Table 2 .... Average Water Content and Specific and Latent Heats of Various Fishery Products

Fish	Water Content %	Average Freezing Point, F	Specific Heat[a] Above Freezing, Btu/(Lb) (F deg)	Specific Heat[b] Below Freezing, Btu/(Lb)(F deg)	Latent Heat,[b] Btu/Lb
Whole Fish					
Haddock, Cod	78	28	0.82	0.43	112
Halibut	75	28	0.80	0.43	108
Tuna	70	28	0.76	0.41	100
Herring (kippered)	70	28	0.76	0.41	100
Herring (smoked)	64	28	0.71	0.39	92
Salmon	64	28	0.71	0.39	92
Menhaden	62	28	0.70	0.38	89
Fish Fillets or Steaks					
Haddock, Cod, Ocean perch	80	28	0.84	0.44	115
Hake, Whiting	82	28	0.86	0.45	118
Pollock	79	28	0.83	0.44	113
Mackerel	57	28	0.66	0.37	82
Shell Fish					
Scallop meat	80	28	0.84	0.44	115
Shrimp	83	28	0.86	0.45	119
American lobster	79	28	0.83	0.44	113
Oysters and Clams (meat and liquor)	87	28	0.90	0.46	125

[a] Calculated by Siebel's formula; for values above freezing $S = 0.008a + 0.20$; for values below freezing $S = 0.003a + 0.20$ where a = water content in percent, 0.20 = specific heat of solid constitutents of the substance.
[b] Values for latent heat (latent heat of fusion) in Btu per lb, calculated by multiplying the percentage of water content by the latent heat of fusion of water, 143.4 Btu.

from the product and does not take into consideration the time required for freezing.

The freezing time of a particular product varies with product temperature, size and shape, method of packaging, refrigeration capacity, method of heat transfer between product and cooling medium (*i.e.*, blast, plate, shelf or immersion freezer) and temperature of the cooling medium. These factors are so closely interrelated that it would be difficult to calculate exactly how much any one factor will affect the freezing time. The freezing time can best be determined by experimentation, recording the change in temperature of the particular sized product in question as it is being frozen in a plate, blast, shelf coil or immersion freezer (freezing times for various fishery products are given in Table 1 and Figs. 1, 2, and 3). Once the freezing time of a particular product has been determined the refrigeration capacity in Btuh can be calculated by dividing the heat withdrawn from the product (Btu) by the time required for freezing (hr). Tons of refrigeration can then be calculated by dividing the heat in Btu per hr, removed from the product by 12,000 Btu.

Assuming the product in *Example 1* represents a 1-in. thick, 1 lb package of haddock fish fillets and it is found that the time required to lower the product temperature from 50 to 0 F is 1 hr if plate-frozen and 2 hr if blast-frozen the refrigeration capacity (q) required to remove the heat from 1 ton of product would be determined in the following manner.

For *plate-frozen* fish fillets

$$q = Q/h = \frac{291{,}600}{1} = 291{,}600 \text{ Btuh}$$

$$\text{Tons of refrigeration} = \frac{291{,}600}{12{,}000} = 24.3$$

For *blast-frozen* fish fillets

$$q = Q/h = \frac{291{,}600}{2} = 145{,}800 \text{ Btuh}$$

$$\text{Tons of refrigeration} = \frac{145{,}800}{12{,}000} = 12.2$$

The refrigeration capacity necessary for product heat removal must be increased by 25 to 50 percent in order to compensate for heat leakage and other losses. The additional capacity necessary would vary with the particular refrigeration system.

STORAGE OF FROZEN FISH

Fishery products may undergo undesirable changes in flavor, odor, appearance, and texture during frozen storage. These changes are attributable to dehydration (moisture loss from the fish), oxidation of the oils or pigments and enzyme activity in the flesh. The rate at which these changes occur depends on (1) the composition of the particular species of fish; (2) the level and constancy of storage room temperature and humidity; and (3) the protection afforded the product through the use of suitable packaging materials and glazing compounds.

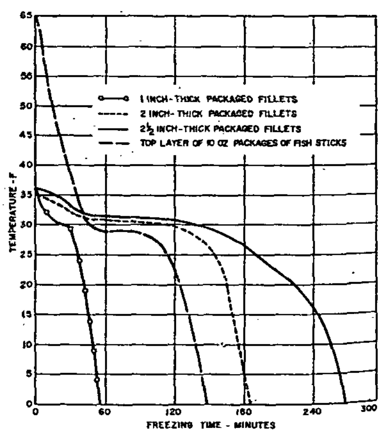

Fig. 3 .... Freezing Packaged Fish Fillets and Sticks in Plate Freezer

Effect of Composition on Quality

The composition of a particular species of fish affects its frozen storage life considerably. Fish having a high oil content, such as some species of salmon, tuna, mackerel and herring, have a comparatively short frozen storage life because of the development of rancidity due to the oxidation of the oils and pigments in the flesh. As often happens, there are certain fish, as sablefish, that, despite high oil content, are quite resistant to oxidative deterioration in frozen storage.

Table 3 .... Relative Susceptibility of Representative Species of Fish to Oxidative Changes in Frozen Storage

Severe	Moderate	Minor	Very Slight
Pink salmon	Flounders and *sole*	Haddock	Yellow pike
Lake chub	Herring	Cod	Yellow perch
	Mackerel	Oysters	Crab
	Chum salmon	Halibut	Lobster
	Sheepshead	Lake herring	
	Smelt	Sablefish	
	Ocean perch	Coho salmon	
	Lake trout	King salmon	
	Tuna	Red salmon	

The development of rancidity may be of less importance in those fish having a low oil content. Therefore lean fish such as haddock and cod, if handled properly, can be kept in frozen storage for many months without serious loss of quality. The relative susceptibility of various species of fish to oxidative changes during frozen storage is shown in Table 3.

Effect of Temperature on Quality

Frozen fish must be kept at 0 F or lower in order to insure adequate shelf life. Storage above 0 F, even for a comparatively short period of time, will result in rapid loss of quality. Time-temperature tolerance studies recently initiated by the U. S. Bureau of Commercial Fisheries show that frozen seafoods have *memory;* that is, each time they are subjected to high temperatures, or poor handling practices, the loss in quality is *recorded*. When the product is finally thawed, the total effect of each and all exposures to high temperatures or other mistreatments is reflected in the quality of the product at the consumer level. Continuous and maintained storage at temperatures lower than 0 F reduces oxidation, dehydration and enzyme changes resulting in longer product shelf life. It is important therefore that frozen seafoods be kept at temperatures as close to 0 F as possible from the time frozen until reaching the consumer.

Information of the shelf life of frozen fishery products stored at different temperatures is given in Table 4.

For many years it was thought too costly to operate refrigerated warehouses lower than 0 F. However, in recent years improvements in the design and operation of refrigeration equipment have made operation of refrigerated warehouses at −10 F and −20 F economically possible. Many new warehouses are now being operated at −10 F or lower.

Effect of Humidity on Quality

A high relative humidity in the cold storage room will tend to reduce the evaporation of moisture from the product. The relative humidity of the air in the refrigerated room is directly affected by the temperature difference between the room cooling coils and the room temperature. An increase in this temperature differential results in decreased relative humidity and accelerated rate of moisture withdrawal from the frozen product. Likewise, small temperature differences between the air and the evaporator cooling coils results in a high relative humidity and reduced moisture loss from the product. The following example illustrates how the design of the refrigerated warehouse governs the relative humidity. Assume the cooling coil temperature is calculated to be −10 F and the room operating temperature 0 F. Then, during operation, moisture in the 0 F air (dry bulb temp) will be deposited on the cooling coils in the form of frost until a state of equilibrium is reached, and the dew point temperature of the 0 F air is the same as the coil temperature. Air at 0 F with a dew point temperature of −10 F exerts a vapor pressure of 0.0108 psi. However, air completely saturated at 0 F has a dew point temperature of 0 F and exerts a vapor pressure of 0.0188. Therefore, the percent relative humidity for an empty room can be calculated by dividing the vapor pressure of the air at its dew point temperature (0.0108) by the vapor pressure of completely saturated air at its dry bulb temperature (0.0188). The relative humidity obtained would be 57.5 percent.

The relative humidity in commercial freezers is 10–20 percent higher than that of an empty freezer because of constant evaporation of moisture from the product. In a freezer operating at 0 F, with a 70 percent rh and pipe coil temp of −10 F, the moisture vapor pressure of the air within the package and in direct contact with the frozen fish would be 0.0188. The air in the freezer would, however, have a vapor pressure of 0.0132 and the moisture vapor pressure at the coils would be 0.0108. These differences in moisture vapor pressure will result in considerable moisture loss from the product unless it is adequately protected by suitable packaging materials or glazing

Table 4 .... Review of Effect of Storage Temperature on Shelf Life of Some Frozen Fishery Products

Product	Temperature, F	Shelf Life, Months	Product	Temperature, F	Shelf Life, Months
Packaged Haddock	10	4 to 5	Glazed Whole Halibut	10	3
	0	11 to 12		0	6
Fillets	−20	Longer than 12		−10	9
				−20	12
Packaged Cod Fillets	10	5	Whole Blue Fin Tuna	10	4
	0	6		0 to −5	8
	−10	10 to 11		−20	12
Packaged Pollock	10	1½ to 2	Glazed Whole Herring	0	6
	0	10		−17	9
Fillets	−20	Longer than 12			
Packaged Ocean Perch Fillets	15	1½ to 2	Packaged Mackerel Fillets	15	2
	10	3½ to 4		0	3
	0	6 to 8		−10	3 to 5
	−10	9 to 10			
Packaged Striped Bass Fillets	15	4	Glazed Blocks of Whale Meat	14	3
	0	9		5	6
				−4	12