United States Department of the Interior, J. A. Krug, Secretary
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FREEZING FISH AT SEA

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Research has shown there is a definite ripening period for harvesting agricultural products in order that a frozen pack of the highest quality can be obtained. To reduce to a minimum the time between harvesting and processing freezing equipment often is moved to points as near the harvesting area as possible.

Fish should be considered a food even more perishable than agricultural products, since it is adjusted to temperatures generally lower than the atmosphere. Fish is either killed in catching or shortly thereafter and, as dead tissue, is subject to enzymatic breakdown which is doubled for each 10° F. increase in temperature. To duplicate the practices applied to other food products it is necessary to freeze fish immediately after they are taken from the water. The merits of this procedure have been under discussion among the commercial producers of fish for a number of years. In some segments of the industry it is an accomplished practice--in others no satisfactory solution for the many accompanying problems has been devised.

Small vessels which make trips of from only a few hours to two or three days are not a problem since the catches landed by them can be frozen while the fish are in prime condition. The larger vessels, the trawlers, which make trips to the distant banks for their catch, constitute the real problem. Trawler trips vary from eight to 14 days and the fish landed may be from six to 12 days out of the water when prepared for freezing. The engineering and economic problems involved in devising and operating freezing equipment for this type vessel are very complex. Radical changes in design and operation of trawlers, as well as the shore methods of handling, will be required before freezing fish at sea can become a common practice.

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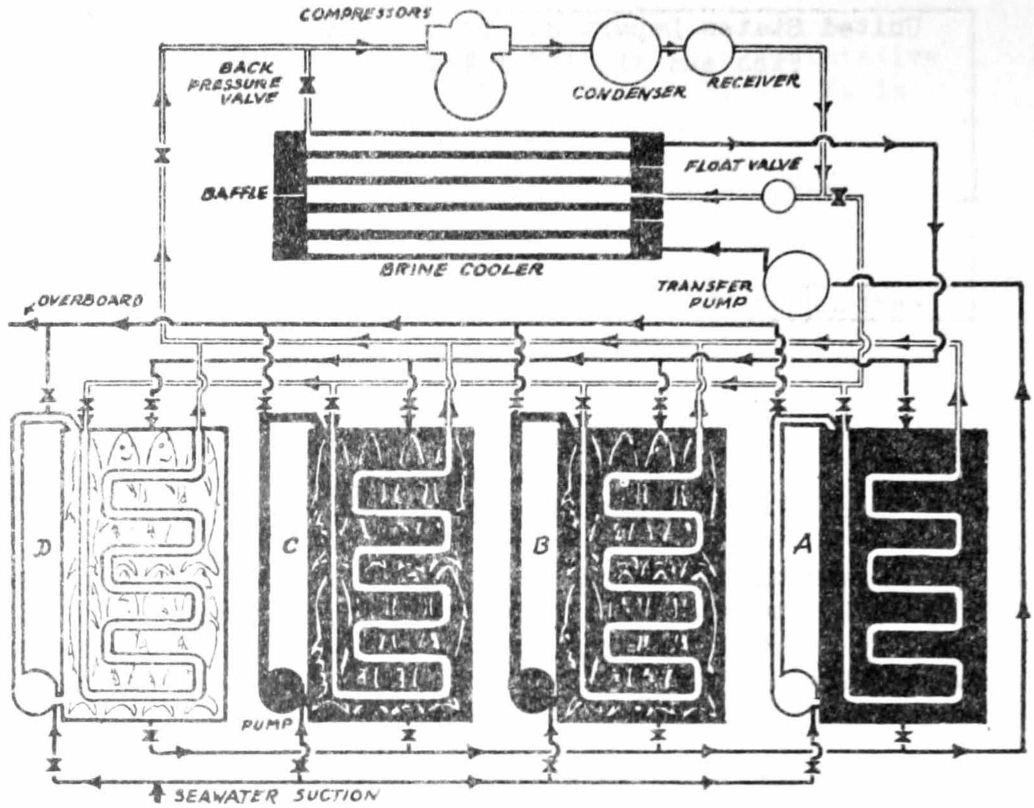
Fig. 1. This schematic drawing shows the brine cooling system used for freezing fish on the tuna clippers.



One of the first large scale fishing operations involving the freezing of fish at sea was undertaken by a company organized in France with headquarters at Boulogne. This firm operated a fleet of several trawlers in the North Atlantic, North Sea, and Mediterranean. All were of similar size and construction and used the same freezing system, and each had a cold storage capacity of about 150 tons of round fish. These vessels operated successfully in freezing fish at sea until 1940 when they were seized after France was occupied by the Germans.

The freezing system used on the vessels was known as the Reeh system, making use of an improved Sacip freezing drum. The freezing unit on these vessels consisted of a drum or cylinder about 8 feet long and 4 feet in diameter revolving around a longitudinal axis and divided into eight compartments which also revolved around the central shaft. The partitions, making up the eight compartments, were perforated for full circulation of the freezing medium. The drum was filled to the axis with circulating cold brine, thus leaving four compartments immersed in brine and four exposed above the brine. Each compartment was fitted with a water-tight door, closed when the drum was rotated.

The vessel's brine tank had a capacity of 21 tons of saturated sodium chloride brine and was cooled to approximately 10° F. by evaporator coils in the tank, using carbon dioxide as the refrigeration medium. The chilled brine was circulated through the freezing drum and in the cold storage hold by means of centrifugal pumps which had a capacity of 100 gallons per minute.

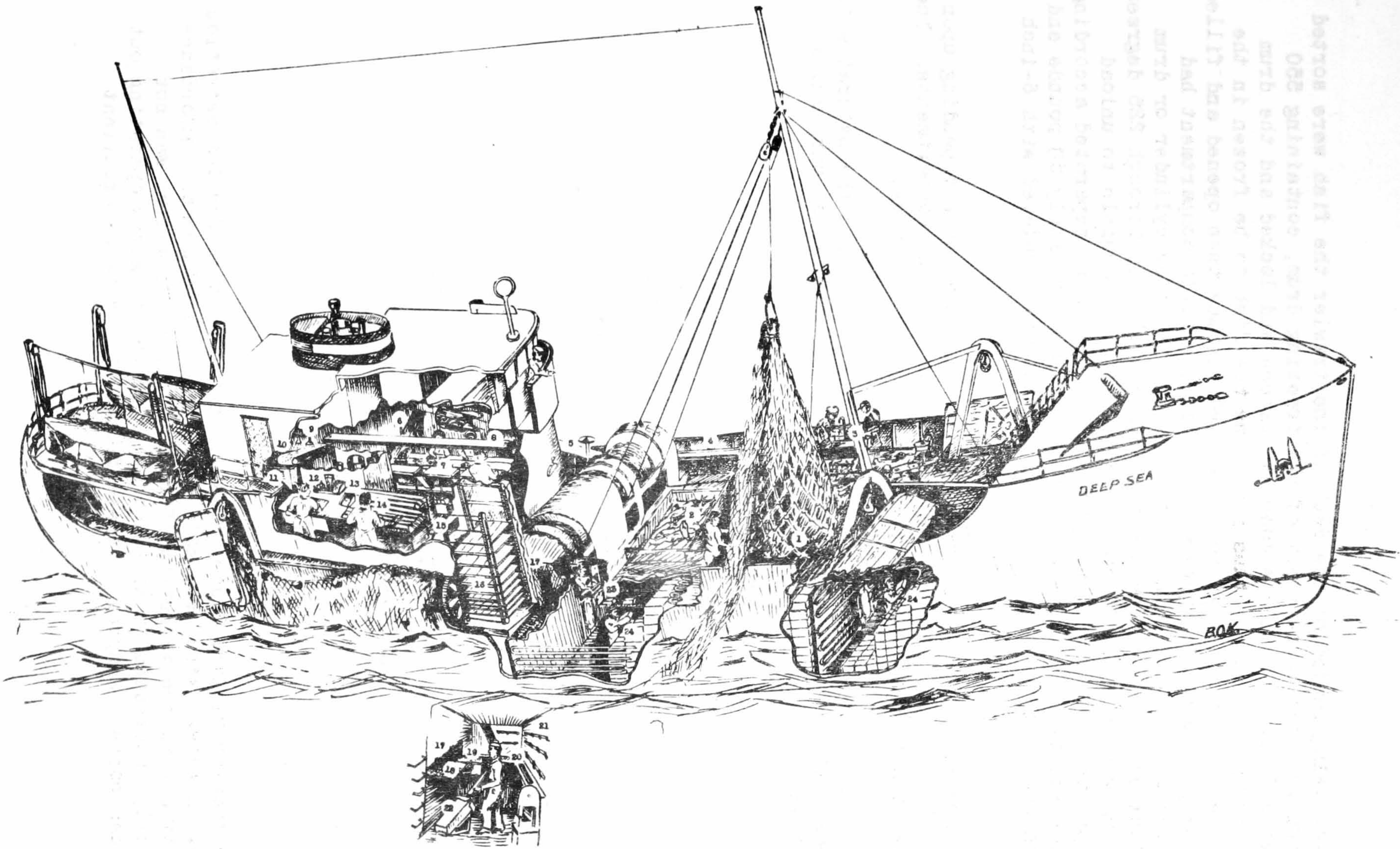


Fig. 2. The recently built motor trawler DEEP SEA has a complete freezing and processing system on board. The cutaway view of the ship shows the various activities performed on board. These are: (1) landing the catch; (2) sorting species of fish; (3) butchering, washing, and cleaning king crabs prior to cooling; (4) sluice conveyor to cooker; (5) cooker conveyor leading to processing room; (6) chute to processing conveyor; (7) processing conveyor to filleters; (8) fish conveyed to spray washer; (9) spray washer; (10) conveyor to hopper; (11) hopper; (12) inspection table; (13) weighing; (14) packing in freezer trays; (15) chute for clean tray supply; (16) quick freezing conveyors; (17) frozen trays; (18) defrost stage; (19) defroster tank; (20) glazing tank; (21) racks for glaze to set; (22) packing cartons; (23) full carton conveyor; and (24) carton storage forward in ship.

After being landed on the deck of the trawler the fish were sorted and placed into one compartment of the freezing drum, containing 550 pounds when filled. Then the door was closed and locked and the drum rotated through 45 degrees thus immersing the fish to be frozen in the brine. The compartment next to the filled one was then opened and filled and rotated, repeating the operation until the fifth compartment had reached the filling point in the cycle. The freezing cylinder or drum was so located that when the compartments had rotated through 225 degrees the opening was in the cold storage room. It was possible to unload each compartment at this point. The frozen fish were separated according to species and placed in net bags containing approximately 50 pounds and stored in the hold which was chilled by coils and insulated with 6-inch cork.

The freezing period varied between one and two hours depending upon the size of fish and the speed of filling the freezing compartments. The total freezing capacity of this trawler was 20 tons per day.

The idea of freezing the fish and storing them with the natural slime intact was that the slime acted as a preventive of freezer burn and a preservative of the natural flavor of the fish.

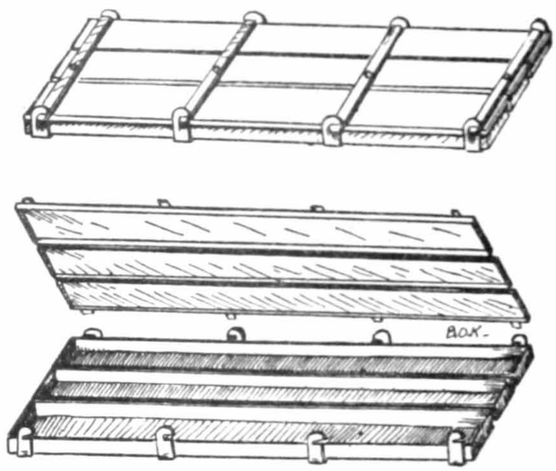


Fig. 3. A typical type of tray mold used for freezing sea products.

The trawler visited Boston, Mass., in August 1932 for demonstration purposes. However, since the sale of fillets was of greater importance at that time than the marketing of round fish, the industry was not particularly interested in making changes in the trawlers operating out of American ports. Samples o^ these frozen fish were of excellent quality.

S. S. PACIFIC EXP

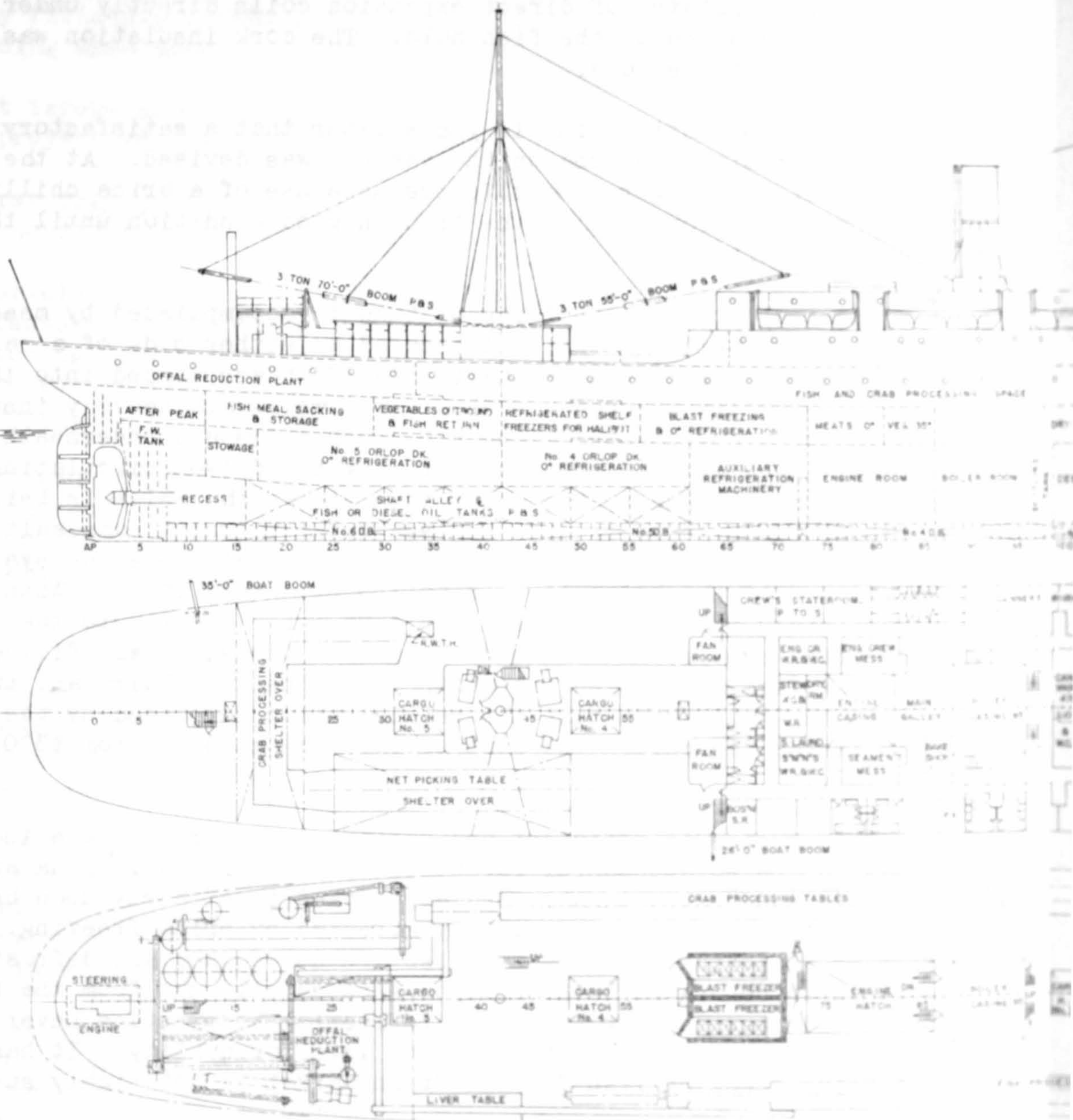
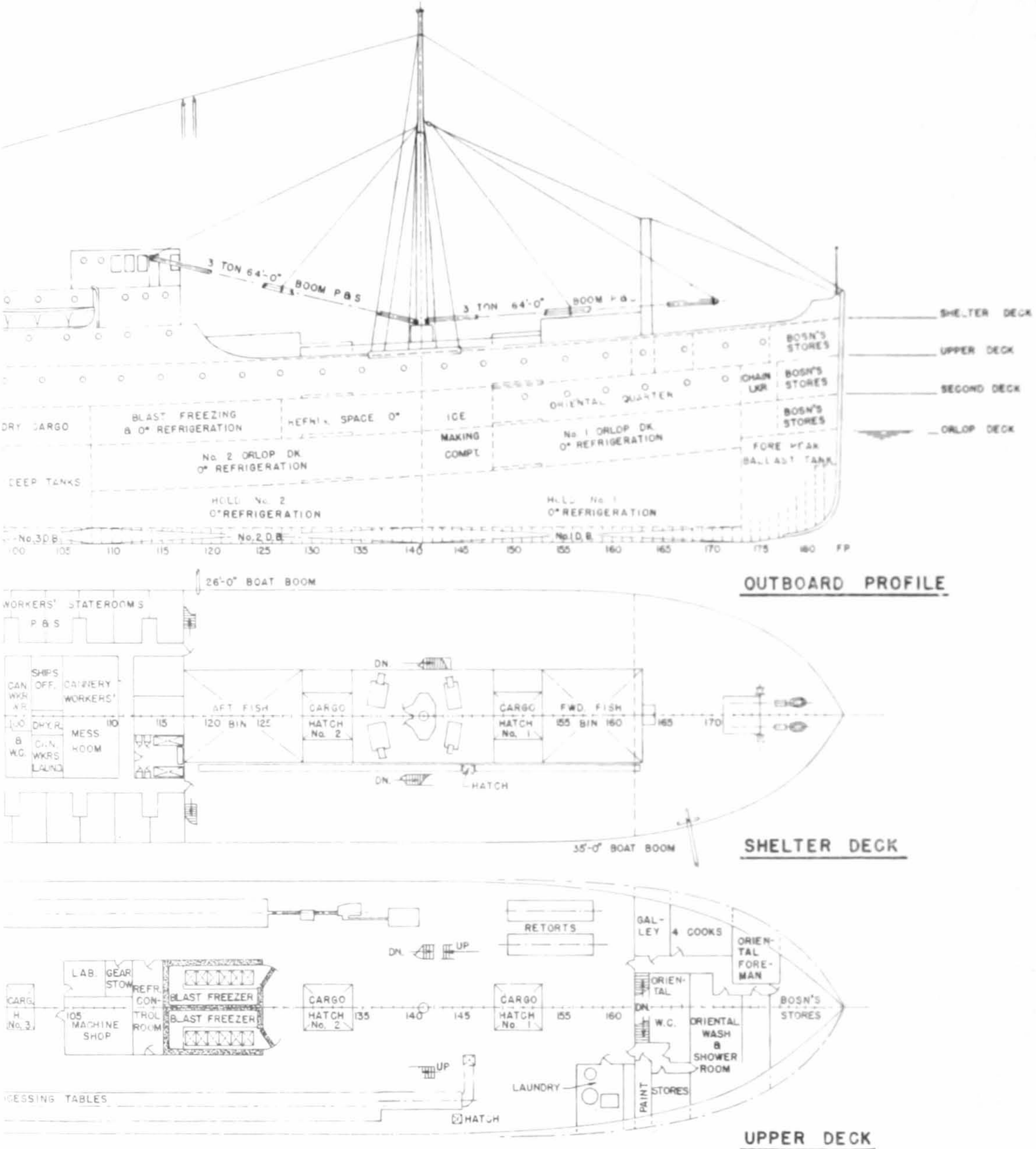


Fig. 4. Outboard profile and upper decks of S. S. PACIFIC
because it serves as a mother ship to a number of smaller
ships and supplying them with fuel and food for their crews

PLORER



C EXPLORER. This is a factory ship so-called
vessels, processing the catch of the small
ws.

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The tuna fishery employed crushed ice as a refrigerant for many years before the inadequacy of this type of cooling was realized. It was when the tuna clippers extended their trips into subtropical waters that it became evident that it was impossible to carry sufficient crushed ice to return with fish in first class condition. During the middle 1920's some of the larger of the tuna clippers installed mechanical chilling, with ice as auxiliary refrigeration. These installations consisted of direct expansion coils directly under the deck and along the sides of the fish hold. The cork insulation was increased on the walls of the hold.

It was not until about 10 years later that a satisfactory method for refrigerating the tuna on the vessels was devised. At the present time all of the larger tuna clippers make use of a brine chilling and freezing system for keeping the fish in good condition until they are brought to port.

The present brine chilling of tuna is accomplished by means of several cargo wells in the hull located on either side of a narrow passage above the propeller shaft. The fish are loaded into the wells by means of manholes through the deck. The wells are heavily insulated and ammonia coils are located along the inner sides and underneath the top of them. Each well is equipped with a motor driven circulating pump and an outlet and intake to the sea. When one of the wells is being prepared to freeze fish, it is filled with sea water to which some salt is added. The cooling coil in the well is cut into the refrigeration system and the temperature of the brine lowered to approximately 15° F. When this well is completely filled with fish, the next well is cut into the ammonia circulating system, and so on until all of the wells are filled with fish. After the fish are frozen, the brine is pumped overboard and the fish are held in the wells with only the refrigeration furnished by the ammonia coils inside the well. The cost of these vessels is from $300,000 to $500,000.

This system is efficient and satisfactory for the tuna industry but it may not be so successful for other species of fish. Tuna are practically all destined for the cannery and are cooked immediately upon being defrosted. Furthermore they are not seriously affected by brine freezing. In the fresh or filleting industry the fish are not cooked and defrosting would be required before fillets could be successfully cut from the frozen fish. This would require defrosting and refreezing, a practice never encouraged since the resulting product may be of inferior quality. It has been found that brine freezing fish for the fresh market is not highly successful.

Within the last year a trawler has been designed for filleting and freezing fish at sea, as described in the August 1947 issue of REFRIGERATING ENGINEERING. This vessel, the DEEP SEA, was designed for trawling both fish and king crab and operates in Alaskan waters. It is of 350 gross tons and has space for 150 tons of frozen fish. The hold is insulated with 4 inches of cork and can be held at a temperature of 0° F. The blast freezer is a vertical descending elevator type adjusted to a speed which permits freezing during the descent from deck to hold. The fish are filleted and packed in metal pans 48 x 12½ inches--each containing approximately 36 pounds of fish.

Waste material--heads, viscera, claws, etc.,--are discharged overboard, which releases storage space for a larger pay cargo of frozen fillets. The waste in any filleting operation represents from 55 to 75 percent of the catch depending upon species of fish being handled.

Present information is not in sufficient detail to indicate whether or not the project is financially successful.

The first trip last summer demonstrated a number of weaknesses in the design, and no doubt these will be corrected.

At intervals during the past several years plans have been prepared for a complete factory ship--that is, a vessel of sufficient size to contain freezing, canning, and by-products equipment. A number of such vessels were in operation by the Japanese prior to the war and at present the Soviet Government is known to operate a fleet of such vessels.

The American counterpart of these vessels is the factory ship PACIFIC EXPLORER which recently returned from her maiden voyage in the South Pacific with a cargo of 2300 tons of frozen tuna. This vessel was authorized by the Defense Plants Corporation, a subsidiary of the Reconstruction Finance Corporation, in the last months of the war.

The Pacific Exploration Company was designated as agent for the RFC in the construction period and as operator under a lease agreement. Provision was made in the contract for representatives of the Government to accompany the expeditions and publish reports on their observations to assure that the information would be made available to the industry.

The PACIFIC EXPLORER was one of the 8800-ton vessels built during World War I--410 feet in length--and was designed as a carrier of bulk or nonperishable cargo. Consequently, extensive alterations had to be made for conversion to a refrigerator and mother ship. Other more suitable vessels were in existence but they were not available because of war needs.

Besides accepting cargo, a mother ship must provide her brood of fishing vessels with fuel, water, ice, fishing gear, and repair facilities. In addition, accommodations for nearly 80 persons had to be provided for tuna trips and 240 persons on the Northern voyage. Approximately 300,000 gallons of fuel oil were carried to run the ship's diesel-electric plant and to service the fishing fleet. Fresh water for making ice, ship's service, and supplying the fishing fleet was prepared by two evaporators having a daily capacity of 40 to 45 tons.

Primary thought during the design and construction periods was concentrated on Bering Sea operations, tuna was of secondary consideration. Changing economic conditions now appear to make the tuna trade more favorable. Unfortunately, the dual purpose design has resulted in a ship that is less efficient for handling tuna than one designed primarily for the purpose. Tuna can be frozen in brine but the Northern products require dry freezing. A considerable space is necessary for the production lines in Northern operations and a large portion of the cargo should be held in dry storage at normal temperatures. In the tuna trade only freezer and cold storage is needed. On the Bering Sea trip it was expected to can crab meat, prepare fillets, and utilize waste for the manufacture of by-products.

Electric power for the PACIFIC EXPLORER is furnished by three diesel-electric units of 450 horsepower each, rated at 300 kilowatts and 440 volts. Two of these are adequate to carry the electrical load; switchboard voltages of 440, 220, and 110 are provided for the various services. All of the motors for the refrigeration and ventilation systems operate on 440 and 220 volts; the domestic services are on 110 volts.

The various cold compartments are made with non-structural steel sheeting and the spaces around the holding rooms are insulated with a minimum thickness of 9 in. of fiberglass. The freezer spaces are protected by cork board insulation with a minimum thickness of 8 in. Walls adjacent to the hot machinery spaces have a minimum of 14 in. of insulation. Incidentally, the living quarters and working spaces are insulated with a one-inch thickness of corkboard bonded to the steel surfaces directly exposed to the sun.

Seven cold storage rooms having a combined capacity of 168,152 cu.ft. and capable of accommodating 2350 tons of tuna are incorporated in the holds. Seven freezers totaling 38,602 cu.ft. are located on the second deck. Three of these are blast freezers, two of which take a charge of 15 to 20 tons, and the largest will accommodate 50 tons. The other four freezers on the second deck are of the shelf type and will each accommodate a charge of 15 to 18 tons. In addition, four small blast freezers are located on the cannery deck for freezing packaged fish but their individual capacity of three tons renders them impractical for tuna.

Approximately 66,750 linear feet of $1\frac{1}{4}$-inch diameter cooling and freezing coils, exclusive of supply and interconnecting piping, are used to refrigerate these areas. About 35,950 feet of coils are in the seven storage rooms and temperatures of -10° F. can be maintained. In the seven blast freezers, eight equal units totalling approximately 7400 feet of fin coils comprise the cooling surface. Two units are used in the 50-ton freezer. The four shelf freezers have a combined coil length of 23,400 feet.

A cake-type ice plant with a rated 10-ton daily capacity was also fitted on the second deck to supplement the ice obtained from shore. Ice could not be made when the vessel had even a slight roll because of sloshing and the resultant mixing of the brine and fresh water to be frozen. The use of flake ice machines would present conveying and storage problems. Furthermore, the ice made aboard the ship would be expensive as the cost of producing potable water is estimated to be between $5 and $6 per ton.

It is believed the refrigeration plant on the PACIFIC EXPLORER has a larger capacity than that installed on any vessel of United States registry. Although there are refrigerated ships having a far greater cubic capacity, they are designed for transporting meat or produce and few, if any, are expected to hold the cargo space at temperatures lower than 15° F. This vessel was designed to hold cargo at 0° F. or lower and has freezer space for stowing about 130 tons of tuna. It was believed, during design, that the refrigeration plant capacity was in excess of the needs, but this was not found to be true under tropical conditions.

It was decided that a flooded system supplied by a two-stage compressor plant would provide the most suitable refrigeration because of the large amounts of ammonia required to do the job and the low ammonia temperatures desired in the blast freezers. Features were also incorporated to permit operation with sub-cooled liquor but operating difficulties were encountered which rendered it impractical.

The main compressors consist of two boosters, two high-stage machines and an additional $6\frac{1}{2}$ by $6\frac{1}{2}$ in. twin-cylinder, high-stage machine which can be directly hooked to the ice-making tank suction. The booster compressors are a four cylinder 15 by 10 in. machine and a twin 13 by 9 in. machine driven by 125 and 50 horsepower motors respectively. These have rated capacities of 134 and 65 tons of refrigeration at a suction temperature of -25° F. and a discharge pressure of 24 pounds per square inch. The two high-stage compressors are twin $11\frac{1}{2}$ by 10 in. units, each driven by a 175 horsepower motor and with a combined rating of 230 tons of refrigeration at a suction pressure of 24 pounds and a discharge pressure of 190 pounds. The $6\frac{1}{2}$ by $6\frac{1}{2}$ in. machine is rated at 21 tons under the same pressures and is driven by a 45 horsepower motor.

The plant is designed to circulate the booster discharge gases through a 20 inch by 17 foot gas cooler and into a direct expansion liquid and gas cooler, then to the second stage machines. Condensation of the high-stage discharge is effected by a pair of 24 inch by 16 foot condensers and the ammonia collects in a high temperature receiver. Here the high temperature liquid can be divided between the direct expansion liquid and gas cooler, and the ventilation water coolers and ice-making tanks.

For purposes of ammonia control, the storage rooms are divided into two sections, one each forward and aft of the engine and boiler rooms. The ammonia flow to each storage room is regulated at one of the two control stations by metering through supply and suction headers thus providing individual control of the rooms. Hot gas from a header could be diverted to the supply side for defrosting. The return suction from the storage rooms enters the subcooled receiver and then passes to the boosters. Here a control valve regulates the suction pressure and the consequent general temperature of the storage rooms.

Each of the freezer surge drums serves two sets of freezing units. Two pairs of the shelf room coils are on two surge drums and each of the four receivers in the blast areas services a unit on the second deck and the cannery deck. The suction lines from all of the six receivers eventually become a common line leading directly to the boosters.

In actual practice under tropical conditions, the plant was found to be quite complex and delicate to operate. Most marine refrigeration men are only familiar with relatively simple single-stage systems commonly used for ship's stores or transporting fresh and frozen foods. Thus the system was beyond the experience of the watch engineers and extensive training and supervision was required. After a training period of three months, the ability of the operating personnel improved considerably. Had the plant been a shore installation, the personnel would normally consider its operation to be a long term job but maritime workers are transient by nature and a turnover was even experienced during the single voyage. Therefore a complex refrigeration system becomes a burden as constant training of personnel is necessary. The operation of the plant was complicated also by several series-parallel flow arrangements.

In time marine growths accumulated in the sea chests and probably in the lines supplying the condensers. This possibility coupled with condenser water temperatures in excess of 84° F. and noncondensible gases tended to raise the head pressures. Difficulty was experienced with the automatic purging system and manual purging became necessary. It was thought that some of the less experienced operators purged the system when other causes might have been responsible for high head pressures, since considerable quantities of ammonia disappeared. Toward the end of the trip the shortage of ammonia was a pressing problem and the storage rooms had to be robbed to freeze fish and a constant juggling of the ammonia flow was required. Further, the ammonia seemed to seek the coldest spots and if rooms were allowed to become warm difficulties arose in resuming refrigeration.

Many problems arose which space will not permit discussing. It should, however, be understood that this was the first attempt to build and operate a factory ship of purely American design.

It is questionable whether or not this vessel is the final answer to freezing fish at sea. It is probable that the much more simple system of the French or the tuna industry can be adapted to the trawlers operating out of New England ports.

One technician formerly connected with one of the large fish producers in Boston has suggested that there is no scientific information to indicate that trawler-caught fish could not be frozen at sea in the round and landed in that condition. When they were received in the shore packing plant they could be softened sufficiently to be cut into fillets and refrozen for the package market. So far this method of operation has not been given a trial.

There is no reason to assume that the New England type trawler will not be redesigned to become adapted to freezing fish at sea. Many engineering problems are involved, but they are not impossible of solution.

As the demand for higher quality frozen fish increases there is every reason to believe that the industry will take steps to convert its vessels into the freezer type so that this demand can be met.