

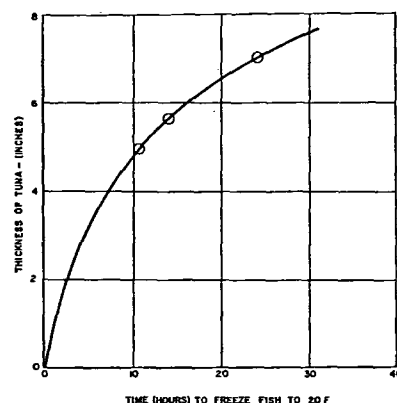


Fig. 2 . . . Freezing Time for Tuna Immersed in Brine

of direct immersion-freezing machines were developed for freezing whole or panned fish. These machines were generally unsuitable for freezing packaged fishery products, which make up the bulk of frozen fish production, and have been replaced by methods employing air cooling, contact with refrigerated plates or shelves, or combinations of these methods.

Immersion freezing is limited mostly to the freezing of tuna, shrimp, salmon, and halibut at sea and to the freezing of shrimp ashore. Extensive research has been conducted on brine-freezing groundfish aboard the vessel, but this method is not yet in commercial use.

An important consideration in immersion freezing of fish is the selection of a suitable freezing medium. The requirements of such a freezing medium are that it be: non-toxic, acceptable to public health regulatory agencies, easy to renew, inexpensive and have a low freezing temperature and viscosity. It is difficult to obtain a freezing medium that meets all of these requirements. For many years sodium chloride brine was the only freezing medium employed commercially in freezing fish. However, experiments by the Bureau of Commercial Fisheries yielded another acceptable freezing medium containing a mixture of glucose and salt in water. This medium reduces salt penetration into the fish and at the same time provides a protective glaze. More recently glycol and glycerine solutions have been used as freezing mediums. However, they have not as yet been used commercially for freezing fishery products because of their high cost.

Immersion freezing of shrimp. A very small quantity of the shrimp landed in the United States are immersion frozen both on the vessel and ashore. A glucose (20%)-salt (20%) solution is employed because it permits the shrimp to freeze individually without fusing together, and also minimizes salt penetration.

Commercial equipment is available for freezing shrimp aboard the fishing vessel. One system in general use employs a stainless steel tank located on the deck of the vessel. Refrigerant 12 circulating through evaporator coils located in one section of the tank provides the necessary refrigeration effect, maintaining the glucose-salt brine at temperatures of 0 to

-5 F. A hydraulically driven propeller inside the tank furnishes the necessary brine circulation. Shrimp, when landed on the vessel, are headed and washed, weighed in 50 or 25 lb lots and sorted into wire mesh freezer baskets. These baskets are then immersed in the brine within the freezing tank. After the proper freezing time elapses, about 15 minutes, the baskets are picked up and the shrimp put into 50, 25 lb or smaller sized cartons and stored in the refrigerated hold of the vessel.

There are several shore-side immersion systems used for freezing fresh, iced shrimp, unloaded from the fishing vessel. One system is similar to that just described for use on the vessel. The freezing tanks may be somewhat larger but essentially the shrimp are frozen in the same manner. Another type of immersion freezing system in use provides continuous freezing. This freezer employs a conveyor belt, located over a steel tank and serviced by a series of nozzles. The equipment is located within a heavily insulated enclosure. The shrimp to be frozen are placed on the conveyor belt. A glucose-salt brine, pumped from the steel tank reservoir through a heat exchanger where it is cooled to 0 F, is discharged from the spray nozzles located over the conveyor belt and flows over the shrimp, thereby freezing them.

Immersion freezing of tuna. The majority of the tuna harvested in this country are brine-frozen aboard the fishing vessel. Freezing at sea enables the fishing vessel to make the extended voyages necessary, because of the poor availability of tuna, and return to port with a full payload of high-quality fish.

Tuna are frozen in brine wells which are lined with galvanized pipe coils on the inside. Direct expansion of ammonia into the evaporator coils provides the necessary refrigeration effect. The wells are so designed that the tuna can first be precooled and washed with refrigerated sea water, and then frozen in an added sodium chloride brine. After the fish are frozen, the brine is pumped overboard and the tuna kept in 10 F dry storage. Prior to unloading, the fish are thawed in a 33 F brine on the vessel. In some cases the fish are thawed in tanks at the cannery. Therefore, if the fish are thawed ashore, thawing on the vessel is not required beyond the stage needed to separate those fused together in the vessel's wells.

In freezing tuna, sometimes the fish are held in the wells for a long period of time prior to freezing, or frozen at a very slow rate because of high well temperatures caused by overloading, insufficient refrigeration capacity or inadequate brine circulation. Any of these practices will have a detrimental effect on the quality of the product, especially the smaller fish which are more subject to salt penetration and quality changes. Tuna not promptly and properly frozen may absorb excessive quantities of salt, rendering them of inferior quality, and may even be bacteriologically spoiled when landed.

Studies by the Bureau of Commercial Fisheries show that tuna may require 5-72 hr to freeze, depending on the size of the fish and the freezing procedures used. Some freezing times for tuna of various sizes are shown in Fig. 2.

Immersion freezing of groundfish. An immersion freezing system for freezing New England groundfish was developed by the Bureau of Commercial Fisheries and installed on its vessel *Delaware*. Results of this research show that freezing groundfish at sea will enable the vessel to stay out until a full payload is obtained and return to port with top quality fish. In developing equipment and handling procedures for freezing fish at sea many technical problems were solved, resulting in the development of freezing and thawing techniques which will make possible the landing of frozen fish, which can be kept in cold storage and thawed, filleted and the fillets re-frozen and marketed as uniformly high quality fish.

In immersion freezing groundfish aboard the vessel *Delaware*,

Table 1 . . . Freezing Time for Whole Round Cod and Haddock, of Various Thicknesses, in Sodium Chloride Brine

Thickness ^a of Fish, in.	Approximate ^b Round Weight of Fish, Lb	Freezing Time Min	
		10 F	0 F
1 1/4	1-1 1/4	55	35
2	1 1/4-2 1/4	85	55
2 1/4	3-5	125	80
3	4 1/4-7 1/4	170	110
3 1/4	7-10	220	145
4	9-12	280	185

^a Side to side thickness (smallest diameter of a cross section at the point of maximum girth).

^b Round weight is generally 10-15 percent higher than is dressed weight.

store, a 23 percent sodium chloride brine was used as a freezing medium. The freezer consisted of a steel tank extending from above the deck to the bottom of the fish hold. The fish were washed with sea water, then put in the round into cylindrical galvanized metal mesh baskets located within the tank and connected at each end by a continuous chain drive. Movement of the baskets through the 0 F brine enabled constant renewal of the film of brine surrounding the fish, insuring rapid freezing.

A ratio of about 20-25 lb of fish per cu ft of basket space was used to prevent packing of this fish. When the proper freezing time elapsed (Table 1) the fish were removed from the individual freezing baskets (which are numbered), glazed with sea water, and put into the 0 F refrigerated hold. For maximum protection the frozen fish were glazed with fresh water during unloading, then transferred to wooden boxes for holding during frozen storage. For processing, the fish were moved from frozen storage and thawed by flooding the box, or a suitable thawing tank if used, with fresh potable water or clean sea water for three to four hours. The fish were then filleted by machine or hand, and the fillets are frozen and marketed. Tests conducted show that fillets from fish frozen at sea compare favorably with fish kept no more than a few days on ice. Fish of this latter level of quality are seldom available on a commercial scale.

Salt penetration studies showed that, as the brine temperature and the period of immersion increased, the salt penetration into the fish also increased. However, use of proper freezing procedures resulted in negligible increase in salt content of the fish.

In investigations on thawing it was found that rapid thawing in water removed most of the salt that penetrated into the fish during freezing and resulted in a firm, fresh fillet. Air thawing did not produce as satisfactory results from the standpoint of residual salt content and quality of thawed fish. In addition, glazing studies have shown that increased storage life can be obtained by washing the brine off the fish with sea water after they are frozen and reglazing the fish with fresh water during unloading from the vessel.

Freezing of salmon at sea was adapted on a commercial basis after World War II, so that the vessels could make longer trips and still land high quality fish. However, the success of refrigerated sea water in preserving fish in recent years has resulted in conversion of some freezer boats and construction of new vessels for storing fish in refrigerated sea water. The equipment, labor, and handling costs associated with the use of refrigerated sea water are much less than those for freezing fish at sea. Therefore, storage in refrigerated sea water might eventually replace freezing at sea, for species of fish such as halibut and salmon. These same techniques of holding fish in refrigerated brine have been tried to provide hold-over facil-

ties at the processing plant and show considerable promise in reducing plant operating costs without loss in quality of the raw material prior to processing.

Immersion freezing of salmon, and other species of fish. Some salmon are still brine-frozen in tanks or wells located in the vessel. The refrigeration effect is provided by ammonia or other suitable refrigerant flowing through pipe coils lining the insides of the tanks. A propeller type agitator or a brine pump provides the necessary brine circulation. A typical freezing operation is a 22 percent sodium chloride brine, made up in the freezer tank and then chilled to about 5 F. Round salmon are then brailed into the tank and allowed to freeze. After the fish are frozen (about eight hours is required for freezing) the brine is pumped to another tank for use in freezing additional quantities of fish. The frozen salmon may then be kept in the dry refrigerated tank for a few hours, providing sufficient refrigeration capacity is available. Transfer of the fish from the freezing tank to the 0 F refrigerated hold is then accomplished by removing a cover plate at the bottom of the tank and allowing the fish to flow from the tank, through an opening in the deck into the refrigerated hold.

CALCULATION OF REFRIGERATION REQUIREMENTS

The total refrigeration requirements for freezing fish or other food products can be determined by calculating the product load and the refrigerator heat load. The latter is due to heat gain through the insulated structure, air infiltration due to personnel usage, dissipation of electrical energy in the refrigerator space (lights, fans, motors, etc.) and losses due to equipment operating efficiency. The calculation of refrigerator heat load is discussed in Chapter 27 of the 1961 GUIDE AND DATA BOOK and would not vary appreciably between freezers for fish and other food products. Therefore, this section is concerned with only the refrigeration requirements that are necessary to remove the heat from fishery products and accomplish the necessary cooling and freezing.

The heat load required to freeze a product is:

$$Q = W[C(t_1 - t_2) + h_f + C_f(t_2 - t_3)] \quad (1)$$

where

Q = heat removed, Btu.

W = weight of product, pounds.

c = specific heat above freezing, Btu per (pound) (Fahrenheit degree).

c_f = specific heat below freezing, Btu per (pound) (Fahrenheit degree).

h_f = latent heat of fusion, Btu per pound.

t_1 = initial temperature of product, Fahrenheit.

t_2 = temperature at which the latent heat is removed from the product, Fahrenheit.

t_3 = final temperature of frozen product, Fahrenheit.

Example 1 illustrates the use of Equation 1. Specific heat, latent heat and freezing point of various fishery products are given in Table 2.

Example 1:

Determine heat, expressed in Btu, that must be removed to lower the temperature of 2000 lb of haddock fish fillets from 50-0 F.

Solution:

$$Q = W[C(t_1 - t_2) + h_f + C_f(t_2 - t_3)]$$

$$Q = 2000 [0.84(50 - 28) + 115 + 0.44(28 - 0)]$$

$$Q = 291,600 \text{ Btu.}$$

Thus to freeze 1 ton of fish from 50-0 F, 291,600 Btu are required. However, Equation 1 merely shows the Btu removed