic quality remained steady until day 35 where brine held fish showed only marginal quality.

DAGBJARTSSON, B., G. VALDIMARSSON, and S. ARASON
1981. Icelandic experience in storing fish in chilled seawater. I.I.F.-I.I.R. Boston 1981.

A progress report on the use of CSW containers in Icelandic fisheries. Included are discussions on transportation of blue whiting, refrigerated water storage, and container vs. bulk storage.

DELMAS, J.
1975. Refrigeration for trawlers. Aust. Fish. 34.(3).15-18, 30.

Chilling and freezing of fish aboard trawlers is discussed with reference to: chilling requirements; chiling with ice; chilling of fish stowed in bulk or in boxes; use of refrigerated sea water; refrigeration equipment; air blast; plate and brine freezers; Insulation; and linings for chilling chambers.

DOUST, D.J.
1975. New freezing system for tuna seiners and stern trawlers. Fish. News Int. 14(10):35,37,38,41-42.

The author discusses the "Confreeze" system for holding tuna on vessels at sea. The system is characterized by use of a calcium chloride brine at -35°C and plastic bags vacuumized around immersed fish.

EDDIE, G.C.
1961. Salt water ice plant. World Fish. 10(4):46,49.

A brief news item describing the technology used in the production of salt water ice. It is discussed as having limited usefulness as a preservation method for the fishing industry.

EDDIE, G.C. and A.G. HOPPER.
1973. Containerized stowage on fishing vessels using chilled sea water cooling. In: R. Kreuzer (ed.), Fishery Products. Fishing News (Books) Ltd. London. p. 69-74.

Very soft herring having high oil content were held for up to 6 days in containerized stowage using CSW. Design and operation of container process is described. Various boat trials resulted in superior herring quality in containerized stowage.

ERNST, R. C. JR.
1982. Holding southeast ground fish (croaker, spot and weakfish) in experimental refrigerated and chilled sea water systems. NOAA Tech. Memorandum NMFS- SEFC-92.

Report of holding the three species on ice, in refrigerated and chilled seawater for 15 days. Fillets were evaluated every two or three days for salt uptake, pH, total volatile nitrogen, trimethylamine nitrogen, color, shear and by sensory tests. Except for salt uptake result were practically equivalent to icing.

ERNST, R. C. JR.
1981. Application of refrigerated and chilled seawater systems to southeast U. S. Fisheries: A project overview and progress report. I.I.F.-I.I.R. Boston. 1981.

Overview of N.M.F. RSW/CSW project and results of a preliminary study of RSW and CSW preservation of croaker and black sea bass. Chemical and sensory tests measured quality deterioration at various temperatures. Chilling rates were characterized.

FARBER, L. and P. LERKE.
1961. Studies on the evaluation of freshness and on the estimation of the storage life of raw fishery products. Food Technol. 15(1):191-196.

A study which suggested that volatile reducing substances and trimethylamine nitrogen (TMN) are useful parameters for determining freshness of raw fish. Also, percentage of pigmented bacteria was evaluated as a freshness criteria.

FARBER, L. and P. LERKE.
1958. A review of the value of volatile reducing substances for the chemical assessment of the freshness of fish and fish products. Food Technol. 12:677-680.

The application of the volatile reducing substances for evaluation of raw fish is discussed. A correlation is established between chemical evaluations and organoleptic judgements for a wide variety of fish.

FISCHER, KNUD and ERLING, LARSEN.
1981. Danish small boat trials with insulated containers. Fish. News Int. 20(4):11-13.

A news item about the use of 200, 500 and 800 liter containers for holding cod, flounder and turbot aboard small fishing vessels. Chill rates are discussed.

GIBBARD, G., F. LEE, S. GIBBARD, and E. BILINSKI
1981. Transport of salmon over long distances by partial freezing in RSW vessels. I.I.F.-I.I.R. Boston 1981.

High capacity RSW systems were used to partially freeze salmon in 6.5 percent salt aboard several Canadian vessels. After an onboard storage period of seven days fish quality was judged in "good" quality.

GIBBARD, G.A. and S.W. ROACH.
1976. Standards for a refrigerated sea water system. Environ. Can., Fish. Mar. Ser., Tech. Rep. No. 676.

A report which seeks to propose standards for the rating of vessels on the B. C. coast. A discussion of equipment, capacity rating, cleaning, sanitation and general guidelines are included.

GOULD, EDITH
1970. The case for accurate labeling of superchilled fish. J. Fish. Res. Board Can. 27(11):2101-2103.

A determination of the malic enzyme activity in super chilled and frozen fish. Latent enzyme activity was discovered in both storage methods thus becoming a reliable test so fish may be accurately and legally labeled.

HAGEN, WILLIAM F.
1981. RSW for the fishing boat. Fish. News Int. 20(10):70-72.

A general description of the mechanics behind the full flooded system and spray deluge system used on fishing vessels. Both are designed and constructed by Turbo Marine Corporation of Denton, Texas.

HANSEN, PAUL
1981a. Containers for chilling, stowage and transport of fresh fish in ice water. I.I.F.-I.I.R. Boston 1981.

A review of past British, Danish and Chilean boat trials using CSW systems. Advantages and disadvantages are discussed.

HANSEN, PAUL.
1981b. The chilled sea water and refrigerated seawater of catch preservation. Fish Boat. 26(2):47,80-81.

A brief descripton about RSW and CSW systems used aboard various commercial vessels. Design considerations, holding capacities and present operations are discussed.

HANSEN, PAUL.
1977. Fresh fish handling in coastal fisheries. Scandnavian Technol. Laboratory, Ministry of Fisheries, Lyngby, Den. Rep. No. 1/77.

A review of handling methods of daily fish catches, up to one ton, on board ships without a protected fish hold. "Isiboxes" are recommended for small vessels being the most efficient ice packing container.

HANSEN, PAUL.
1956. Icing cod with saltwater ice. F.A.O. Intrim Committee on fish handling and processing. Ministry of Agriculture Fisheries and Food. The Haque, Netherlands. p. 109-112.

Headed and gutted cod were stored in freshwater, brackish water, and sea water ice for a comparison of flesh quality. After 17 days the report stated that seawater ice maintained the highest quality.

HANSEN, P., B. FELDSTEDT, L. QUIROGA, and T.E. PETERSON.
1977. Container and bulk stowage aboard purse seiners. Fish. News Int. 16(2).

An FAO project developed to increase landed small fish quality for suitable human consumption. The onboard system has a group of nine or twelve containers which hold 12 tons of sardines at 0°C in ice water.

HANSEN, P., P. IKKALA, and M. BJORNUM.
1970. Holding fresh fish in refrigerated sea water. I.I.R., Bull. 50 (2):300-309.

A review of various laboratory and field tests which investigated the quality and storage life of fish held in RSW. Discussions of the physical aspects of holding, system installations and container storage are included.

HANSEN, P., K.B. OLSEN, and T.E. PETERSEN
1976. Development in bulk preservation at sea of small whole fish. In: R. Kreuzer (ed.), Fishery Products. Fishing News (Books) Ltd. London p. 64-69.

A review of the advances in bulk handling methods for use in Danish fishing vessels. Influence of air, storage temperature, ice chilling, and RSW chilling.

HARRISON, J.S.M. and S.W. ROACH.
1955. Transport and storage of fish in refrigerated sea water: I. refrigerated sea-water installation on the vessel J.R.D. Fish. Res. Board Can., Pro. Rep. No. 104:3-6.

A field performance report on RSW systems. Aluminum tanks (50,000 lbs fish total), Al. cooling coils, 13 hp diesel drive, Freon-12 compressor of 60,000 BTU per hour, SS sea water condenser, 70 gpm centrifuged circulating pumps, fish held at 30° F, brail unloading are used.

HEERDT, M., D.L. BUCHER, and M.E. STANSBY.
1949. Refrigerated locker storage of fish and shellfish. U.S. Dep. Interior, Fish. Wildl. Ser., Fishery Leaflet No. 128.

A general review of past information regarding cold storage, ice glazing, cleaning, and cooking of fish. Material is out dated but contains useful diagrams for basic preparation of fish.

HILTZ, DORIS FRASER, BARBARA SMITH LALL, D.W. LEMON, and W.J. DYER
1976. Deteriorative changes during frozen storage in fillets and minced flesh of silver hake (Merluccius bilinearis) processed from round fish held in ice and refrigerated sea water. J. Fish. Res. Board Can. 33:2560-2567.

The frozen storage of silver hake was marked by the production of dimethylamine, a decrease in extractable protein, and by lipid hydrolysis. A comparison between RSW and ice-held fish is reported.

HULME, STEVEN E., and DANIEL W. BAKER
1977. Chilled seawater system for bulkholding sea herring. Mar. Fish. Rev. 39(3):4-9.

A report of the results of on-board tests for holding herring in CSW bulk holding tanks and containers. Ice quantities and temperatures are reported along with a description of the system and its operation.

HUMAN, J. and A. KHAYAT.
1981. Quality evaluation of raw tuna by gas chromatography and sensory methods. J. Food Sci. 46:868-873,879.

A method of evaluating raw tuna based on volatile profile pattern obtained by gas chromatography is discussed. Ethanol, propanol, butanol, hexanal, and 1-pentene- 3-ol showed a correlation to the acceptability of sensory taste tests.

INTERNATIONAL INSTITUTE OF REFRIGERATION.
1972. Recommendations for the processing and handling of frozen foods. 2nd ed. Paris.

A publication that reviews the general principles for the freezing, storage, and thawing of foodstuffs. Included are sections on scientific background and applications.

JAHNUS, F.O., F.L. HOWE, R.L. CODURI, JR., and A.G. RAND, JR.
1976. A rapid visual enzyme test to assess fish freshness. Food Technol. 30(7):part 2; 27-30.

A study which developed the hypoxanthine assay into an enzyme strip test for winter flounder. Rapid estimations of hypoxanthine could be used to judge freshness in fish products on a visual basis.

JONES, N.R., J. MURRAY, E.I. LIVINGSTON and C.K. MURRAY
1964. Rapid estimations of hypoxanthine concentration as indices of the freshness of chill stored fish. J. Sci. Food Agric. 15:763-774.

This report verifies a comparison between two methods of estimating hypoxanthine concentration. Use of the xanthine oxidase reacion agreed well with values found by ion-exchange chromatography.

KELLY, K. O., and W. T. LITTLE
1968. The use of seawater ice for storage of cod. J. Food Technol. 3:151-158.

The storage life of cod proved to remain constant when stored in saltwater ice or freshwater ice. Chemical and sensory tests were undertaken and quality deterioration was not significantly affected by the use of saltwater ice.

KELMAN, J.H.
1977. Stowage of fish in chilled sea water. Ministry of Agriculture, Fisheries and Food. Torry Advisory Note No. 73. 10p.

Describes design and operation of RSW, CSW systems and containerization with advantages and disadvantages. Compares tank design and insulation on vessels.

KOLBE, EDWARD.
1981a. Onboard freezing systems: some options for the small vessel. Oregon St. Univ., Sea Grant Pub. No. 56-67.

A bulletin which suggests various freezing systems for vessels from 40 to 60 ft long. Freezer companies, cost estimates and refrigeration theory is covered for the holding of salmon, cod, halibut and prawns.

KOLBE, EDWARD.
1981b. A mechanism to support preservation studies of freshly caught fish and shellfish. I.I.F.-I.I.R. Boston 1981.

A discussion of the design and development involved in an RSW system. The technique described is an active transfer of caught species from a fishing vessel on to a receiving vessel.

KOLBE, EDWARD
1979a. Cooling Pacific shrimp (Pandalus jordani) with sprayed seawater. J. Food Sci. 44:1418-1424.

A study of the effects of various flow patterns on spray cooling of Pacific shrimp. A spray rate of 0.4 gpm/sq.ft. is suggested for high catch rate conditions.

KOLBE, EDWARD.
1979b. Refrigerated seawater spray system model for shrimp vessels. J. Food Sci. 44:1420-1424.

A description of a mathematical simulation of an RSW system. Attention is given to compressor and chiller performance as related to heat transfer between shrimp and recirculated spray water.

KOLBE, EDWARD.
1979c. Refrigerated seawater spray for shrimp vessels: design and operation notes. Oregon St. Univ., Sea Grant Advisory Program.

A summary of the theory and technology behind RSW systems for shrimp vessels. Included topics: operation and processing, seawater pumping and spray, refrigeration system sizing, tips on cleaning and sanitizing, fish hold construction, and temperature measurement.

KORDYL, E., J. PIELICHOWSKI, and J. KOCHANOWSKI.
1973. Acceleration of prechilling process of fish in refrigerated sea water. Proc. Int. Congr. Ref. (13th Wash.) 4:591-596.

A series of trials in which herrings, hake and horse mackerel were held on board at -1^{o}C for up to 72 hours. Water was agitated by induction of air. Water to fish ratios are given.

KRAMER, DONALD E.
1980. Chilled and refrigerated seawater - easier and faster cooling of fish. Alaska seas and coasts, Univ. of Alaska, Sea Grant. 8(4):2-8.

A description of chilled liquid systems, including RSW and CSW mechanisms, for fishing vessels. Advantages and disadvantages, operations, equipment, and cleaning are discussed.

LAUTERBACK, N. and S. KAVIL.
1982. Small boat refrigeration: cooling the catch. Fish. News Int. 21(5):66-67.

A brief news item regarding the "HRSWC" system for onboard circulation of refrigerated seawater or fortified brine. Designed for the small vessel by Deepwater Marine of Richmond, Va.

LEE, J. S. and E. KOLBE.
1982. Microbiological profile of Pacific shrimp (Pandalus gordani), stowed under refrigerated seawater spray. Mar. Fish. Rev. 44 (3): 12-12.

The initial microbial load of the RSW system and the shrimp played a greater role in determining the bacterial quality of held shrimp than the growth of organisms in chilled seawater. RSW spray shrimp maintained freshness for five days.

LEE, F. N., and S. W. ROACH.
1976. The measurement of temperature in refrigerated sea water fish storage tanks. I. I. R. Comm. 81, Washington.

(Have not received copy for review).

LEE, JONG
1973. Cleaning and sanitizing agents for seafood processing plants. Oregon St. Univ. Extension Ser. Bull. S. G. No. 21.

Bulletin to assist in selection of cleaning and sanitizing agents. Defines terminology, types of agents and discusses pros and cons.

LEMON, D.W., and L.W. REGIER
1976. Slush ice holding of mackerel. Environ. Can., Fish. Mar. Ser., No. 56.

An efficient, inexpensive system was desired for slush ice holding of mackerel. Slush ice cooled the samples quicker and equilibrated at a flesh temperature of $-1^{\circ}C$.

LEMON, D.W., and L.W. REGIER.
1977. Holding of Atlantic Mackerel (Scomber scombrus) in refrigerated sea water. J. Fish. Res. Board Can. 34(3):439-443.

RSW proved to be an improved method of holding Atlantic mackerel. Uniform lower temperature and O_2 reduction were said to have inhibited the effects of oxidative rancidity and texture deterioration.

LICCIARDELLO, JOSEPH.
1980. Handling whiting aboard fishing vessels. Mar. Fish. Rev. 42 (1):21-25.

Various recommendations are suggested for improving the quality of landed whiting: washing the catch prior to storage; shelving fish pens at up to 4A intervals; reducing dockside layovers; and for short trips, iced storage. RSW is suggested for trips over 4 days.

LONGARD, A.A., and L.W. REGIER
1974. Color and some composition changes in ocean perch (Sebastes marinus) held in refrigerated sea water with and without carbon dioxide. J. Fish. Res. Board Can. 31(4):456-460.

A comparison of skin color of ocean perch held in ice versus perch held in RSW for 12 days. Skin color was the same for both methods, however fish stored in RSW with CO_2 proved to exhibit the highest quality.

LUPIN, H.M., D.H. GIANNINI, C.L. SOULE, L.A. DAVIDOVICH, and R.L. BOERI
1980. Storage life of chilled patagonia hake, (Merluccius hubbsi). J. Food Technol. 15(3):285-300.

The storage life of hake was measured by means of TVB, pH and sensory assessments during various times of the year. The fish caught during the summer months had a keeping time of not more than 10 days while winter fish kept for 15 days at $0^{o}C$.

MCBRIDE, J., J.F. MURRAY, and R.A. MACLEOD.
1955. Transport and storage of fish in refrigerated sea water: V salt penetration. Fish. Res. Board Can., Progress Rep. No. 104. p. 19-22.

A study of sodium accumulation in coho, salmon under four sets of conditions. They concluded potassium chloride was a better chill media than sodium chloride.

MEAD, JOHN T.
1973. Marine refrigeration and fish preservation. Business News Publishing Co. (Birmingham, Mich.) 248 p.

A book which discusses refrigeration principles, refrigeration systems components, power sources, selection of systems, preserving the quality of the catch, processor and freezer vessel, planning, maintenance and future of fish perservation.

MERRITT, J.H.
1969. Refrigeration on fishing vessels. Fishing News (Books) Ltd. London. 148 p.

Attention is given to spoilage and refrigeration, icing, fish insulation, RSW, refrigeration plants, freezing at sea and processing rooms. A book which is useful for both the engineer and operator of processing equipment.

MING, ZHANG.
1981. Application of partial freezing technique on fishing vessels operating in the South China Sea. I.I.F.-I.I.R. Boston 1981.

Results of trial runs for chilled brine held fish proved favorable in respect to cost and quality of iced fish. This method reduced fish flesh temperature quicker and more uniformly than ice.

MJELDE, A., and N. UPDAHL
1976. Latest results in technology of preserving and handling small pelagic fish for food and feed. In: R. Kreuzer (ed.), Fishery Products. Fishing News (Books) Ltd. London. p. 74-77.

A report which discusses current research on spoilage prevention in respect to bacterial activity in capelin flesh. Effectiveness of chemicals on fish preservation is also discussed.

MOORJANI, M.N., B.R. BALIGA, B. VIGAYARANGA, and N.L. LAHIRG.
1962. Post-rigor changes in nitrogen distribution and texture of fish during storage in crushed ice. Food Technol. 16(1):80-84.

A study of the nitrogen distribution changes of freshwater fish stored in ice. Non-protein nitrogen fraction remained constant while soluble protein nitrogen decreased after 16 days in ice.

MYERS, M.
1981. Planning and engineering data. Fresh fish handling. F.A.O. Fisheries Circular No. 375.

Major fields covered concern ice, its production, storage and use with catch, chill storage, insulated vs. non-insulated containers, in-plant transportation and fish work-up rooms.

NELSON, R.W. and H.J. BARNETT.
1973. Fish preservation in refrigerated sea water modified with carbon dioxide. Proc. Inter. Congr. Refrig. (13th Wash.) 3:57-64.

RSW system modified with CO_2 proved to extend storage life of 3 fish species when compared to ordinary RSW. Past report findings on fish and pink shrimp holding, metal corrosion, heat exchangers and hardware limitations are cited.

NOWLAN, S.S., W.J. DYER, and R.A. KEITH.
1975. Temperature and deteriorative changes in postrigor cod muscle stored up to 14 days in the superchill range -1 to -4 C. J. Fish. Res. Board Can. 32:1595-1605.

An assessment of the effect of storage temperatures in the superchill range on bacteria in cod flesh. At -4^{o}C bacterial inhibition was observed but at -1.6^{o}C spoilage occured and samples became unacceptable after 10 days.

OSTERHAUG, KATHRYN L.
1957. Refrigerated sea water bibliography. Commer. Fish. Abst. U.S. Fish. Wildl. Ser. Seattle, Wash. Pub. B-SSU-No. 2.

A bibliography taken from the files of Commercial Fisheries Abstracts. Included summaries are detailed and lengthy.

PERIGREEN, P.A., S. AYYAPPAN PILLAI, P.K. SURENDRAN, and T.K. GOVINDAN
1975. Studies on preservation of fish in refrigerated sea water. Fish. Technol. 12(2):105-111.

Storage in RSW was found to be superior to crushed ice storage for mackerel and oil sardines. Both methods provided quality fish for up to two days of storage and after that time, RSW fish surpassed ice stored fish in quality assessment.

PETERS, J.A. and J.W. SLAVIN
1958. Comparative keeping quality, cooling rates, and storage temperatures of haddock held in fresh water ice and salt water ice. Commer. Fish. Rev. 20(1):6.

A report on the effect of freshwater ice storage versus saltwater ice storage for haddock. The saltwater ice proved to cool fish quicker but melted faster leaving fish unprotected.

PETERS, J. A., E. H. COHEN, and F. J. KING.
1963. Effect of chilled storage on the frozen storage life of whiting. Food Tech. 17 (6): 109-110.

Headed and eviscerated whiting were stored in a one to one ratio with ice and in RSW at 30^{o}F. The effects of storage time were monitored. After 7 days the fish were moved to 0^{o}F where they could be sampled at various intervals. RSW revealed an extended storage life.

POLLEY, S.L., O.P. SNYDER, and P. KOTNOUR.
1980. A compilation of thermal properties of foods. Food Technol. 34(11):76-94.

Data providing specific heats above and below freezing, latent heats, thermal conductivity and heats of respiration are listed for various food stuffs.

POULTER, R.G., C.A. CURRAN, and J.G. DISNEY
1981. Chill storage of tropical and temperate water fish differences and similarities. I.I.F.-I.I.R. Boston 1981.

A study of the technological differences between holding methods in the tropics compared to cold water areas. The spoilage rates of warm and cold water fish are listed in table form. A lengthy bibliography is included.

RAMEY, FREDA A., J.A. TAYLOR, and FRANK THOMAS.
1979. The washing of fish: a literature assessment. Sea Grant College Pub. UNC-SG-79-07.

An annotated bibliography on the washing of fish, equipment for washing fish and the implications of general handling and preserving techniques.

REPPOND, KERMIT D., F.A. BULLARD, and J. COLLINS.
1979. Walleye pollock (Theragra chalcogramma): physical, chemical, and sensory changes when held in ice and in carbon dioxide modified refrigerated sea water. U.S. Nat. Mar. Fish. Serv., Fish. Bull. 77(2):481-488.

Pollock can be held 6 days if iced thoroughly and for 4 days in CO_2 modified RSW. It was concluded that palatable fillets can be obtained from ice-held fish that otherwise would have been rejected if in round form.

ROACH, S. W.
1981. Going heavy duty with R.S.W. installations. Fish. Boat. June pp. 32-33, 70-71.

The design and operation of two RSW vessels built by Marco Seattle Co. is discussed. Heavy duty classifications are listed for tanks, drives, circulation systems, application rates, and chillers.

ROACH, S.W.
1973. Operating instructions for RSW systems on B.C. salmon packers. Fish. Res. Board Can.

A summary of the refrigeration mechanisms used on board the wooden vessels in B.C.. Sections include; salinity measurement, refrigeration theory, heat exchangers, circulating pumps, suction screens, control systems, fish quality and rating the holding capacity of tanks.

ROACH, S.W., K.M. HARRISON.
1954. Use of chilled sea water and dilute brines in place of ice for holding shrimp aboard a fishing vessel. Fish. Res. Board Can., Prog. Rep., Pac. Coast Sta. 98:23-24.

A brief summary of the design and operation of a CSW brine system aboard a Canadian shrimp trawler. Results of a trial run are cited.

ROACH, S.W., TARR, H.L.A., TOMLINSON, N., and HARRISON, J.S.M.
1967. Chilling and freezing salmon and tuna in refrigerated sea water. Fish. Res. Board Can., Ottawa. Bulletin No. 160.

Engineering and biochemical investigations are reported for the chilling and freezing of salmon. Sections include; RSW systems, ice and salt mixtures, brine-spray freezing, changes in fish flesh during RSW storage and storage in salt-fortified RSW.

ROACH, S. W.
1974. Hydraulic model studies of flow conditions in refrigerated sea water storage tanks on salmon tenders. I.I.R. Comm B2, B3, Tokyo.

(Have not received copy for review.)

ROACH, S.W., J.S.M. HARRISON, and H.L.A. TARR
1961. Storage and transport of fish in refrigerated sea water. Fish. Res. Board Can. Bulletin No. 126. 61p.

A bulletin which provides valuable information on design and operation of RSW systems; includes information on tanks, compressors, condensers, evaporators, pumps, piping, pratical applications to several fisheries, physical and chemical changes of fish, bacterial spoilage and control and results of several RSW experiments.

RONNING, JOHN P.
1971. Refrigeration on smaller fishing vessels. Wash. Sea Grant, Clover Park Vocational Tech. Inst. Pub.

General information and useful guide lines about on board refrigeration systems. Discussions include; equipment considerations, operations and maintenance, pipe coils, cold plates, air blast, seawater brine solutions, brine spray, and a listing of equipment suppliers.

RONSIVALLI, L.J. and D.W. BAKER II.
1981. Low temperature preservation of seafoods: a review. Mar. Fish. Rev. 43(4):1-15.

A review of the common refrigerants used in the preservation of seafoods. Discussion includes use of brines, ammonia, fluorocarbons, cryogenic gases and liquids, CSW, and RSW. Gas and liquid refrigeration systems are described.

SANTOS, L., D. JAMES and F. TENTSCHER.
1981. Guidelines for chilled fish storage experiments. F.A.O. Fish. Tech. Paper No. 210.

Instructions for performing experiments to determine the chilled storage life of fish. Included topics are icing, CSW, RSW, quality assessment methods, organoleptic assessment, bacteriological examinations, and chemical assessment.

SCARLATTI, E.
1967. Results on the storage and transport of fish in the holds of Portuguese fishing vessels using super chilling equipment. Proceedings of the International Congress of Refrigeration (12th Madrid).

A fishing trip duration of 24-25 days is possible using superchilling techniques. Fish are held in drawers, partitioned by brine-refrigerated shelves whose temperature is -1 to -1.3^{o}C. Approximately 1/3 of fish is frozen and internal ice damage is slight.

SCHMIDT, P.J. and D.R. IDLER.
1955. Transport and storage of fish in refrigerated sea water: III Curd in canned salmon as related to post-mortem age of fish. Fish. Res. Board Can. Prog. Rep. No. 104. 9-10.

An experiment which sought a method of canning and storage which would not form curd in blue-back salmon. A curd-free method was not found but wide variations in curd production were exhibited by the same species.

SEAGRAN, H., J. COLLINS and J. IVERSON
1960. Processing and quality studies of shrimp held in refrigerated sea water and ice. Commer. Fish. Rev. 22(5):1-5.

The effects of holding variables (temperature, brine concentration, shrimp to brine ratio) on the quality of pink shrimp were studied. Lowering the temperature and increasing the brine concentration were judged to have the greatest effect on storage life.

SHAW, D.H., and BOTTA, JR.
1975. Preservation of inshore male capelin (Mallotus villosus) stored in refrigerated sea water. J. Fish. Res. Board of Canada 32:2047-2053.

Results of this study showed male spawning capelin having a increased rate of deterioration in RSW when compared to storage in ice. Contrary to other reports RSW held fish were unacceptable after 3 days.

SLABYJ, BOHDAN, M. and RUTH H. TRUE.
1978. Effect of preprocess holding on the quality of canned maine sardines. J. Food Sci. 43:1172-1176.

The effect of preprocessed brine holding on sardine quality was studied. A temperature of 0.6°C and 12% brine concentration exhibited the longest storage time of 3 days. Spoilage was not attributed to bacterial activity.

SLAVIN, J.W.
1965. Sea water ice for preserving fish in the U.S. F.A.O., Proc. Indo-Pac. Fish. Council 11(III):249-253.

The results of U. S. studies on the use of sea water ice in fish preservation are reported. Researchers concluded that salt-water ice had no advantages over fresh-water ice in terms of extended storage life.

SMITH, J.G.M., R. HARDY, and K.W. YOUNG.
1979. A seasonal study of the storage characteristics of mackerel stored at chill and ambient temperatures. In: J.J. Connell (ed.), Advances in Fish Science and Technology. Fishing News (Books) Ltd. Surrey, England.

Various analyses were conducted on mackerel fillets held in CSW and ice. Hypoxanthine was selected as the best indicator of spoilage in fish held in ice. Winter caught fish provided the highest sensory assessments.

SMITH, JAMES G.M., ROY HARDY, JAN McDONALD, and JAMES TEMPLETON
1980. The storage of herring (Clupea harengus) in ice, refrigerated sea water and at ambient temperature. Chemical and sensory assessment. J. Sci. Food Agric. 31(4):24-34.

Results of this study indicated that spoilage changes in herring stored in ice and RSW are similar. RSW held fish was stated as having "off" flavors due to a non-renewal of the surrounding water

SPENCER, R. and C.R. BAINES.
1964. The effect of temperature on the spoilage of wet whitefish. Food Technol. 18(1):769-773.

A linear relationship was formed between holding temperature and rate of spoilage of white fish. Sensory, chemical, and bacteriological tets were performed which provided a value constant around which an equation could be formed.

SPINELLI, J., M. EKLUND, and D. MIYAUCHI.
1964. Measurement of hypoxanthine in fish as a method of assessing freshness. J. Food Sci. 29:710-714.

Hypoxanthine contents of sole and perch fillets increased iniformly during the first 8-10 days of ice storage. After 10 days hypoxanthine content reached a maximum. It was judged as a speedy and reliable method for determining storage time of fish.

STANSBY, M.E.
1958. Problems in determining fish freshness. Food Technol. 12:260-262.

Criteria are set forth for determining useful tests which evaluate fish freshness. Freshness tests should be able to measure (1) loss of normal flavor (2) development of off flavor (3) estimate keeping quality or (4) estimate of time since the fish were caught.

STEINER, G. and H.L.A. TARR.
1955. Transport and storage of fish in refrigerated sea water: II bacterial spoilage of blue-back salmon in refrigerated sea water and in ice, with and without added chlortetracycline. Fish. Res. Board Can., Pro. Rep. No. 104. p. 7-8.

Blue-back salmon were held in refrigerated seawater plus the antibiotic CTC, ice, ice containing CTC, and RSW alone. Bacteriological examinations revealed RSW plus CTC provided the lowest plate counts and the longest storage times.

STERN, JOSEPH
1958. Considerations on the use of refrigerated brine for chilling and storing fresh fish. Comm. Fish. Rev., Tech. Note No. 43, 20(2): 17-20.

A comparison of the keeping quality of fish in refrigerated brine and in ice. Brine held English sole exhibited equal or greater quality when compared to ice held fish, providing proper, circulation of brine and maintenance of low temperatures.

STUTTAFORD, M.
A South African company, Da Gama, near Cape Town, has devised a mechanical pumping system operating under low vacuum to reduce damage during off-loading of fish kept in refrigerated or chilled sea water and also avoid polluting the harbour with blood water.

THROWER, S.J. and I.A. STAFFORD.
1981. A mobile unit for comparative studies of chilled storage systems for trawl fish. I.I.F.-I.I.R. Boston 1981.

A description of the equipment and operation of a mobile unit designed for conducting RSW, CSW or ice storage trials used on the Australian coastline where ice is scarce and RSW holding is untested for many fish species.

THURSTON, C.E.
1961. Proximate composition and sodium and potassium contents of four species of commercial bottom fish. J. Food Sci. 26:495-498.

The proximate composition along with sodium and potassium contents were examined in four species of fish. Pacific ocean perch, cod, sablefish and lingcod were quite uniform in composition.

TOMLINSON, N., S.E. GEIGER, G.A. GIBBARD, D.T. SMITH, B.A. SOUTHCOTT, and J.W. BOYD
1978. Improving landed quality of groundfish by modification of refrigerated seawater. Can. Fish. Mar. Ser. Tech. Rep. No. 783.

Various means of modifying the standard RSW systems were studied. Half-strength RSW plus 0.2% potassium sorbate was effective in extending shelf life of fillets by 4 days.

TOMLINSON, N., S.E. GEIGER, W.W. KAY, J. UTHE, and S.W. ROACH.
1965. Partial freezing as a means of preserving Pacific salmon intended for canning. J. Fish. Res. Board Can. 22(4):955-968.

Partial freezing through the use of salt-reinforced RSW was effective in inhibiting belly-burn and bacterial spoilage in pacific salmon. The greatest rancidity build up was in the red lateral muscle.

TOMLINSON, N., S.E. GEIGER, and W.W. KAY.
1965. Sodium, potassium, and magnesium concentration and weight changes in fish stored in refrigerated sea water in relation to biochemical changes associated with rigor mortis. J. Food Sci. 30:126-134.

In trout stored in RSW, sodium ions did not penetrate muscle until ATP had been destroyed. Potassium loss and magnesium uptake was also examined.

TOMLINSON, N., GEIGER, S.E., BOYD, J.W., SOUTHCOTT, B.A., GIBBARD, G.A., and ROACH, S.W.
1974. Comparison between refrigerated sea water (with or without added carbon dioxide) and ice as storage media for fish to be subsequently frozen. Bull. Inst. Int. Froid 1 (suppl):163-168.

A study of the feasibility of a CO_2 modified RSW system for preservation of lingcod and salmon. Although RSW + CO_2 was effective in controlling bacteria, saltiness rendered the fish unacceptable after 8 days. Impairment of flesh color also became apparent.

TOMLINSON, N., KRAMER, D.E., GEIGER, S.E., ROACH, S.W., and MANN, J.H.
1973. A comparison of the quality of sockeye salmon canned after storage in ice and in refrigerated sea water. Proc. Inter. Congr. Refrig. (4): 597-600.

Samples of freshly caught sockeye salmon were held for 4, 12, or 48 hours at 14°C and then stored in ice or in RSW. Evaluations on fresh and canned products showed a higher free oil content for ice held fish.

TRETSVEN, WAYNE and HAROLD BARNETT
1970. Recommendations for handling and icing fresh pacific halibut aboard vessels. Fish. Ind. Res. 6 (1): 5-13.

Factors affecting the handling and icing of Halibut are; size of poke, density of ice, handling, stunning, bleeding, cleaning and the drainage of meltwater. Recommendations and suggestions are made to improve landed quality.

VARGA, S., and C. M. BLACKWOOD
1969. Effect of seawater chilling on landed quality of scallop meat. J. Fish. Res. Board Can. 26:2523-2526.

The quality of scallop meat was improved by chilling in sea water prior to bagging and icing. An increase in storage time of 2-9 days on trips of 14 or 15 days was observed.

WATERMAN, J. J., and J. GRAHAM.
1975. Ice in fisheries. F.A.O. Fisheries Rep. Torry Res. Sta., Aberdeen, England. No. 59, Rev. 1:57p.

An outline of the nature, properties and manufacture of ice. Applications to fishing industry are discussed in regards to ice manufacturing equipment, ice plants, preservative effect of chilling, nature and properties of ice, and other methods of chilling.

WATERMAN, J. J.
1980. Which kind of ice is best? Torry Res. Stn. Aberdeen Scotl., Advis. Note 21.

A discussion regarding the various types of ice used for fish preservation in British fisheries. Advantages and disadvantages are discussed for ice types and methods of manufacturing.

WATERS, MELVIN E.
1978. Storage characteristics of several underutilized fish from the gulf of Mexico. Proc. 3rd Ann. T & Sub T. Fish. Tech. Con of Amerc., Tex A & M Univ. New Orleans, La.

The refrigerated shelf life of croaker, white trout, spanish mackerel and king mackerel was determined by chemical, microbial and organoleptic tests. A strong correlation was exhibited by chemical and organoleptic evaluations. Conway microdiffusion was useful for determining TVN and TMA-N.

WHYTE, JOHN C. and JOHN ENGLAR.
1978. Direct potentiometric measurement of chloride in fishery products by ion selective electrode analysis. J. Fish. Res. Board Can. 35(2).

Chloride in thawed, smoked fish, and fish roe was estimated by direct application of a chloride electrode. This method was suggested as rapid, accurate and convenient for determining chloride content in marine products.

WOOLRICH, W. R.
1966. Handbook of refrigerating engineering. Vol 1 + 2. Avi Publishing Co., Inc. Westport, Conn.

A general review of the procedures, methods and fundamentals of low temperature food preservation. Refrigerated storage and processing for foods, beverages, and juices are discussed.

YU, T.C. and R.O. SINNHUBER.
1952. Two thiobarbituric acid methods for the measurement of rancidity in fishery products. Food Technol. 11:104-108.

Modified TBA method was effective in the determination of oxidative rancidity in fish meal, oil, fresh and frozen fish. Procedure and methodology is discussed.