REFRIGERATION OF FISH [1]

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[1] Appendix VIII to the Report of the U. S. Commissioner of Fisheries for 1926. Bureau of Fisheries Document No. 1016. Technological contribution No. 29.

INTRODUCTION

Cold is the nearest approach to an ideal preservative that we have. It has been employed from the most ancient times for preserving foods, jars of milk and butter in cool spring water, meats exposed to outside temperatures in winter, and melons and fruits in cool caves and cellers being ancient examples; but it was only with the development of machinery for producing and controlling cold artificially, beginning in the latter part of the last century, that cold was applied systematically and in a large way to the preservation of perishable foods. During the greater part of the time since the first practical ice machine was invented, attention and scientific study have been concentrated on the perfection of mechanical means of producing cold rather than on the best methods of utilizing cold to preserve various classes of foods. This order of progress is natural and logical, but the time has arrived when study is being directed more specifically to the best methods of applying cold to keep the various kinds of perishable commodities. The aim of this paper is to present and discuss the application of refrigeration to fish and sea foods as a special class in which sufficient progress has been made in recent years to justify such a presentation.

FUNCTION OF REFRIGERATION IN THE FISH INDUSTRY

Before artificial refrigeration was used as a method of preserving fish they were dried, salted, or pickled, and later were canned; but fish preserved by any of these methods are greatly changed and are suitable for special purposes only. They do not at all meet the demands for fresh fish. Refrigeration is the only method of preserving that keeps fish in essentially its original condition over long periods and during transportation over long distances.

Perhaps few who are not directly connected with the fish industry fully realize the importance of refrigeration in the distribution of fish to the consumer. Fish are highly perishable; yet if there were a regular and dependable supply, and if the demand for fish were also steady and continuous, there would be little need for artificial refrigeration. But both supply and and demand are highly irregular. Nearly all fishes are migratory; they have their seasons of abundance and scarcity; weather influences the capture and chance plays an important part in locating the schools of fish. Many fishes, like the mackerel, may be taken in diminishing numbers from year to year, and then, all of a sudden, appear in tremendous abundance, choking the market and demoralizing prices.

The demand for fish also is subject to marked fluctuations because of social, racial, and sectarian customs. In summer, when fish are generally abundant and the weather is fair, the popular demand declines and fish move much more slowly in the markets than they do in winter. In the Lenten season often more fish are demanded than can be obtained from the local supply. Friday has become, by long custom, the fish day of the week. The causes that influence fluctuations in demand bear no relation whatever to the causes that control the supply. Under such circumstances refrigeration is absolutely necessary in order that the industry may meet the demand with the available supply without ruinous waste.

It is natural that when fish are present in abundance the fisherman will catch all he can. If hundreds of other fishermen are doing the same thing (as they must to earn their living), the market may be glutted, and but for refrigeration it would be necessary to dump edible fish because of a lack of market. Refrigeration is thus an agency of conservation of no little importance.

POPULAR OBJECTIONS TO FROZEN FISH

Little need be said here of the widespread suspicion of frozen or cold-storage fish if special pleading is to be avoided. In so far as these objections are based on impaired edible quality, pleadings are of no avail—the grounds for objection must be removed. Many refinements and improvements already have been introduced in the art, other improvements are known and will be put into practice, and research may be expected further to advance and perfect the art. If this treatise hastens the introduction of improvements, it will serve well its purpose.

EFFECT OF REFRIGERATION ON THE PRICES OF FISH

There is also a popular conception—or, perhaps, misconception—that refrigeration raises the price of fish unfairly. If this were true, the immense refrigeration industry would rest on an unsound economic basis. After all, the price of fish, like that of other commodities, is fixed by the interaction of supply and demand. Refrigeration increases neither supply nor demand. Without it prices would be disastrously low in glutted markets and exorbitantly high in seasons of scarcity. Refrigeration serves to spread the supply over the year at a comparatively uniform price. If the year's supply exceeds the year's demand, prices drop. Fish that otherwise would be dumped are saved. The cost of refrigeration is undoubtedly a proper charge for a valuable service rendered.[2]

HISTORY OF REFRIGERATION OF FISH[3]

Until the early part of last century, when ice came into use, refrigeration was not applied to the preservation of fish in any systematic way. In northern latitudes fish were allowed to freeze naturally in winter and were transported frozen to market. Fresh fish were kept as cool as possible with wet seaweed. Between 1820 and 1850 natural ice came into use, and transportation facilities were developed. The cooling of fish with ice began in 1838 at Gloucester, Mass., when a

[2] For data and discussion of the economics of cold storage see G. K. Holmes, Cold Storage Business Features, Bulletin 93, and Cold Storage and Prices, Bulletin 101, U. S. Department of Agriculture, Washington.

[3] For an account of the history of the refrigeration of fish up to 1900 see Modern Refrigeration of Food and Drinks—Refrigeration of Fish. Ice and Refrigeration, Vol. XXI, 1901, pp. 91–94, Chicago. Also, Preservation of Fishery Products for Food, by Chas H. Stevenson. Bulletin, United States Fish Commission, Vol. XVIII, 1898 (1899), pp. 335–563. Washington.

halibut smack first carried ice. The practice came into more general use in 1845. At first the ice was kept in a corner of the hold, separate from the fish, because of a prejudice against iced fish. Eventually it was found that ice in contact did not materially affect the fish, which were thenceforth packed in ice. Because of the prejudice against iced fish (such as we now encounter against frozen fish) iced packages were not shipped until 1858, when New England dealers shipped iced fish as an experiment to New York City; the practice rapidly grew, and a large trade was quickly developed.

Enoch Piper [4], of Camden, Me., was first to freeze fish artificially. He laid out the fish in racks in an insulated chamber and set pans of crushed ice and salt mixture on them, which froze the fish in about 24 hours. The frozen fish, after being glazed by a dip in cold water, were transferred to an insulated chamber provided with vertical metallic tubes filled with the freezing mixture to keep the fish frozen until used. He improved his process in a patent of 1862.[5]

In 1866 and 1867 Charles F. Pike,[6] of Providence, R. I., applied similar principles to refrigeration aboard ship.

The method of freezing fish in cakes, by packing them in pans or molds to be placed in freezing chambers, was originated by David W. and Samuel H. Davis,[7] of Detroit, Mich. In the earlier form of the invention the pans were truncated cones of such size and shape as to make a series of cakes just to fit a barrel in which the frozen fish were shipped. In 1880 D. W. Davis [8] patented a method of packing fish in finely crushed ice in a barrel and subjecting the entire barrel to refrigeration to freeze the contents to a solid mass. D. W. Davis's work culminated in 1902 [9] in the invention of a process of freezing in a rectangular pan, the pan being covered with a lid, packed in an ice-and-salt mixture for freezing, the frozen cake removed with the aid of water, glazed in cold water, and stored. Aside from the freezing in ice and salt this is essentially the method in widespread use to-day.

In 1876 Robert C. Armstrong [10] patented a shipping package consisting of a small barrel inside a larger one, with sawdust between the two, and an outlet pipe. Fish and ice were put in the smaller barrel and the whole was headed for shipment.

Numerous other patents and improvements came forth in the eighties and nineties, relating to various methods of freezing, the discussion of which will fall more logically in this paper in the sections devoted to special processes of freezing and will be treated elsewhere. Meanwhile, the most important step in the artificial refrigeration of fish was the introduction of refrigerating machines using ammonia, which came into use for freezing and storing fish in 1892 at Sandusky, Ohio. Since that time, and particularly since the beginning of the present century, the method of freezing fish in cold rooms has come into widespread use.

In 1879 winter-frozen salmon were first shipped to England by Sir Charles Petrie, but for lack of suitable storage facilities in

[4] U. S. Patent 31736, Mar. 19, 1861.
[5] U. S. Patent 36107, Aug. 5, 1862.
[6] U. S. Patent 72894, Dec. 31, 1867.
[7] U. S. Patent 161596, Apr. 6, 1875.
[8] U. S. Patent 226890, Apr. 13, 1880.
[9] U. S. Patent 709751, Sept. 23, 1902.
[10] U. S. Patent 178094, May 30, 1876.

that country the venture was not successful. By 1888 fish were frozen in large quantities at Astrakhan, Russia, and numerous warehouses were opened in various European cities for this trade. In 1894 artificially frozen steelhead salmon were first shipped from Vancouver, British Columbia, to England. In the following year close upon 6,000,000 pounds of salmon, halibut, and sturgeon were frozen in British Columbia, and more than 1,000,000 pounds were shipped to Europe, principally to Hamburg. In this same year, Sir Charles Petrie began his importations of Loggie salmon into England.

By the beginning of the present century the fish-freezing industry was well established, since which time it has expanded to a large business, conducted in various parts of the world, reaching its highest development in the United States and Canada. Immense warehouses are now filled with frozen fish, large cargoes cross the ocean, and highly elaborate and expensive machinery is built to furnish the refrigeration. The art of freezing and transporting fish has been refined by engineers, chemists, and practical men until it is now an industry of which we may well be proud.

In 1889 two Englishmen, Hesketh and Marcet,[11] patented the process of freezing meat, fish, etc., which consists of immersing them in cold brine or inclosing them in hollow-walled cells, with cold brine circulating in the walls. In the same year two other Englishmen—Douglas and Donald[12]—patented the freezing of foods by inclosing them in bags, immersing them in water, and freezing. Nothing came of these inventions at the time, but the idea was revived later by numerous inventors. It was upon the discovery several years ago that rapid freezing produces frozen fish of much better quality, that serious and widespread attention was given to these and similar methods. Numerous patents have been issued and several of the newer methods are in practical application. These will be considered more fully later.

STATISTICS OF FISH FROZEN IN THE UNITED STATES

The amount of fish frozen annually in the United States comes close upon 100,000,000 pounds. The year 1924 was the record year, with 97,324,144 pounds frozen. In 1925 the total was 91,165,068 pounds. Of this amount 54.95 per cent were six varieties—ciscoes, halibut, the salmons, lake trout, mackerel, and whiting. The remainder is made up largely of squid, the pikes and pike perches, shellfish, whitefish, and butterfish. Receipts at the warehouses begin to exceed the withdrawals in May, and from then until November the holdings rapidly increase, particularly from July to November. In November, 1925, 61,849,359 pounds were in storage. Withdrawals exceed receipts from November to April. In the latter month in 1925 holdings had been reduced to 22,441,873 pounds from the holdings in November, 1924, which were 70,405,786 pounds. When allowance is made for the fish frozen during that period, amounting to 22,309,214 pounds, there is shown a withdrawal of 70,273,127 pounds in the five months from November 15, 1924, to April 15, 1925. In 1925, between April 15 and November 15, 70,686,243 pounds were frozen and 31,278,757 pounds were withdrawn. The average hold-

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[11] British patent 6117, Apr. 9, 1889. [12] British patent 20614, Dec. 28, 1889.

ings for the year were 44,084,251 pounds. It is impossible to determine from the available statistics the average term of storage.

NUMBER AND LOCATION OF COLD-STORAGE WAREHOUSES THAT HANDLE FISH

According to such information as is available, there are in the United States 169 warehouses that handle frozen fish. Of this number 102 handle only fish while 67 handle fish and other goods. Many of these are private warehouses, several of them do a public business, and some of them combine a public and private business. The distribution of these warehouses is shown in Table 1.

TABLE 1.—*Cold storage warehouses that handle fish in the United States*

State, Territory, or district	Number of warehouses			State, Territory, or district	Number of warehouses		
	Fish only	Fish and other goods	Total		Fish only	Fish and other goods	Tota
Alaska	3		3	Mississippi	1		1
California	4	6	10	Nebraska	1	1	2
Colorado	1	1	2	New Jersey	1	3	4
Florida	2	1	3	New York	12	8	20
Georgia	1		1	Ohio	17	4	21
Illinois	1	4	5	Oklahoma	1		1
Iowa	1	1	2	Oregon	6	1	7
Kentucky		1	1	Pennsylvania	8	7	15
Louisiana		1	1	Rhode Island		1	1
Maine	4	1	5	Tennessee	2	1	3
Maryland		2	2	Virginia		3	3
Massachusetts	11	6	17	Washington	5	6	11
Michigan	8		8	Wisconsin	7	1	8
Minnesota	1	4	5				
Missouri	4	3	7	Total	102	67	169

GEOGRAPHICAL DISTRIBUTION OF THE FISH-FREEZING BUSINESS

The region of the United States where the largest amount of fish is frozen is the Pacific coast, including Alaska, where 31.12 per cent of the total was frozen in 1925. The New England States, with 26.94 per cent of the total, appear in the statistics as next in volume of fish frozen. In 1924 the Middle Atlantic States occupied second place, largely because of the ciscoes frozen in New York and Pennsylvania where these States border on the Great Lakes; but because of a large decrease in the amount of ciscoes frozen in 1925 this region fell behind in that year. The North Central divisions, east and west, which include the Great Lakes region (except those parts of New York and Pennsylvania already referred to), together account for 18.79 per cent of the total in 1925.

It is significant that the South Atlantic and Gulf States freeze only the negligible quantity of a little more than 1 per cent of the total. The southern Pacific region also freezes very little, the amount not being shown separately.

In Canada the distribution of the industry is similar to that in the United States. In British Columbia there are large freezers whose business is chiefly in salmon, halibut, and black cod. Along the Great Lakes whitefish, lake trout, and ciscoes make up the bulk, while in the eastern Provinces salmon, eels, herring, and smelts constitute the greater part of the frozen fish.

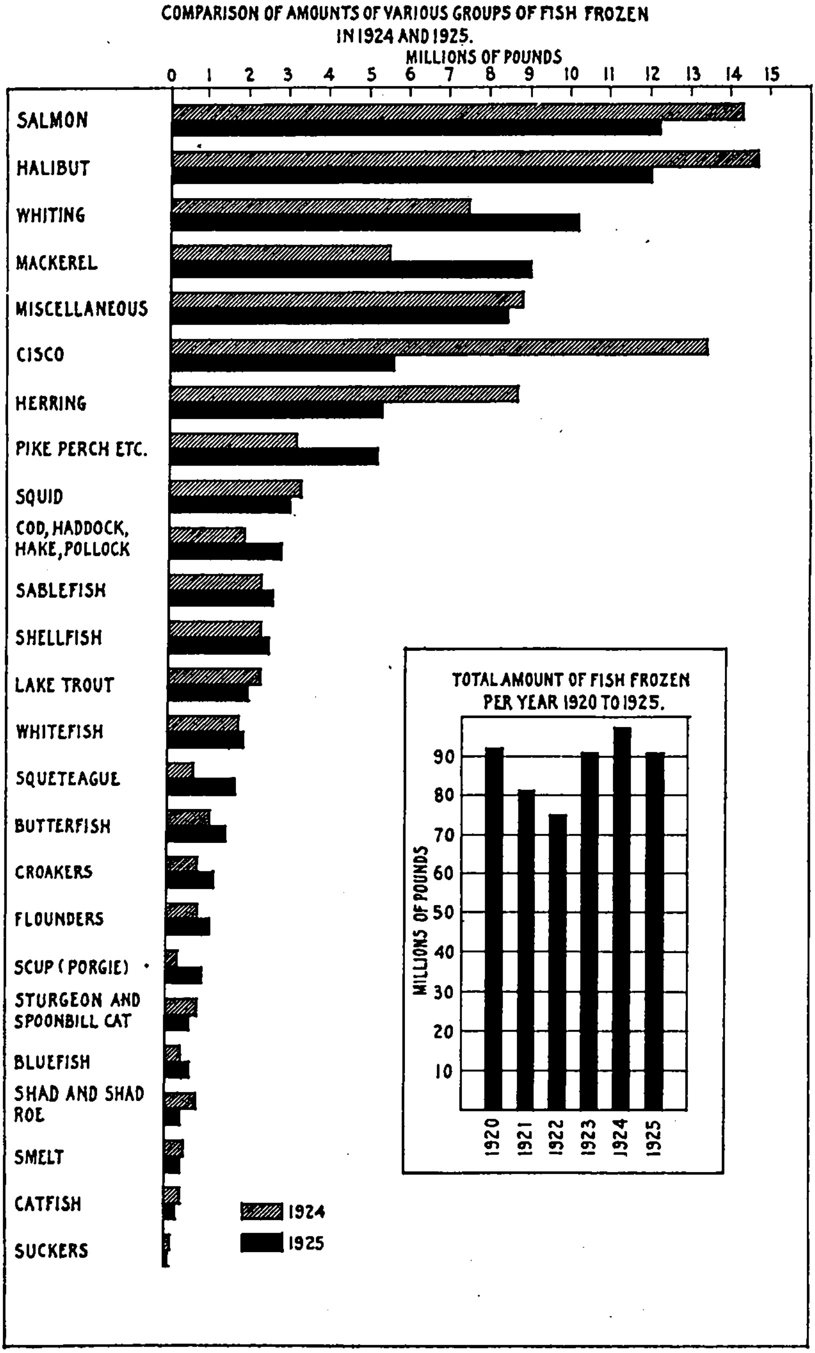
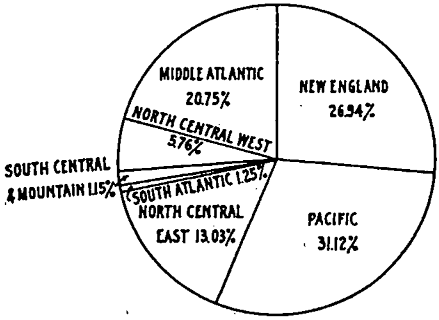

COMPARISON OF AMOUNTS OF VARIOUS GROUPS OF FISH FROZEN IN 1924 AND 1925.
MILLIONS OF POUNDS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
SALMON
HALIBUT
WHITING
MACKEREL
MISCELLANEOUS
CISCO
HERRING
PIKE PERCH ETC.
SQUID
COD, HADDOCK, HAKE, POLLOCK
SABLEFISH
SHELLFISH
LAKE TROUT
WHITEFISH
SQUETEAGUE
BUTTERFISH
CROAKERS
FLOUNDERS
SCUP (PORGIE)
STURGEON AND SPOONBILL CAT
BLUEFISH
SHAD AND SHAD ROE
SMELT
CATFISH
SUCKERS
1924
1925
TOTAL AMOUNT OF FISH FROZEN PER YEAR 1920 TO 1925.
MILLIONS OF POUNDS
90
80
70
60
50
40
30
20
10
1920
1921
1922
1923
1924
1925

Fig. 1

In general, the more expensive varieties are frozen—salmon, halibut, whitefish, mackerel, etc. Herring, and to some extent squid, are frozen for bait. Ciscoes are frozen almost entirely for smoking purposes. Whiting are frozen to meet the demand in the Central States, while much of the frozen salmon is exported to Europe. The United States are principally exporters rather than importers of frozen fish.

The detailed statistics of fish frozen in the United States are given in Tables 2, 3, 4, and 5. Figure 1 gives a comparison of amounts of various groups of fish frozen in 1924 and 1925. The percentage of the total amount of fish frozen by the several sections of the United States in 1925 is shown by Figure 2.[18]



PERCENTAGE OF THE AMOUNT OF FISH FROZEN BY THE SEVERAL SECTIONS OF THE UNITED STATES IN 1925.

FIG. 2

TABLE 2.—*Fish frozen monthly in 1925, by species, and in 1920–1924, by totals* [a]

Species	Month ended—						
	Jan. 15	Feb. 15	Mar. 15	Apr. 15	May 15	June 15	July 15
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bluefish (all trade sizes)	94,746	600	14,493	3,810	11,082	12,512	41,705
Butterfish (all trade sizes)	7,320			1,781	8,327	146,666	141,856
Catfish	6,454	1,577	7,784	11,127	98,698	38,594	50,563
Ciscoes (including bluefin, blackfin, chub, lake herring, etc.)	1,026,651	90,562	42,969	149,517	76,309	94,422	63,018
Ciscoes (tullibees)	185,599	91,457	110,312	55,955	36,000	246	2,618
Cod, haddock, hake, pollock	134,607	113,170	175,122	326,679	315,094	122,485	105,106
Croakers	2,100		414	1,500	411,470	69,399	395,532
Flounders	57,168	21,492	37,633	85,394	211,581	206,834	117,072
Halibut (all trade sizes)	453,098	121,227	1,533,414	1,339,498	869,324	1,923,334	1,344,419
Herring, sea (including alewives and bluebacks)	150,625	421,342	224,231	9,096	375,773	244,624	492,886
Lake trout	217,945	50,653	29,884	12,862	63,460	107,333	142,065
Mackerel (except Spanish)	90,220	26,640	48,167	72,251	101,784	1,916,841	648,501
Pike perches and pike or pickerel	321,847	76,174	126,076	65,421	574,547	477,060	59,218
Sablefish (black cod)	72,992	19,359	54,399	8,718	85,920	89,786	387,501
Salmon:							
Silver and fall	154,958	16,651	68,967	45,636	141,587	332,156	446,572
Steelhead trout		23,160	7,600	16,675	2,933	19,670	237,511
All other	42,896	10,314	74,452	1,288,787	87,811	588,269	1,040,399
Scup (porgies)					78,885	838,838	353,875
Shad and shad roe	620	1,724	8,540	21,506	91,494	204,954	17,865
Shellfish	236,627	117,497	101,149	82,051	191,345	143,401	174,639
Smelts, eulachon, etc	83,747	34,296	42,493	39,366	8,918	22,602	505
Squeteagues or "sea trout"	2,601				142,615	131,430	38,001
Squid		287	49,120	540	499,790	1,277,225	375,289
Sturgeon and spoonbill cat	19,865	6,579	14,624	14,553	71,215	62,226	107,540
Suckers	7,635	2,335	26,850	973	464	3,178	223
Whitefish	79,583	103,834	295,701	186,489	88,131	65,338	139,987
Whiting	12,119	410,386	178,199	74,460	299,991	1,410,344	3,657,351
Miscellaneous frozen fish	470,530	432,105	220,280	400,236	913,059	800,653	640,058
Total frozen fish, 1925	3,932,553	2,193,421	3,487,823	4,314,881	5,857,557	10,799,920	11,221,875
Total frozen fish, 1924	3,179,098	2,440,163	2,417,473	2,729,366	6,040,261	8,281,516	11,996,011
Total frozen fish, 1923	2,741,538	1,662,185	1,412,490	1,400,078	5,026,888	7,671,127	11,871,645
Total frozen fish, 1922	2,441,892	1,452,801	1,363,942	1,496,538	1,980,435	5,849,537	7,376,237
Total frozen fish, 1921	4,005,000	2,843,000	1,770,000	2,413,000	2,698,000	9,624,000	10,151,000
Total frozen fish, 1920	2,291,082	2,273,744	2,630,482	2,465,375	3,687,536	10,094,367	12,761,791

[a] These figures have been revised in accordance with further reports received since original publication of data for the month.

[18] Tables taken from Fishery Industries of the United States, 1925, by Oscar E. Sette. Appendix V, Report, U. S. Commissioner of Fisheries for 1926. Bureau of Fisheries Document No. 1010. Figs. 1 and 2 furnished by the U. S. Bureau of Fisheries.

TABLE 2.—*Fish frozen monthly in 1925, by species, and in 1920–1924, by totals*—Continued

Species	Month ended—					Total	Per cent of total
	Aug. 15	Sept. 15	Oct. 15	Nov. 15	Dec. 15		
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
Bluefish (all trade sizes)	16,638	28,708	267,703	74,196	3,110	569,303	0.62
Butterfish (all trade sizes)	113,372	812,835	640,238	94,069	53,184	1,519,648	1.67
Catfish	3,377	5,861	8,587	81,380	7,627	271,579	.30
Ciscoes (including bluefin, blackfin, chub, lake herring, etc.)	162,156	66,161	44,388	1,091,342	1,845,344	4,752,839	5.21
Ciscoes (tullibees)	8,810	9,634	182,063	74,192	71,548	828,434	.91
Cod, haddock, hake, pollock	179,369	631,744	226,930	330,472	120,641	2,781,419	3.05
Croakers	157,523	122,773	2,442	53,899	4,436	1,221,488	1.34
Flounders	109,843	120,000	30,859	47,527	78,504	1,123,407	1.23
Halibut (all trade sizes)	1,432,984	1,419,346	729,794	395,244	479,473	12,041,155	13.21
Herring, sea (including alewives and bluebacks)	158,145	1,017,650	706,028	959,502	504,367	5,264,269	5.77
Lake trout	138,145	112,811	209,140	790,488	180,995	2,055,781	2.26
Mackerel (except Spanish)	1,989,476	2,472,091	952,611	401,849	228,416	8,948,297	9.82
Pike perches and pike or pickerel	99,413	99,584	230,277	2,187,898	916,140	5,233,655	5.74
Sablefish (black cod)	347,438	274,830	625,904	557,624	144,575	2,619,046	2.87
Salmon:							
Silver and fall	777,276	436,788	949,721	966,997	211,148	4,548,457	4.99
Steelhead trout	610,097	373,104	128,974	33,621	28,033	1,481,378	1.62
All other	1,057,206	812,276	517,354	515,532	88,384	6,123,680	6.72
Scup (porgies)	112,047	2,148	12,612	128	1,500	899,528	.99
Shad and shad roe	4,587	137	133	2,187	2,500	351,247	.39
Shellfish	221,882	278,222	324,423	311,678	273,704	2,456,618	2.69
Smelts, eulachon, etc	4,380	21,288	18,359	47,988	26,738	350,680	.38
Squeteagues or "sea trout"	149,443	465,966	650,306	66,415	650	1,647,427	1.81
Squid	216,097	211,870	220,497	65,909	98,769	3,015,393	3.31
Sturgeon and spoonbill cat	100,761	67,699	85,917	50,722	2,408	604,109	.66
Suckers	2,455	2,847	2,962	8,276	12,801	70,999	.08
Whitefish	45,874	42,772	11,032	642,339	155,918	1,856,998	2.04
Whiting	2,223,927	268,757	253,495	973,701	390,069	10,152,799	11.13
Miscellaneous frozen fish	459,266	1,916,761	560,782	942,540	619,165	8,375,435	9.19
Total frozen fish, 1925	10,901,987	11,594,663	8,593,031	11,717,710	6,550,147	91,165,068	100.00
Total frozen fish, 1924	15,541,641	10,585,272	14,877,934	10,854,873	8,380,536	97,324,144	------
Total frozen fish, 1923	13,943,978	16,417,132	12,511,606	6,951,639	9,938,387	91,548,643	------
Total frozen fish, 1922	9,121,160	10,826,942	16,830,080	9,344,469	7,069,995	75,154,028	------
Total frozen fish, 1921	9,845,000	9,356,000	9,990,000	9,869,000	8,173,000	80,737,000	------
Total frozen fish, 1920	13,620,232	11,803,606	11,168,810	9,711,800	9,750,844	92,259,671	------

TABLE 3.—*Monthly holdings of frozen fish in the United States in 1925, by species, and in 1917–1924, by totals*

Species	Month ended—					
	Jan. 15	Feb. 15	Mar. 15	Apr. 15	May 15	June 15
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bluefish (all trade sizes)	287,873	196,732	67,264	32,193	48,655	59,715
Butterfish (all trade sizes)	480,051	365,363	253,829	94,848	48,106	154,945
Catfish	172,927	101,070	44,661	38,352	124,441	131,846
Ciscoes (including bluefin, blackfin, chub, lake herring, etc.)	7,623,852	5,830,439	3,887,880	2,067,075	1,315,934	1,008,189
Ciscoes (tullibees)	853,357	802,836	985,698	1,046,781	969,132	883,460
Cod, haddock, hake, pollock	795,276	605,187	509,747	651,839	796,798	804,987
Croaker	129,765	89,766	19,123	3,754	440,435	478,656
Flounders	336,226	245,819	248,923	274,889	489,848	608,082
Halibut (all trade sizes)	8,507,465	5,740,740	4,108,588	4,402,656	5,179,520	7,206,590
Herring, sea (including alewives and bluebacks)	3,776,670	3,827,486	2,132,352	828,812	785,586	819,447
Lake trout	1,610,461	1,235,694	773,277	410,344	417,885	556,574
Mackerel (except Spanish)	3,241,991	2,483,916	1,553,862	854,320	711,726	2,456,607
Pike perches and pike or pickerel	1,324,998	1,016,647	618,509	324,360	722,773	1,199,810
Sablefish (black cod)	1,038,382	678,081	872,163	592,085	568,261	224,954
Salmon:						
Silver and fall	4,126,643	3,476,931	1,940,826	1,097,303	846,995	1,184,307
Steelhead trout	310,609	267,091	247,745	174,789	96,906	103,492
All other	4,886,949	3,948,546	2,022,251	2,836,151	2,617,159	2,908,282
Scup (porgies)	65,835	24,076	10,047	3,679	80,074	401,183
Shad and shad roe	713,394	789,288	522,909	474,252	611,105	762,217
Shellfish	1,278,772	1,227,341	1,018,057	702,089	656,750	667,756
Smelts, eulachon, etc	522,242	503,278	747,700	862,171	779,707	765,886
Squeteagues or "sea trout"	306,138	164,144	33,315	13,214	152,634	263,473
Squid	1,532,879	1,238,888	840,105	199,876	574,285	1,764,218
Sturgeon and spoonbill cat	497,454	466,696	303,490	244,440	273,737	306,296
Suckers	42,107	40,059	49,993	31,448	29,983	32,458
Whitefish	1,951,795	1,745,562	1,743,448	1,294,723	1,224,435	1,132,629
Whiting	2,780,416	2,296,944	1,834,682	827,252	848,234	2,033,689
Miscellaneous frozen fish	6,113,065	4,676,880	2,974,669	2,059,178	2,343,723	3,060,426
Total, 1925	55,307,587	44,034,450	29,864,613	22,441,873	23,749,277	31,979,574
Total, 1924	52,627,290	40,420,614	29,570,628	21,488,525	21,839,714	27,115,359
Total, 1923	40,032,255	27,069,882	16,723,513	10,589,532	12,312,003	17,779,934
Total, 1922	48,320,212	37,742,262	25,474,714	17,484,975	17,075,917	20,821,845
Total, 1921	53,851,000	42,116,000	33,404,000	28,440,000	26,346,000	32,311,000
Total, 1920	61,510,857	47,904,057	29,958,132	20,632,834	19,803,817	27,779,280
Total, 1919	80,683,761	67,617,478	50,036,475	37,110,856	37,174,104	48,840,859
Total, 1918	51,116,037	35,907,071	28,457,301	26,548,272	31,403,425	50,298,027
Total, 1917	32,234,530	14,727,099	13,374,429	9,516,217	14,040,024	27,791,047

TABLE 3.—*Monthly holdings of frozen fish in the United States in 1925, by species, and in 1917–1924, by totals*—Continued

Species	Month ended—					
	July 15	Aug. 15	Sept. 15	Oct. 15	Nov. 15	Dec. 15
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bluefish (all trade sizes)	135,699	95,285	103,139	335,288	474,565	547,724
Butterfish (all trade sizes)	275,866	387,932	715,684	1,294,183	1,247,847	1,056,582
Catfish	151,328	111,904	110,507	95,055	105,863	82,448
Ciscoes (including bluefin, blackfin, chub, lake herring, etc.)	746,398	833,540	684,706	539,609	1,541,644	3,180,117
Ciscoes (tullibees)	853,362	824,855	764,274	573,041	510,488	451,232
Cod, haddock, hake, pollock	820,537	926,122	1,582,536	1,564,557	1,523,124	1,104,155
Croaker	1,118,090	1,218,590	1,111,570	866,730	775,331	534,764
Flounders	691,281	745,878	824,185	775,410	710,311	647,035
Halibut (all trade sizes)	8,448,458	9,752,570	10,616,852	10,995,236	9,400,480	7,038,674
Herring, sea (including alewives and bluebacks)	1,109,606	991,553	2,018,314	2,481,383	2,951,672	3,253,802
Lake trout	746,417	819,352	840,348	987,468	1,850,380	2,143,548
Mackerel (except Spanish)	2,880,270	4,596,567	6,867,043	7,643,432	6,910,402	5,342,937
Pike perches and pike or pickerel	1,000,495	825,002	716,983	863,897	2,952,476	3,842,287
Sablefish (black cod)	532,061	851,587	1,082,614	1,601,240	2,145,559	2,153,802
Salmon:						
Silver and fall	1,558,764	2,142,690	2,462,339	3,210,257	3,840,903	3,379,724
Steelhead trout	331,904	654,497	652,261	841,464	730,774	644,580
All other	3,569,736	4,464,728	5,133,344	5,360,481	5,036,230	4,257,296
Scup (porgies)	667,853	736,385	699,321	672,325	544,926	419,557
Shad and shad roe	763,710	749,935	687,870	734,651	702,123	672,014
Shellfish	637,127	733,080	795,964	927,355	1,081,106	1,267,692
Smelts, eulachon, etc	717,405	568,334	583,681	578,451	582,812	650,393
Squeteagues or "sea trout"	366,233	481,108	1,029,771	1,638,534	1,615.814	1,296,381
Squid	2,028,068	2,110,170	2,034,939	2,079,704	1,870,558	1,597,404
Sturgeon and spoonbill cat	365,510	444,625	408,970	403,623	376,572	298,560
Suckers	30,837	32,906	34,282	36,467	43,792	51,104
Whitefish	1,282,559	1,373,567	1,393,188	1,327,803	1,907,364	2,315,779
Whiting	5,208,604	7,065,724	7,022,677	6,700,948	6,773,678	6,144,851
Miscellaneous frozen fish	3,419,991	2,935,029	4,469,186	3,229,172	3,642,565	3,673,838
Total, 1925	40,458,169	47,473,515	55,446,548	58,357,764	61,849,359	58,048,280
Total, 1924	36,036,010	49,026,140	56,606,759	67,024,996	70,405,786	68,324,572
Total, 1923	27,237,105	39,100,868	53,220,398	62,616,212	63,457,565	64,289,945
Total, 1922	25,620,042	32,226,170	41,141,144	54,756,783	54,502,283	48,689,830
Total, 1921	40,160,000	47,431,000	54,469,000	58,899,000	61,228,000	59,125,646
Total, 1920	36,617,706	47,140,132	56,295,975	64,730,531	67,549,377	65,841,000
Total, 1919	59,674,301	65,145,234	69,580,555	76,763,253	78,769,101	74,202,339
Total, 1918	64,864,532	82,554,798	89,203,946	93,811,909	99,631,789	96,600.247
Total, 1917	38,431,221	44,024,666	47,197,660	60,676,722	70,938,957	69,986,671

TABLE 4.—*Fish frozen in 1925, by geographical sections and by months*[1]

Month ending the 15th of—	New England	Middle Atlantic	South Atlantic	North Central, East	North Central, West	South Central and Mountain	Pacific	Total	Per cent
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
January	203,523	1,180,883	20,778	1,685,205	407,656	102,816	331,692	3,932,553	4.31
February	305,352	284,905	15,780	344,941	637,455	125,603	479,385	2,193,421	2.41
March	153,001	281,922	14,350	911,939	354,174	90,735	1,681,702	3,487,823	3.83
April	460,556	339,903	13,850	605,821	281,937	108,190	2,504,624	4,314,881	4.73
May	1,307,604	1,842,571	147,466	860,186	328,475	151,127	1,220,128	5,857,557	6.43
June	8,659,546	3,191,453	71,630	557,356	150,897	115,403	3,053,635	10,799,920	11.85
July	4,870,932	1,590,684	190,208	385,089	374,993	108,040	3,701,429	11,221,875	12.31
August	4,662,590	1,075,488	163,121	366,714	260,868	66,909	4,306,297	10,901,987	11.96
September	4,203,276	1,717,800	275,070	298,216	324,521	45,545	4,730,235	11,594,663	12.72
October	2,121,635	2,392,983	109,936	474,231	410,097	26,496	3,057,653	8,593,031	9.43
November	1,838,686	3,945,272	76,578	2,613,414	769,258	25,814	2,448,688	11,717,710	12.85
December	774,297	1,072,256	38,411	2,771,552	949,431	84,106	860,094	6,550,147	7.17
Total	24,560,998	18,916,120	1,137,178	11,874,664	5,249,762	1,050,784	28,375,562	91,165,068	
Per cent of total	26.94	20.75	1.25	13.03	5.76	1.15	31.12		100.00

[1] New England includes the 6 States of that section; Middle Atlantic—New York, New Jersey, and Pennsylvania; South Atlantic—Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida; North Central, East—Ohio, Indiana, Illinois, Michigan, and Wisconsin; North Central, West—Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas; South Central and Mountain—Kentucky, Tennessee, Alabama, Mississippi, Louisiana, Texas, Oklahoma, Arkansas, Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada; Pacific—Washington, Oregon, California, and Alaska.

TABLE 5.—*Fish frozen in 1925, by geographical sections and by species*

Species	New England	Middle Atlantic	South Atlantic	North Central East	North Central West	South Central and Mountain	Pacific	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bluefish (all trade sizes)	4,439	441,766	....	115,568	....	7,530	....	569,303
Butterfish (all trade sizes)	153,775	1,311,983	29,097	24,633	160	....	....	1,519,648
Catfish	19,135	8,688	....	53,761	175,742	14,253	....	271,579
Ciscoes (including bluefin, blackfin, chub, lake herring, etc.)	11,696	977,531	....	3,108,701	636,286	18,625	....	4,752,839
Ciscoes (tullibees)	25,445	219,431	14,220	401,751	105,673	2,312	59,602	828,434
Cod, haddock, hake, pollock	1,613,233	483,298	13,730	85,356	106,814	....	478,988	2,781,419
Croakers	414	804,806	346,123	70,145	....	....	....	1,221,488
Flounders	427,906	585,383	....	10,387	22	....	99,709	1,123,407
Halibut (all trade sizes)	419,904	323,368	4,828	1,829,191	184,467	2,400	9,776,997	12,041,155
Herring, sea (including alewives and bluebacks)	4,002,057	398,667	55,000	178,288	249,987	2,151	378,119	5,264,269
Lake trout	3,995	377,536	....	1,351,820	287,653	4,085	30,692	2,055,781
Mackerel (except Spanish)	6,526,800	1,547,301	12,250	140,841	59,397	....	661,708	8,948,297
Pike perches and pike or pickerel	2,795	3,124,869	....	1,935,443	165,848	75	4,625	5,233,655
Sablefish (black cod)	....	900	....	25,096	41,719	....	2,551,331	2,619,046
Salmon:								
Silver and fall	183,314	153,871	100	222,083	106,054	....	3,883,035	4,548,457
Steelhead trout	....	18,581	....	817	....	....	1,461,980	1,481,378
All other	341,183	137,454	....	238,847	49,272	30,066	5,326,858	6,123,680
Scup (porgies)	238,292	658,792	....	....	1,500	....	944	899,528
Shad and shad roe	59,765	95,775	....	22,127	4,402	1,240	167,938	351,247
Shellfish	557,273	637,957	160,453	354,542	131,517	7,889	606,987	2,456,618
Smelts, eulachon, etc.	69,672	26,247	....	128,441	3,605	....	122,715	350,680
Squeteagues or "sea trout"	140	1,518,600	128,037	....	....	650	....	1,647,427
Squid	2,524,318	438,393	....	43,210	9,185	....	287	3,015,393
Sturgeon and spoonbill cat	....	359,641	3,100	24,470	....	64,133	152,765	604,109
Suckers	....	2,378	....	66,167	2,454	....	....	70,999
Whitefish	830	613,374	....	1,019,027	217,513	3,894	2,360	1,856,998
Whiting	6,452,962	1,952,967	....	18,319	1,728,551	....	....	10,152,799
Miscellaneous frozen fish	921,655	1,096,563	370,240	905,633	981,941	891,481	2,607,922	8,375,435
Total	24,560,998	18,916,120	1,137,178	11,874,664	5,249,762	1,050,784	28,875,562	91,165,068

SCIENTIFIC PRINCIPLES INVOLVED IN REFRIGERATION

Heat and its relation to other forms of energy is one of the most intricate and difficult branches of science, and the practical refrigeration man need not be a master of it. Yet there are certain principles, the understanding of which is of great value to an intelligent conduct of a refrigerating business. Reference will be made, in connection with the many details of this subject, to the more important scientific papers which the reader who is interested to pursue the subject more extensively may consult.

NATURE OF HEAT

All matter or substance consists of extremely minute particles or molecules. Motion of these molecules is heat. Many of the simpler substances, for example water, are capable of existing in three states—solid, liquid, and gas—the differences being only in the amount of motion in the molecules and their distance apart. In the gaseous state (steam) the molecules are far apart and in great activity or motion, like a swarm of insects, each free to move long distances with little interference. Unless confined they will keep on going or expanding and diffusing into space. If the motion is reduced (that is, if the gas is cooled), the molecules travel less freely and for shorter distances, the gas volume contracts, and a liquid (water, in the example chosen) is formed. In this condition the molecules move less freely, but still get about with many collisions and glancing motions. The whole mass is fluid and will assume the shape of its container, while at the exposed surface many of the molecules escape into space—a process known as evaporation. If more heat is taken from the water (that is, if the motion of the molecules is still further reduced), the molecules are no longer free to move about from place to place, but each is confined to occupy a small space, within which it performs a restricted vibratory motion. In this condition, where the molecules are too much crowded to move freely, the substance is a solid (ice). In solids the molecules often are found to be arranged in definite rows or patterns, in which case the solid is a crystal of definite geometric form. Only at absolute zero (459.2° F. below zero) are the molecules absolutely at rest, but this temperature has never been attained.

The differences between solid, liquid, and gas are thus purely differences in the amount of motion in the molecules—hot, gas; cool, liquid; cold, solid. The solid condition is the frozen condition, ordinary iron, for example, being frozen iron. Cold is a purely relative term meaning less heat. Ordinarily we think of things as cold when they contain less heat than we are accustomed to in our sourroundings.

TEMPERATURE AND HEAT UNITS

The degree of motion of molecules is expressed in temperature and is measured by the thermometer. Temperature alone tells us nothing about the quantity of heat. This is obvious if we consider that a drop of molten iron may have a temperature of 2,720° F., yet when dropped in a bucket of cold water the water is not noticeably warmed. This is because the *quantity* of heat in the drop of iron is too small, though the temperature of the drop is very high. The quantity of heat in the English system is measured in British thermal units (B. t. u.); a British thermal unit is defined as the amount of heat required to raise the temperature of a pound of water 1° F. If a pound of water is to be warmed from 32° to 100° F., 68 B. t. u. of heat would be required; 2 pounds of water would require 136 B. t. u. to be warmed 68°. Likewise, if 1 pound of water is to be cooled from 100° to 32° it must give off 68 B. t. u.

FREEZING

If water has been cooled to 32°, its freezing point, it can not ordinarily be cooled any further until all of it is frozen, after which the temperature of the frozen water begins to drop again if heat continues to be extracted. The heat that exists in water and all other crystallizable liquids, and which must be extracted to convert it to a solid without change of temperature, is called *latent* heat. The term is often misapplied to the animal heat in fresh fish. The latent heat of water is 144 B. t. u.; that is, 144 B. t. u. of heat must be taken out of a pound of water to convert it from a liquid at 32° to a solid at 32°. After it is all frozen the ice may be cooled further, but ice requires only about one half B. t. u. per pound to cool it 1°.

An example of this may help to clear the matter further. How much refrigeration is required to cool 10 pounds of water from 100°, freeze it, and chill the ice to 0°? To cool the water from 100 to 32° would require the removal of 68 B. t. u. per pound, or 680 B. t. u. To freeze the water at 32° would require the removal of 144 B. t. u. per pound, or 1,440 B. t. u. To reduce the ice to 0° would require the removal of one-half B. t. u. per pound per degree, or $\frac{1}{2} \times 10 \times 32 = 160$ B. t. u. The sum of the number of B. t. u. required to be removed to cool the water from 100 to 32°, to freeze it, and cool the ice to 0° is thus $680+1{,}440+160$ B. t. u., or 2,280 B. t. u.

A ton of refrigeration is, according to accepted usage, the amount of refrigeration required to freeze 2,000 pounds of water at 32° to ice at 32°, or $2{,}000 \times 144 = 288{,}000$ B. t. u. A ton of ice in melting absorbs 288,000 B. t. u. It will cool off 288,000 pounds of water 1°, or 28,800 pounds 10°, etc.

Fish consist of 60 to 82 per cent water. Neglecting the nonwater portion of, say, haddock, which contains about 80 per cent water, to freeze a ton of haddock would require approximately $0.80 \times 288{,}000 = 230{,}400$ B. t. u. of refrigeration. It is customary to consider fish as all water for purposes of calculation, the difference being a safe allowance for conservative estimates.

WHAT HAPPENS WHEN FISH FREEZE

What was said above about freezing substances to a solid at a definite point without change of temperature until all the substance is solid applies to pure simple substances like water. But a fish is not all water; it is made up of millions of microscopic cells. These cells may be conveniently thought of as something like hen's eggs with the limy shell removed but with the membrane lining the shell left on. It would be a membranous bag inclosing a semigelatinous or albuminous substance like the white of raw egg. In fact, an egg is a large cell; reduced by millions in size and multiplied by millions in number it represents fairly well what the flesh of fish is made of. The gelatinous contents of these cells is about 80 per cent or more water. If the fish freezes extremely rapidly, the jelly solidifies as a mass of frozen jelly; but if slowly, the water has a tendency to separate from the jelly as microscopic ice crystals. The water diffuses out of the jelly to build these crystals larger and larger as freezing proceeds, until finally a large part of the water has separated out as ice. These crystals—long, sharp needles—may rupture the delicate cell membranes, so that when the fish is defrosted the juice is free to run out. Hence, the desirability, as will be referred to often later, of the most rapid freezing.

While pure water freezes at 32°, if anything is dissolved in the water its freezing point is lowered. The water in fish contains mineral and other substances in solution. The fish, therefore, does not begin to freeze until it is cooled to 31.5° or 30.5°; but it will not freeze hard and solid even at this temperature, because as part of the water freezes out what is left has a higher concentration than it had at the beginning, and a lower temperature is required for further freezing. Probably not all the water in fish is ever frozen at ordinary freezing temperatures. A fish will be apparently hard at 20°, but at 0° it is harder. At 5° F. about 17 per cent of the water remains unfrozen; at 31° F. below zero, about 2.66 per cent remains liquid. Only at about 75° below zero is it all frozen.

CONDUCTIVITY

Heat is conducted through any substance, as, for example, when one end of a metal rod is heated the other end becomes warm. This conduction is a matter of the molecules striking against one another and transmitting the motion. Some substances conduct heat better than others. All metals are relatively good conductors, silver and copper being the best. Air and all gases generally are exceedingly poor conductors, especially if they are prevented from circulating. This is true because the molecules are farther apart and collide less frequently. For the same reason, solids generally are better conductors than liquids.

Substances like cork, feathers, wool, sawdust, etc., that hold much air entrapped, are poor conductors of heat and are called insulators. When heat or cold must be confined in a space it must be surrounded by an insulator. Cork, wool, and like materials serve this purpose when they are dry because of the air they contain, but when water enters them and drives out the air the insulating value is impaired, because, as already said, liquid is a better conductor of heat than gas.

The rate of transfer of heat through an insulating medium is approximately inversely proportional to the thickness of the insulating substance. About half as much heat will flow per minute through a square foot of cork 2 inches thick as through a square foot of cork 1 inch thick, and a third as much will flow through a slab 3 inches thick. On the other hand, when it is desirable to cause heat to flow as rapidly as possible from one body to another the path of travel of the heat must be through as good a conductor as possible. For example, in a sharp freezer, where fish are in a metal pan and the pan rests on a metal pipe, the heat travels freely through the points of contact between fish and pan and pan and pipes; but most of the fish is in contact with air, which is an exceedingly poor conductor, hence the comparatively slow freezing attained in this way. If more rapid freezing is to be attained the fish must be brought into intimate contact with a good conductor that is refrigerated.

The rate of transfer of heat from one place to another is in direct proportion to the difference in the temperature of the two places. For example, a can of water at 32° is immersed in brine at 22°. The difference in the temperatures of the water and the brine is 10°. Another can of water at 32° is immersed in brine at 12°. The difference in temperature in this case is 20°. The water in the second can will freeze twice as rapidly as the first if the conditions remain constant, because the difference in the temperature of water and brine is twice as great in the second case as in the first. Another can in brine at 2° would freeze three times as fast as the one at 22°. This simple fact, taken together with the desirability of rapid freezing of fish, explains why such cold temperatures are necessary in sharp freezers.

Ice is about four times as good a conductor of heat as water. When a fish is freezing the outer frozen part (containing about 80 per cent ice) conducts heat outward about four times as fast as it did before it was frozen; but when a frozen fish is thawing the outer thawed layer conducts heat only about one-fourth as rapidly as it did while it was frozen. A fish will therefore freeze more rapidly than it will thaw if there is the same difference between the temperature of the air and the fish in both cases.

CHANGES THAT TAKE PLACE IN FISH AND THEIR PREVENTION BY COLD

Two classes of changes that take place in fish will be considered in this section, (*a*) those that occur in fresh fish and (*b*) those that occur in frozen fish.

CHANGES IN FRESH FISH[14]

When a live fish is taken from the water its parts are all intact stomach usually full of food, intestines with digested food and residue, and its body and gills covered with a heavy mucus. Its muscle tissue is able to contract, and the entire fish is chemically normal and wholesome and all internal tissues sterile or nearly so. When the fish dies there begins a series of many kinds of changes that affect the wholesomeness and appearance of the fish. To prevent these changes from taking place is to preserve the fish. In order to do this intelligently an understanding of the nature of these changes is valuable.

COLOR OF THE SKIN

The first noticeable change in the fish after death is in the coloring of the skin. This color is due largely to variously colored pigment cells, which are contractile and controlled by nerves. Upon release of nervous control at death these pigment cells contract, the blend of colors becomes dull, and the appearance is generally less attractive than that of the living fish.

RIGOR MORTIS

One of the earlier changes in the fish after it dies is a development of lactic acid in the muscles, causing them to contract, the fish in consequence becoming rigid. This condition is called *rigor mortis.* The warmer the fish the sooner rigor mortis begins and the shorter time it lasts. The colder the fish (not frozen) the slower rigor is to appear and the longer it lasts. Rigor is a sign of freshness and

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[14] See A. G. Anderson, "On the decomposition of fish." Fishery Board for Scotland, 26th Annual Report, 1907, Part III, pp. 18–39. Edinburgh. Clough, R. W., "A biochemical study of Pacific coast salmon, with particular reference to the formation of indol and skatol during decomposition." University of Washington, Department of Chemistry. 27 pp., bibliography. The University Press, Seattle. L. Gross, "An investigation into the rate of putrefaction in the common food fish caught in and around Passamaquoddy Bay, New Brunswick." Department of the Naval Service, Biological Board for Canada, Contributions to Canadian Biology, 1918–1920, Vol. IX, pp. 99–102. Ottawa. Hunter, A. C., "Bacterial growths in decomposing salmon." Journal of Bacteriology, Vol. V, 1920, pp. 543–552. Also, "The sources and characteristics of bacteria in decomposing salmon." *Ibid.*, Vol. VII, 1922, pp. 85–109.

wholesomeness, well recognized by fishmongers. There is some question as to whether fish are best frozen before, during, or after rigor.[15] Some investigators have observed that cod frozen before rigor had a dry and disagreeable taste. Others have thrown doubt on this conclusion and indicated by experiments that it is possible to have fish of good flavor in both cases.

AUTOLYSIS

As rigor subsides another change comes about, perhaps assisted by the lactic acid that causes rigor. This is autolysis, or self-digestion of the tissues. It is an important change that requires some explanation.

There are certain substances called enzymes that are capable of decomposing or breaking down complex into simpler substances. A familiar example of such a substance is pepsin in the stomach, which breaks down the complex substance (protein) of lean meat into simpler substances that dissolve in water to form liquid solutions. This liquefaction of food is digestion and serves to prepare the food for absorption into the blood through the intestinal wall. There are many such enzymes in the animal body, most of the tissues containing enzymes capable of liquefying or digesting them. These enzymes serve an important purpose in the living animal, but upon its death they set to work to soften and liquefy the tissues. This self-digestion of fish substance is called *autolysis.*

The products of autolysis are not unwholesome. Indeed, a certain amount of autolysis or ripening, as butchers call it, is desirable in red meats, for it makes them tender and juicy, and most people prefer the flavor. In fish, however, autolysis, while harmless, gives rise to a fishy flavor that is distinctly objectionable. Fish that have undergone autolysis are soft and flabby. Impressions made on the fish with one's fingers remain when the fingers have been removed. Autolysis occurs in fish after rigor has passed away. It is hastened by warmth and retarded by cold. The maximum rate is at temperatures varying with different fishes from about 65 to 81° F. Bruises promote autolysis, for it has been shown that bruised or crushed meat softens and digests itself much more rapidly than meat not bruised. Autolysis is prevented entirely by freezing the fish solid, but it begins again when the fish is defrosted. Salt in small quantities increases autolysis. Slowly frozen fish autolyze more rapidly than fresh fish, while rapidly frozen fish autolyze less rapidly.[16]

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[15] The subject is discussed by the following authors, whose works are extensive theoretical studies of scientific principles of freezing fish: W. D. Richardson and E. Scherubel, "The deterioration and commercial preservation of flesh foods." Journal of the American Chemical Society, Vol. XXX, pp. 1515–1564. Easton, 1908. J. M. Bottemanne [Ed.], "Verslag van de door Nederlandsche Vereeniging voor de koeltechniek ingestelde Commissie voor de Vischconserveering, etc." Delft, 1915. See also, Third International Congress of Refrigeration, Chicago, 1913. R. Plank, E. Ehrenbaum, and K. Reuter, "Die Konservierung von Fischen durch das Gefrierverfahren." 248 pp. Zentral Einkaufsgesellschaft, Berlin, 1916. See also, Stiles, footnote 45, p. 580, and Ogura and Fujikawa, footnote 20, p. 526.

[16] See Oya, Takeo, and Kiyoshi Shimada on the "Autolysis of fish muscle." I. Journal of the Imperial Fisheries Institute ,Vol. XIX, No. 3, 1923. Oya, Takeo, Ei-etsu Sumi, and Kiyoshi Shimada II. *Ibid.*, Vol. XXI, 1926, pp. 49–149. Callow, E. H., "The autolysis of the muscle of the cod." Biochemical Journal, Vol. XIX, 1925, pp. 1–6. Cambridge.

PUTREFACTION

Putrefaction is caused by bacteria or microscopic living things entirely too small to be seen without a microscope. They exist almost everywhere. Sea water and other natural waters contain millions of them. As long as fish are alive and healthy bacteria do them no harm, though they occur in the body slime, on the gills, and in the intestines and probably, also, to some extent in the blood and flesh. When the fish dies there is no longer any resistance to the growth of bacteria; they begin at once to multiply rapidly in the body slime and in the intestines, soon invading the flesh and gills, break down and disintegrate the intestinal walls, and ultimately spoil the fish.

Bacteria do not obtain their nourishment by biting or digging in. They are plants by nature and live, as other plants do, by absorbing food from their surroundings. They secrete enzymes from their bodies; these enzymes liquefy or digest the surrounding flesh, and this digested flesh is then absorbed by the bacteria. The products of bacterial action, unlike those from autolysis, are usually offensive and unwholesome. The process of decomposition brought about by bacteria is known as putrefaction.

To prevent putrefaction, the bacteria must be killed or their activities prevented. Bacteria are killed by cooking and also by certain chemicals, both of which agencies are impracticable for fresh fish. Their activities can be retarded by low temperature, which greatly slows down the multiplication of bacteria. Ice temperature serves well to delay putrefaction for several days.

Bacteriological investigation[17] has shown that development of bacteria in fish is arrested by freezing, and that the bacterial content of fish after a term of storage was essentially the same as it was when the fish went into storage.

As the source of infection of fish is usually the surface slime, gills, and intestine, it follows that fish should be washed before freezing, unless they are perfectly fresh at the time, and that preferably they should be gutted and the gills removed. Gutting is, however, not always desirable because of trade requirements.[18]

CHANGES DURING THE FREEZING PROCESS

Some reference already has been made to the freezing of water in the tissues of fish. When fish are exposed to a low temperature they freeze—that is, they become solid—apparently simple enough, but in reality a very complex phenomenon. Exactly what happens depends largely on just how the freezing is done.

GROSS EFFECTS OF SLOW AND RAPID FREEZING

The most important single factor that affects the internal condition of the fish is the speed of freezing. If a fish is placed in a sharp freezer or cold room the temperature of the entire fish is gradu-

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[17] See, for example, H. D. Pease, "Effect of prolonged periods of cold storage on the bacteria in the tissues of fish." Proceedings, Third International Congress of Refrigeration, Chicago, 1918, Vol. I, Sec. III, pp. 560–573.

[18] See footnote 25 on p. 537.

ally lowered. When the body of the fish reaches the freezing point of body juice, it begins to freeze. In general, the outer parts of the fish are colder than the inner parts, though there is no sharp line of demarcation. The fish gradually becomes firm, and finally hard throughout. In this case the factor controlling the speed of freezing is the removal of heat from the surface, for the heat flows from the inside of the fish to the surface as fast as it can be carried away by the air, which is a very poor conductor of heat. When heat is removed very rapidly, as by immersing it in very cold, rapidly moving brine, the factor that limits the rate of freezing is the conductivity of the fish itself. The surrounding brine, being a good conductor and in rapid motion, removes the heat from the surface as fast as it can be conducted from the inner parts. The outer parts of a fish may be frozen hard, while the innermost parts are still quite unfrozen. The outer frozen shell becomes thicker and thicker as freezing proceeds inwardly, always sharply demarked from the inner unfrozen core until freezing is complete. The slowly frozen fish is highly solidified, while rapidly frozen fish are of a more waxy consistency. Between the two there are other profound differences in microscopic structure that will be referred to later.

CHANGE IN VOLUME

Water in freezing expands by about 8.8 per cent of its volume. Fish expand accordingly, in proportion to the amount of water present and the amount of that present which is frozen. It is not all frozen in ordinary practice. It has been shown by measurements of expansion that in gels not all the water is frozen until extremely low temperatures are reached (about 103° F. below zero). It is supposed that some of the water remains diffused in the " capillary " condition. As fish contain from 65 to 80 per cent water, the expansion may be estimated at from 5.7 to 7.1 per cent of volume. Whether this expansion is responsible for any of the structural changes in fish, such as rupture of gall bladder or destruction of cell membranes, is as yet uncertain. It is not now considered to be so important as it was some years ago. Expansion is of importance where fish are frozen confined in molds or cans, where allowance must be made for expansion. It can not be prevented or resisted.

COAGULATION OF PROTEIN GELS

As stated previously, the cell contents of fish are a semiliquid gel of protein in water, with small amounts of numerous substances in solution. It has been reported by various investigators that such gels, on being frozen and under certain conditions, become coagulated. In the report of the Food Investigation Board of Great Britain for 1923 it is shown that egg albumen, if frozen at a temperature not colder than 21° F., will defrost as a liquid similar to what it was in its unfrozen state, but that if frozen at a moderately lower temperature it can not be returned to its original condition by defrosting but will be coagulated. However, if frozen with extreme rapidity in liquid air and defrosted with great rapidity in warm mercury it is not coagulated. These experiments indicate that there is a temperature zone below 21° in which coagulation occurs, but that if the albumen is passed quickly through this zone in freezing and defrosting coagulation does not occur. Coagulation that is progressive through the storage period has been observed in frozen haddock.

Brine-frozen fish, not being damaged by internal crystallization, are, because of coagulation, firmer than fresh fish. They are of a firmness strongly suggesting rigor mortis, even after months of storage, and this firmness does not pass away after a brief period as rigor mortis does. Kept in a cool place, brine-frozen fish will remain in this artificial rigor for days, until they are spoiled. The effect probably is due to a small amount of salt that penetrates during the freezing.

HÆMOLYSIS

The red substance of blood—hemoglobin—is contained in microscopic corpuscles. On freezing, many of these corpuscles are ruptured, and the contained red hemoglobin diffuses into the blood plasma and surrounding tissues, discoloring them. This is noticeable in fish mainly in the neighborhood of the large arteries, especially those near the backbone, where the red matter diffuses into and discolors the muscle tissue.

INTERNAL CRYSTALLIZATION

The freezing of fish is essentially the freezing of a watery gel. A large part of the water is transformed into the crystalline solid state. It is well known to chemists that when substances crystallize the size of the crystals formed is determined by the time required for them to form. Diamonds are large crystals of carbon, requiring prolonged periods to form. Man, in the short time available for his processes, has been unable to duplicate nature's effort. Rock candy is sugar crystallized slowly over a period of days or weeks. Fudge is also sugar, but is crystallized quickly by cooling a hot solution in a few seconds. One is composed of large crystals, the other small. Water frozen slowly to ice in ice factories splits easily because its internal structure is characterized by large crystal faces or planes of cleavage, while rapidly frozen ice is hard and shatters like stone because its internal crystals are small and numerous. Crystals grow. A nucleus or seed is formed and more substance is laid on in layers, if time permits, until the liquid substance is exhausted in building large crystals. If heat is extracted too fast, this growth does not have time to take place, and the crystals are small and numerous.

This principle applies to the freezing of fish. When a piece of fish is frozen with extreme rapidity by dipping in liquid air and examined under the miscroscope while still frozen, no perceptible change except solidification will be found to have taken place; but if it is frozen somewhat less rapidly (as in the outer portion of fish frozen in very cold brine) and examined while still frozen, there will be observed several parallel columns of clear ice running lengthwise of the muscle fibers. Part of the water originally contained in the protein gel has separated and frozen as long crystals of clear ice. If this piece of fish is defrosted, the water is slowly reabsorbed

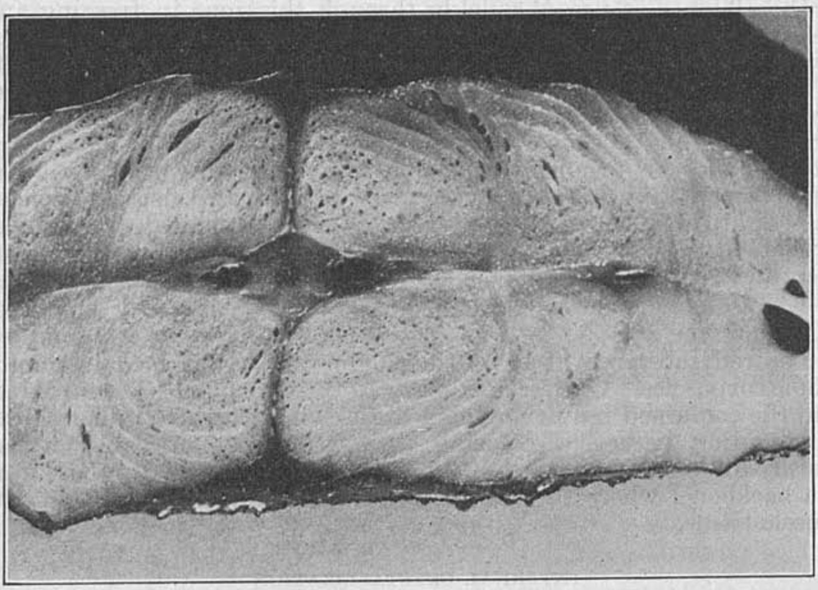

FIG. 3.—Cross section of halibut frozen slowly in ordinary sharp freezer and defrosted. Note honeycombing of tissues by ice crystals. Courtesy, Atlantic Coast Fisheries Co.

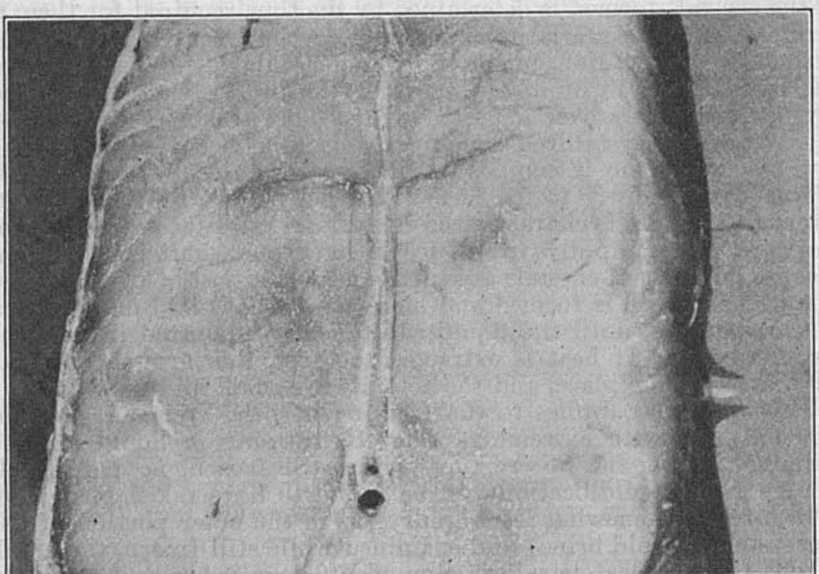

FIG. 4.—Cross section of halibut frozen rapidly (in brine). The tissues are intact. The white dots are reflection of light from surface moisture. Courtesy Atlantic Coast Fisheries Co.

into the protein. Virtually, if not absolutely, the changes that occur in freezing of this degree of rapidity are reversible on thawing. In a yet slower rate of freezing, such as occurs in the inner portions of brine-frozen fish, one single large column of ice forms in the muscle fiber; but here, also, little practical damage is done.

In very slow freezing large ice crystals are formed—so large that they do not remain in the muscle fibers or cell. Cell walls are ruptured and the crystals form in the interstitial spaces. When such fish are defrosted, the juice runs out of the fish, carrying much of the valuable fish substance with it. Unfortunately, this is the kind of freezing that commonly occurs in "sharp" freezers and accounts for the many efforts that have been made in recent years to achieve more rapid freezing. Especially in large fish, such as halibut, large crystals, half an inch or more long, may be extracted easily from the tissues; and the tissues when defrosted are characterized by a honeycomb structure. Compared with fresh fish, the flesh is dry and the taste flat.

Furthermore, it was shown that autolysis is promoted by bruising. The formation of large internal crystals is equivalent to a severe bruising or physical damage to all the tissues of the fish. Such fish on defrosting autolyze very rapidly.

CHANGES DURING COLD STORAGE

If frozen fish are held for a protracted time in cold storage, other changes may occur.

BLOOD PIGMENTS

The red coloring matter of blood—hemoglobin—is sensitive to the gases of the air. On long standing in the presence of air, hemoglobin is converted to methemoglobin, a brownish-gray substance that gives the color to corned beef. The blood of fish after prolonged storage undergoes this change. The writer has prevented it experimentally by the use of substances like carbon monoxide and nitric oxide, which form stable red compounds with hemoglobin.

DESICCATION

It is universally known that water will evaporate when exposed to dry air. That ice also will evaporate is not so well recognized, yet it is so. An understanding of the laws of vapors is necessary to a clear conception of the movements of moisture in a cold-storage room.

If a pan of water is placed in a closed chamber, and if the air in the chamber is not already saturated with water vapor, water will evaporate until the vapor (or air) in the chamber is saturated—that is, until it contains all the water that it will hold. How much water will it hold? This depends on the temperature of the chamber. The warmer the chamber the more water is required to saturate it. If the temperature in a saturated chamber is raised, more water will evaporate; if it is lowered, some will condense as dew if the temperature of the condensing surface is above 32° F., or as ice or snow crystals if below this point.

If moisture is present in a sealed room, and if the temperature of the room is constant and uniform throughout, the vapor will soon come to saturation and remain saturated as long as the conditions are not changed.

Table 6 shows the number of grains of water vapor per cubic foot of saturated vapor at cold-storage temperatures.

TABLE 6.—*Weight of a cubic foot of saturated moisture*

Temperature, °F.	Moisture per cubic foot, grains	Temperature, °F.	Moisture per cubic foot, grains
−20	0.167	+20	1.244
−10	.286	+30	1.942
0	.479	+40	2.863
+10	.780		

These conditions of constancy and uniformity of temperature are not realized in a fish cold-storage room. The temperature fluctuates from hour to hour or day to day. If a room is at 0°, each cubic foot of saturated air contains 0.479 grain of water vapor. If the temperature rises next day to 10°, 0.780 grain, or nearly twice as much water, is required to saturate the air, and this must evaporate from the fish. (The quantities are actually somewhat smaller because the juice of fish is not pure water.) The temperature in the room also is not uniform. Heat is coming into the room through the walls, etc., and is being absorbed by the cold pipes. The fish, being near the walls, on the floors, and surrounded by air that is warmed from the same sources, are warmer than the pipes, which are absorbing the heat. The saturation point is lower at the pipes and higher at the fish. Under these conditions the moisture will evaporate steadily from the fish but can not saturate the air because the cold pipes condense the moisture. There is thus a continuous travel of moisture from fish to pipes, which will dry the fish completely unless remedial measures are taken.

The commonest remedial measure is an ice glaze on the fish. The glaze, being of pure water, has a slightly greater tendency to evaporate than the juice of the fish, and, being exposed, evaporates first. Other practical measures will be considered in more detail later.

RUSTING

The fats in fish are a mixture of fatty substances, some of which are unsaturated. That is to say, they are capable of combining with either oxygen or hydrogen under proper conditions. They combine directly with oxygen on exposure to air, or they may become "hydroxylated" by combining with both oxygen and hydrogen, in which case they are rancid. When they take oxygen from the air they become viscous or rubbery, as linseed oil becomes on drying when applied as paint.

The tissues of fish contain enzymes that are capable of decomposing fats, and as long as the fats are in the presence of their mother tissues (as they are in stored fish) they are subject to decomposition.

When decomposed, they are readily attacked by oxygen and form various unpleasant substances; that is, they become rancid. This decomposition and oxidation occurs in the cold-storage room unless measures are taken to prevent it and is manifested by a yellowish, rusty, gummy accumulation on the surface of the fish, especially around the bases of the fins and, in the case of gutted fish, in the belly cavity. Cut surfaces are prone to rust.

These changes are chemical and, in common with chemical changes generally, are accelerated by heat and retarded by cold. For example, ethyl acetate, a fatty substance, at 72° decomposes one-half as fast as it does at 104°; at 32° it decomposes about one-seventh as fast, and at 18° only one-twentieth as fast as it does at 104°. The rate of decomposition would be even lower at the temperatures commonly found in fish cold storages, namely, 10 to 0°. It follows that low temperatures will prevent rusting, or at least greatly reduce it. In practice it has been found that 8° F. is about the highest temperature at which fat fish can be kept for ordinary storage periods without serious rusting. Lower temperatures are recommended, and many fish freezers regularly maintain temperatures of 5 or even 0°.

The oxidation of fat generates heat. The rising temperature in turn accelerates oxidation. This vicious cycle may ruin fish like smelt, which are particularly liable to rust. The writer has seen smelt completely ruined and covered with mold, though they had been kept at 5° F. The mold could not have grown at that temperature. Rapid oxidation had raised the temperature to a point where the mold could grow. The fat had run out of the boxes copiously. This is, of course, an extreme condition—small fish, exposing much surface without glaze, and very rich in highly oxidizable fat. Glazing is a great help in preventing oxidation of fat but is not completely efficacious without a low temperature.

LOSS OF SAVORY SUBSTANCES

Fish that have been frozen and stored for a long time frequently are observed to have lost much of their flavor. We do not know definitely just what substances in fish are responsible for flavor. Most probably the flavor is the blend of flavors and odors from many substances that are present in small quantities. The loss of flavor or odor possibly may be caused by (1) escape of volatile substances by evaporation, (2) reaction of the atmospheric gases (oxygen and carbon dioxide) with the constituents of the fish, or (3) reactions between or among the various constituents of the fish themselves. The last-mentioned of these would seem more likely to increase than decrease the flavor. If loss is caused by evaporation of savory substances or by reaction with atmospheric gases, the remedy lies clearly in a protecting glaze that seals in the natural constituents of the fish and excludes the air. In practice it is common experience that fish held at low temperature and fully protected by a glaze lose nothing of taste or flavor in months or even years. It seems much more likely that the loss of flavor often observed occurs at the time of defrosting fish that have been frozen slowly. The loss of juice made possible by internal crystallization easily accounts for the loss of soluble principles that give taste and flavor as well as nutriment.

INTERNAL CHANGES IN FISH IN STORAGE

Reuter, in the German work already referred to, observed changes in the consistency of fish flesh that are progressive in prolonged storage. These changes occur in fish frozen by any method. Immediately after rapid freezing and defrosting the tissues of haddock, for example, resemble those of fresh fish so closely that one can scarcely distinguish the difference, but in storage they begin to show changes after a time. Reuter's observations are shown by the following scheme:

Term of storage	Consistency of tissues after defrosting	Tendency of juice to exude from fish spontaneously after defrosting
24 hours	Firm as fresh muscle. Gelatinous consistency when rubbed or squeezed between fingers.	Cut surfaces dry; free outflow of juice at a minimum; on pressure almost none could be squeezed out.
18 days	Muscle still tenacious, viscous, and gelatinous, though slightly less than in above.	Cut surfaces dry; small drops of tissue juice flows out spontaneously; on pressure the tissue juice runs out in moderate abundance.
103 days	Muscle much less gelatinous and viscous; also dryer than preceding.	Juice runs out spontaneously a little more freely than in the preceding; on pressure it runs out very freely, leaving the muscle fibers dry.
149 days	No gelatinous property; fibers crumbly and dry.	Cut surface moist; spontaneous outflow of tissue juice not more considerable than after 18 or 103 days' storage, but on pressure the juice continuously exudes as if out of a sponge, so that the muscle fibers remain a friable and plastic mass.

In 1922[19] the present writer suggested, on theoretical grounds, that it was possible that fish containing only minute ice crystals immediately after freezing might contain larger ones after a period of storage. There was reason to believe that, because of fluctuations in temperature in storage, the larger crystals might grow at the expense of the smaller ones. The Japanese investigators Ogura and Fujikawa[20] report in a recent publication that this is true, though they do not give, in the English summary (the publication itself is in Japanese), the nature of their observations, nor do they indicate the extent of growth of the crystals. The writer can state from his own observations, however, that the change is not great, for rapidly frozen fish after a period of storage do not, on close visual examination but without a microscope, show any noticeable crystallization. The Japanese observers also state that, although the ice crystals in the tissues were very small, the muscle cells invariably suffered some damage. "For instance, if a slice of frozen flesh is cut off and immersed in cold water, the cell contents will soon dissolve out into the water, leaving the stroma substance something like cotton fiber. This was not the case with the flesh which was not frozen. By this means the fresh can easily be distinguished from the frozen flesh."

ACQUISITION OF UNDESIRABLE ODORS

Not only may fish in cold-storage rooms lose some of their natural flavor and odor, but they may also acquire foreign odors and flavors.

[19] H. F. Taylor, "Brine Freezing of Fish." U. S. Bureau of Fisheries Economic Circular No. 54. Washington, 1922.

[20] Z. Ogura and K. Fujikawa, "On the refrigeration and preservation of fish." Bulletin of the Government Fishery Experimental Station of Chosen, No. 1, 1925, 162 pp. (Japanese abstract in English, 8 pp.) Fusan.

The air of a cold-storage room is stagnant. No ventilation is provided, except that which is occasioned by opening the doors.. Being in contact with fish continuously, it doubtless becomes charged with volatile substances from fish. If fish are stale when frozen, they have small quantities of ammonia, amines, hydrogen sulphide, and the like, which are volatile. Oxidation of fats produces aldehydes and other offensive substances, some of which are volatile. Smoked fish have a decided odor, which arises from the volatile constituents of smoke.

When large quantities and numerous varieties of fishes are stored together in an unventilated room the air may, and probably does, become charged with these volatile substances. Fish may absorb them to some extent. Round fish, well glazed, may not be appreciably affected, but fish without these protections, and especially those of slight flavor of their own, like haddock fillets and cod steaks, may be distinctly tainted with these odors. Protective wrappings for these products are necessary, therefore, not only to prevent drying out, but to prevent taint from foreign substances in the air. Low temperatures reduce the tendency to taint from the air, because the lower the temperature, the lower the tendency of volatile substances to evaporate, and the more completely they are condensed on the cold pipes along with the water. Smoked fish should be stored apart from other fish as far as possible.

This subject is of much practical importance, and has not been sufficiently studied. Steamship or railroad companies hesitate or refuse to forward fish in refrigerated compartments with meat, eggs, butter, and poultry. General cold storage warehouses either do not accept fish, or else store them in separate rooms, or, as in the case of the cold-storage warehouse of the Harbour Commissioners of Quebec, in an entirely separate building. Retailers usually avoid putting fish in their refrigerators along with other food products because of possible taint with fishy odors. Scarcely enough of this subject is definitely known to justify any broad generalizations. The writer has done some investigating and found that if an impervious covering is used, such as the various moisture-proof papers, and tight boxes, with low temperatures, taint may be reduced to a negligible amount.

CHANGES THAT DEPEND ON THE TEMPERATURE AT WHICH FISH ARE FROZEN

Generally, the colder the freezing medium the faster the fish freeze, and it has been shown already that the rapidity of freezing has much to do with the frozen product. Rapidity of freezing, however, can be had without excessively low temperatures by having good contact between fish and, say brine, and having the brine in rapid circulation. It has been shown that temperatures at which fish are frozen have an effect independent of the rate of freezing. The lower the temperature the more of the water is frozen out. The more water frozen out the more concentrated the remaining solution. At 104° F. below zero all the water is frozen out of the fish and the fish substance is completely dehydrated. It does not return to its original condition when defrosted. The implication of this finding is that rapidity of freezing should be obtained by other means than excessively low temperatures.

CHANGES THAT AFFECT THE FOOD VALUE OF FISH

Among the changes already referred to that affect the food value of frozen fish the loss of juice caused by crystallization and the degradation of fats are the most important. The juice that runs out of a frozen fish on defrosting contains so much albumen that it coagulates like white of egg when it is heated. The fats, being partly oxidized, have lost part of their fuel value and interfere with digestion.

On devoting attention particularly to the protein constituents of fish, several chemists have found no significant changes that could affect food value.[21] Their conclusions are based largely on a study of the nitrogenous constituents. There is no doubt that changes that affect food value may and do occur in frozen fish, and that the seriousness of these changes depends on the methods of freezing and storage. That fish can be so frozen and stored that no important change will occur that would affect their food value is likewise well established.

DESIGN, CONSTRUCTION, AND EQUIPMENT OF FISH FREEZERS

The design, construction, and equipment of plants for freezing fish is a subject the adequate treatment of which is beyond the scope of the present work and must be left to refrigeration engineers, who are nearly always called upon where questions arise or plans for construction are to be made. However, a brief discussion of some aspects of the subject may be useful to the readers to whom this work is addressed.

LOCATION

Fish freezers should be located with respect to accessibility to boats that bring in fish, railroad tracks and wharves for cargo ships for transportation, an adequate source of clean water, and availability of coal or electric power and labor. A water-front location is most to be desired, of course, but it is not always available. The nearer to the point of actual production of fish that a freezer can be located the better in general, though public warehouses are located conveniently near wholesale fish markets. As large volumes of water are required for the condensers, it is economical to have access to a lake, river, artesian well, or other free water, which need not be highly pure, and also to filtered pure water for washing the fish.

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[21] C. S. Smith, "A study of the influence of cold-storage temperatures upon the chemical composition and nutritive value of fish." Biochemical Bulletin, Vol. III, 1913, pp. 54–68. New York. W. A. Perlzweig and W. J. Gies, "A further study of the chemical composition and nutritive value of fish subjected to prolonged periods of cold storage." *Ibid.*, pp. 69–71. E. D. Clark, L. H. Almy, and M. E. Pennington, "The commercial freezing and storing of fish." U. S. Department of Agriculture, Bureau of Chemistry, Bulletin 635, 1918. Washington. E. D. Clark and L. H. Almy, "A chemical study of frozen fish in storage for short and long periods." Journal of Industrial and Engineering Chemistry, vol. 12, 1920, pp. 656–668. Easton. L. H. Almy and E. Field, "Preservation of fish frozen in chilled brine. II. The keeping quality of the fish." Journal of Industrial and Engineering Chemistry, vol. 14, p. 203, 1922. Easton.

GENERAL FEATURES OF DESIGN

The freezer as a unit should be so designed that all parts are proportioned to the capacity desired. The sharp-freezer space should

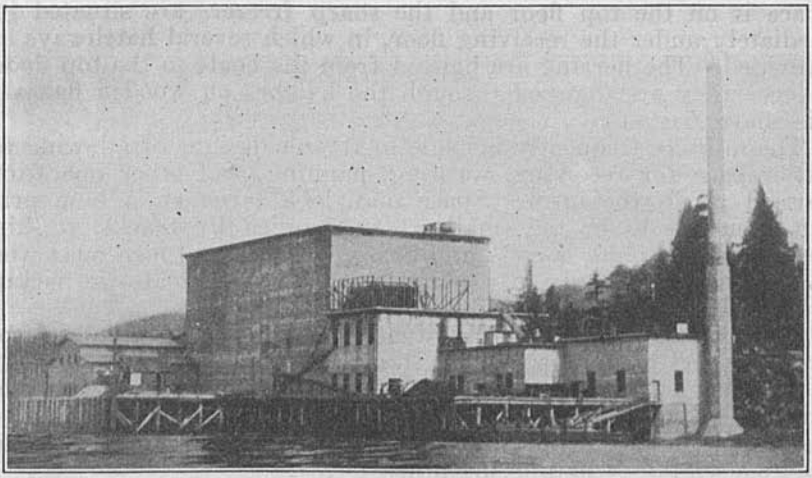

FIG. 5.—Fish freezer of 14,000,000 pounds storage capacity at Prince Rupert, British Columbia

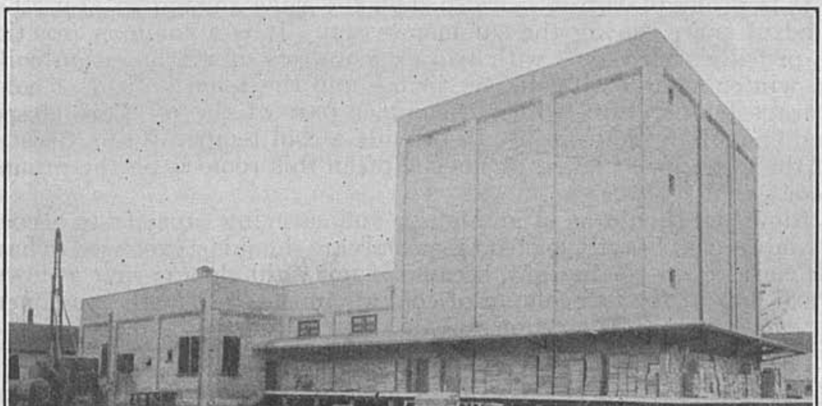

FIG. 6.—Freezer of brick construction and cork insulation, Bay City, Mich. Courtesy, Bay City Freezer

be calculated for maximum daily requirements, due regard being had for the frequency with which these maxima are likely to occur. In public warehouses, where the first month's storage includes the freezing charge, this first month yields more profit than succeeding months of storage. Quick turnovers are therefore desirable. In private freezers, where the goods are held for a favorable market, the storage space may be the limit to the amount of business possible.

The sharp freezers, engine room, receiving, washing space, and clerk's office usually are located on the first floor. In some freezers in New England that freeze much herring for bait the receiving space is on the top floor and the sharp freezers are situated immediately under the receiving floor, in which several hatchways are provided. The herring are hoisted from the boats to the top floors, whence they are dumped through the hatches on wooden flakes in the sharp freezers.

The mistake frequently is made in freezer designs of allowing too little space for receiving, washing, panning, and other operations carried on in the open. Space may look large on a blue print but turn out to be too small when occupied by trucks, washing trough, empty pans, barrels, and boxes, when several men must work expeditiously, not only in washing and panning but also in packing and stenciling boxes.

The glazing room should be situated preferably on the route from sharp freezer to storage rooms. In many cases it is situated adjacent to the sharp freezers and serves a double purpose as glazing room and anteroom for the sharp freezers. In some cases it is on one of the upper floors. Ample room should be provided for shooks and, where advisable, a nailing machine.

In localities where conditions warrant it, a room held at about 32 to 35° for short-term storage of fresh, mild cured, and smoked fish, is profitable, often more so than the same amount of any other kind of space during the summer season. It is a common practice to provide such rooms with two or more sets of refrigeration coils. In winter months all coils are in use and the room is held at cold-storage temperature, while in summer part of the coils are closed, and enough are kept in use to provide a cool temperature. Because of the necessity of quick turnovers, often this room is on the ground floor.

Elevators should be of ample size and carrying capacity to accommodate trucks heavily loaded. Especial care should be exercised to have all elevator doors air-tight, because if not tight they permit a downward flow of the tall column of cold air in the shaft with consequent serious loss of refrigeration.

INSULATION

Some freezers are of frame construction insulated with sawdust. Lith and other materials frequently are used. Without a doubt cork is the most satisfactory insulating material we have. It is used best in connection with brick or concrete construction, though when properly protected with waterproofing materials is quite satisfactory in frame structures. Either excess or deficiency of cork insulation is false economy. Too little cork is wasteful of refrigeration and makes the maintenance of a proper temperature difficult. Where more than enough is used, depreciation and interest on investment more than equal the expense for refrigeration saved.

FLOORS

Floors in cold rooms generally are insulated. Usually they are waterproof and are designed to withstand heavy trucking. Those that are wet should be provided with floor drains connected with a sewer.

FIG. 7.—Conveying machinery in a fish freezer. The pans of fish are placed on the roller conveyor at right. At the end of the conveyor, in background, they pass on a pair of scales (shown in fig. 8), where they are weighed. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

LIGHTS

Electric wiring should be insulated to resist dampness that may accumulate heavily on a change of temperature. Pilot lights should be placed at conspicuous places outside the rooms, and the lights always should be turned off when not in use.

CONVEYING MACHINERY FOR LABOR SAVING

The opportunities for saving labor by the use of conveying apparatus appear to have been largely neglected in fish freezers. Elabo-

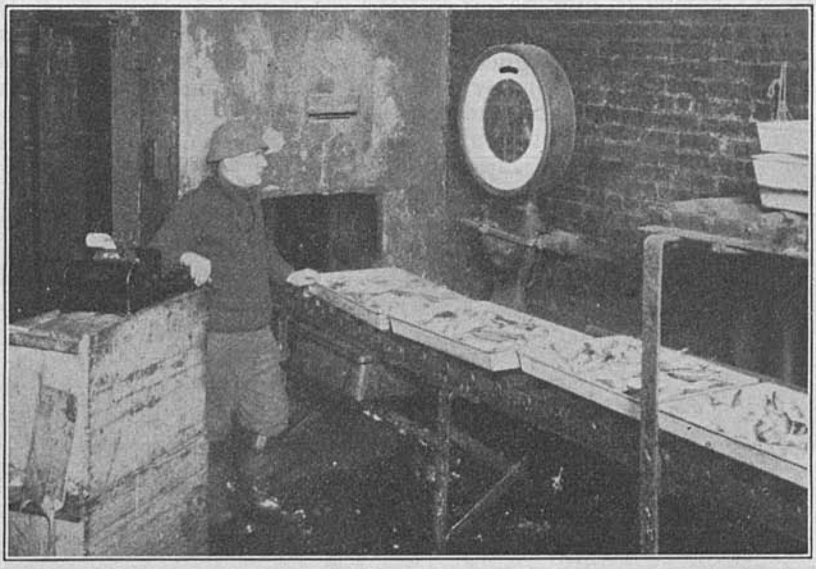

FIG. 8.—Conveying machinery in fish freezer. The fish pass on a roller scale platform. The weights are recorded on an adding machine. The fish then pass into the vertical conveyor to the top floor sharp freezers. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

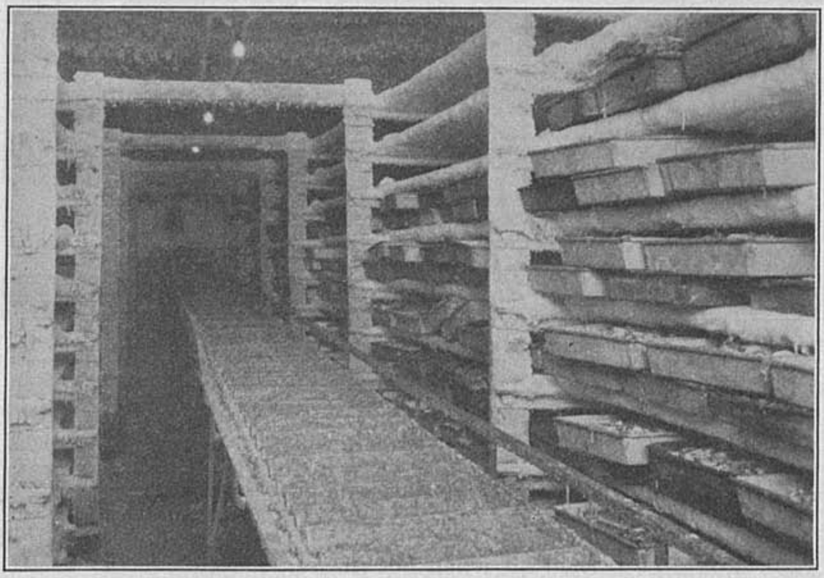

FIG. 9.—Conveying machinery in fish freezer. The fish pans pass down the roller conveyor in the sharp freezer, to be placed on the pipes. When frozen, they are again placed on the conveyor and pass out through an opening in the door in the other end to the glazing rooms. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

rate conveying apparatus has been installed in the plant of the Brooklyn Bridge Freezing and Cold Storage Co. in New York.[22]

Here the fish are panned at a long washing and panning trough on the ground floor, the pans being placed on a roller conveyer that conveys them toward a pan elevator in the rear of the building. On the way to the vertical hoist they pass over platform weighing scales. A man stands at the scales and notes on an adding machine the weight of each pan. The pans then go on the continuous vertical hoist that carries 8 to 9 pans per minute to the top floor, where the sharp freezers are situated. From the hoist the pans move by gravity on another roller conveyer into the sharp-freezer room, where they are placed on the shelves by hand. In an anteroom at the front of

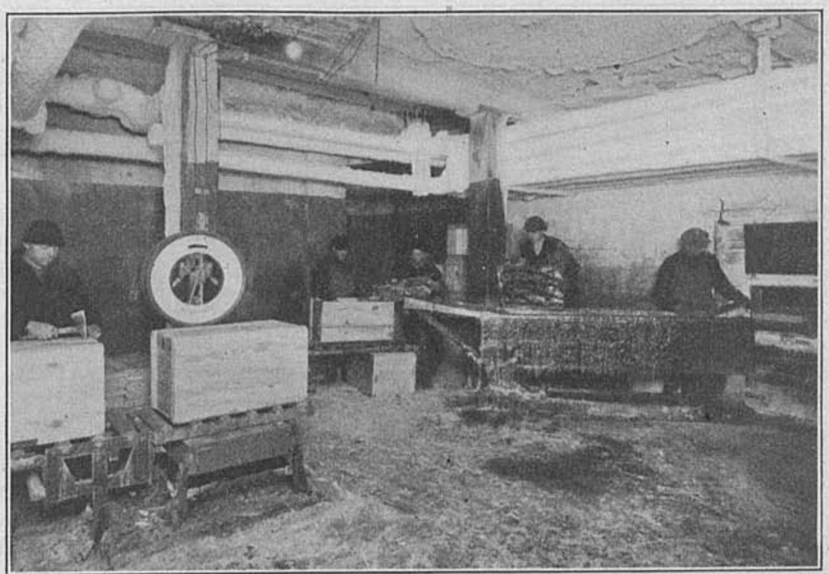

FIG. 10.—Conveying machinery in fish freezer. The pans of frozen fish emerge from the sharp freezer (right), are passed through the glazing pot, where the pans are removed from the cakes, glaze applied, and the cakes boxed and weighed. The boxes pass down a spiral chute to the storage rooms below. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

the building the fish are glazed and boxed and conveyed by a gravity roller conveyer to a weighing scale, where the filled boxes are weighed. The roller conveyer then takes them to an elevator that carries them to the lower floors.

A similar plant, with automatic conveying machinery, nailing machines, and other labor-saving devices, is the fish-freezing plant that was built for the French Government on the Island of St. Pierre, Miquelon.[23]

In both of these freezers the fish are handled after panning only in putting them on and taking them off the shelves and in glazing and boxing.

[22] For a description of this plant see Refrigerating World, vol. 56, No. 8, August, 1921. New York.

[23] Refrigerating World, vol. 56, No. 1, January, 1921. New York.

REFRIGERATION MACHINERY

Ammonia machinery is almost universally used in the United States for freezing fish. In some of the plants machines of the absorption type are used. While these are less efficient than compression machines for theoretical reasons, they are found in some excellent freezers. The loss of efficiency at low temperatures is relatively less than it is in compression machines, and the temptation to allow the temperature to rise is not so great. Therefore, though they are less efficient at all temperatures than compression machines, the very low temperatures necessary for the best freezing of fish are almost always maintained by them.

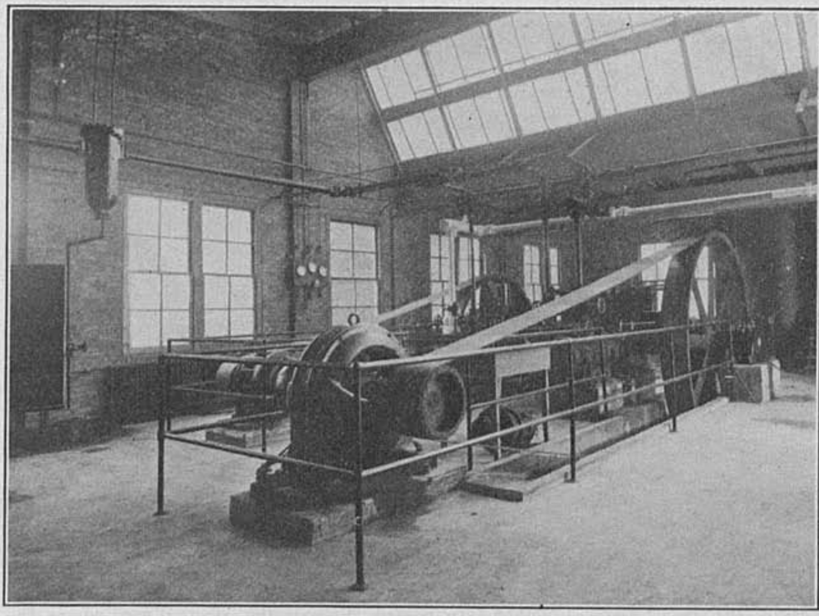

FIG. 11.—Refrigeration machinery, ammonia compression, electric drive. The electric drive is becoming more and more used. Where steam power is employed the compound Corliss engine gives a highly efficient service. Courtesy, Bay City Freezer

The two-stage compression machine that has come into use within the past few years is much more efficient than the single type at low temperatures. A large cylinder draws in the gas from the expansion element, gives it a preliminary compression, and passes it on to the final-stage cylinder of smaller diameter, where it is compressed to the condenser pressure. These machines approach the absorption machine in their maintained efficiency at low temperatures and are well suited to fish freezers.

For compression machines electric power is preferred; for absorption machines steam, of course, is necessary.

Many plants employ brine circulation, which gives more stable temperatures and permits easier regulation.[24] When brine is circu-

[24] For a compact and practical handbook of operating refrigerating plants see "Instructions for the care and operation of refrigeration plants." Department of the Navy, Bureau of Engineering, N. Eng. 144, revised edition, 1921. Washington.

lated, all the pipes are filled with the refrigerating medium and are therefore effective. In direct expansion systems a deficient charge of ammonia or improper regulation of the expansion valves may give rise to a condition wherein only a part of the piping is actually effective. For example, the writer has seen a sharp freezer heavily piped but with a temperature far too high. Examination revealed that all the ammonia admitted to the coils evaporated in three turns of pipe, and only these three were frosted. Further, really efficient operation of an ammonia machine requires skill, understanding, and watchfulness on the part of the operator. These qualities are more likely to be manifest if there is one expansion valve under his immediate care in the engine room than if several are located in various parts of the building. Another reason for preferring brine, especially in sharp freezers, is that the large volume of cold brine in the pipes prevents an excessive rise of temperature when the rooms are first loaded. The higher first cost of apparatus for brine circulation is justified in most cases by the more satisfactory operation.

Air washers, deodorizers, and dehumidifiers are not used and appear to be unnecessary in fish-freezing plants. Deficient rather than excessive humidity occurs in the rooms, but no satisfactory mechanical means has been devised for correcting this trouble. Drip pans sometimes are placed under the pipes but appear to be unnecessary, except in cool rooms kept above the freezing point of water; and even then, if the pipes remain frosted, they are not needed.

PRACTICAL FREEZING METHODS

FREEZING IN COLD ROOMS

As freezing in cold rooms is in almost universal use in the United States, the method will be described in detail, together with all necessary operations, some of which apply also to other methods that will be treated later.

RECEIVING AND INSPECTION

If the fish are received from the hold of a boat, usually they are hoisted mechanically to the platform. For salmon a satisfactory hoisting vessel is a wooden box lined with galvanized sheet iron. The ends of the box slopes outward and a rope is fastened by a hook in a ring at each end. When one end of the box is released on the platform and the other lifted, the salmon slide out easily and without impact. Halibut are hoisted by a 6-inch mesh cargo net woven of ½-inch manila rope, which, when caught by hooks at the corners, makes a large bag. This serves to hoist large quantities of halibut but seems to squeeze the fish against the ropes excessively. In most commercial freezers the fish arrive in boxes or barrels, iced. Immediately upon being landed western halibut are beheaded, the head portion is lifted with a meat hook, and the head is cut off with a butcher knife.

Before the fish are accepted they are, or should be, inspected for quality. It can not be repeated too often or too emphatically that this inspection should be severe. The temptation to save their fish when they can is but natural among fish merchants, and they as naturally prefer to send them to the freezer rather than to the garbage dump when the exigencies of the trade make them unsalable for the time. Yet fish that are stale when frozen will not be less stale when they are defrosted. Every pound of off-quality fish that is frozen impairs the public esteem of frozen fish.

It is to be presumed that those in charge on the freezing platforms know the marks of fresh, old, or spoiled fish. General marks may be tabulated as follows:

GOOD FISH	BAD FISH
1. Odor of fish, fishy.	1. Odor stale, sour, or putrid.
2. Eyes bright, not wrinkled or sunken.	2. Eyes dull, wrinkled, sunken.
3. Gills bright red, covered with clear slime; odor under gill covers fresh, fishy.	3. Gills dull brown or gray, slime cloudy; odor under gill covers sour and offensive.
4. Colors bright.	4. Colors faded.
5. Flesh firm; in quite fresh fish the body is stiff; impressions made by fingers do not remain; slime present and clear (eels, halibut).	5. Flesh soft and flabby; impressions made by fingers remain; slime absent (halibut), slime cloudy, ropy (eels).
6. Belly walls intact.	6. Belly walls often ruptured, viscera protruding.
7. Muscle tissue white.	7. Muscle tissue becomes pinkish, especially around backbone.
8. The vent is pink, not protruding.	8. The vent is brown, protruding.

Many fish have marks of quality peculiar to them. Halibut often turn yellowish on the white side, the skin on the tail wrinkles when the tail is bent around, and the belly cavity becomes red and sour-smelling. Eels become covered with a white ropy slime. Such marks can be learned only by experience and careful observation. In some instances freezers, especially those conducted for private business, establish quality grades with more or less definite standards. In public freezers note is taken of the quality and entered in the records. One large private firm uses the following grades for halibut:

1. Perfect fish: White side not stained or colored; no cuts or wounds; black side bright; slime present and clear; blood bright, fresh red; fish firm and plump; smell sweet.
2. Fish of high grade but for a minor reason not in grade 1: As slime leaves body a yellow color spreads over white side; blood blanches and flesh becomes softer. These defects in moderate degree, slight wounds or gray spots on white side will cause halibut, otherwise excellent, to fall into grade 2.
3. As conditions described under 2 advance, the fish becomes slimeless and yellow, inside of belly cavity pink or stained; sour odor becomes evident; flesh soft, imprints of fingers remain; skin wrinkles when tail is bent; flesh lean or "loggy"; white side gray. Still fit for food but far from fancy.
4. Fish so far spoiled as to be unfit for food. If the inspector himself would not be willing to eat the fish they go in this class.

CLASSIFICATION OF TRADE SIZES

At the time of receipt fish are often sorted according to size, and there may be many size categories for one kind of fish. For example, in mackerel there are spikes, tinkers, medium, and large; bluefish, baby, small, medium, large; halibut, chicken, small, medium, large, whales. These are so numerous and varied that they can not be given in a work of this scope. Fish that are panned and frozen in cakes are sorted during the panning operation. Fish that are frozen singly, like halibut and salmon, are sorted after the glazing operation.

In private freezers (especially for salmon and halibut on the Pacific coast, where the fish are purchased by the freezer) the fish are next weighed. For this purpose, two-wheel carts are provided, with the body lined with galvanized sheet iron and with the forward end sloping outwardly so that when dumped the fish slide out without violence. These carts are tared; with their load of fish they are rolled upon the scale platform and weighed.

DRESSING AND CLEANING

Fish freezers generally do not make a practice of dressing fish before freezing. In some cases this is done, especially in salmon. The salmon are dumped into a washing tank with fresh water running continuously. They are taken from the tank, beheaded, and gutted. The slit in the belly is sometimes made so as to leave the napes of the two sides connected (that is, the shoulder girdle bones are not separated). This prevents the fish from spreading open.

The belly membranes are rubbed out and the kidney (bloody organ in the belly cavity running along the backbone) is removed. For this work the operators use cotton gloves. In some instances hand brushes are used. The importance of removing the kidney and blood is overlooked frequently. It has been found that the blood of fish decomposes much more readily than the flesh of fish. If all the blood is removed carefully the fish will keep much better than it will if some blood is left. It is impossible to remove all blood if the kidney is left in the fish.

In public freezers fish usually are frozen as received—sometimes gutted, sometimes not. Salmon, halibut, and haddock always are gutted, and usually also medium and large bluefish, weakfish, and lake trout; mackerel, eels, smelt, butterfish, and the smaller pan fish are usually frozen round.

Apart from the desirability or undesirability of gutting as a trade practice, it deserves and has received some consideration as a question of sanitation and keeping quality. Green[25] investigated the subject; the following extracts from her memoir show her results:

(*a*) *Physical examination.*—Altogether about 50 gutted and ungutted fish were examined carefully, externally and internally, and comparisons made. Each fish was cut down the length of the spine and opened out like a kipper for inspection. Little difference in external appearance could be detected between gutted and ungutted fish, but much difference was apparent internally. Comparisons were best made after the fourth day at ordinary temperature.

The flesh of the ungutted herrings was still fairly white, firm, and in most cases free from any putrid smell. The muscle tissue immediately round the spine was inclined, on the whole, to be more bloodstained than was the case with the gutted ones, but in spite of this the flesh was firmer, whiter, and in better condition.

The flesh of the gutted ones, on the other hand, was much yellower and more discolored although not so bloodstained down the spine. They also had a very strong oily smell, which was completely lacking in the ungutted ones; in fact, the general appearance and smell of them was not nearly so good.

[25] Ione H. Green, "Report of experiments on the cold storage of herrings carried out at North Shields [June and July, 1919]." Department of Scientific and Industrial Research, Food Investigation Board, Memoir No. 11, 6 pp. London, 1920.

(*b*) *Bacteriological examinations.*—A large number of fish-agar Petri dishes were inoculated with samples of muscle from gutted and ungutted herrings after four or five days at ordinary temperature, and comparisons were made of the amount of bacterial growth produced. The result was that in about two-thirds of the total number of plates the largest amount of growth came from gutted herrings. In view of the fact that the bacteriological samples were taken with extreme care in every case, and the muscle always taken from the same part of the fish, it was proved pretty definitely that more bacteria made their way into the muscle tissues of the gutted than of the ungutted specimens.

This result is due to the gutting process, wherein a large amount of gut contents are left behind upon the inner body wall; and although much of it is washed off in the brine tank, a large number of gut bacteria penetrate the flesh and start putrefaction more quickly than in the case of the ungutted fish, where the bacteria are imprisoned within the gut whose wall has first to be penetrated. Moreover, in the case of the gutted fish the inner as well as the outer surface is exposed to foreign contamination of all sorts, particularly after coming out of store, and this certainly hastens putrefaction more than when only the outer surface of the fish is open to infection.

It ought perhaps to be mentioned that the colonies produced on all the plates were chiefly of the same kind, namely, moist, round, buff-colored, fairly large, irregular-sized, Gram negative diplococci. All the plates gave off a strong smell of ammonia after the third day.

The strong smell of the fish referred to evidently was oxidation or rusting of the fat. The fish were kept at from 18 to 25°, which, of course, is far too warm to prevent rusting. These excessively warm temperatures may explain in large measure the difference she found.

This criticism applies to much of the otherwise valuable research work done in England and in Europe on freezing and cold storage of fish. The work of Plank, Ehrenbaum, Reüter, Stiles, Fortuyn, and others applies largely to freezing and storage at temperatures much above zero. It is well known in this country that satisfactory results can not be so produced.

WASHING

The commonest method of washing is to dump the fish, together with the ice in which they are packed, into a trough of water. This trough usually has a slat framework in the bottom and a standpipe for overflow of water. Usually water runs continuously into and out of the tank. Water serves to wash the fish and at the same time to remove the cracked ice. Sometimes the fish are roused about in the water with a wooden rake. When the washing consists in no more than putting a large quantity of fish into a small quantity of water and taking them out to pack them obviously it can do little good. The slime is tenacious and is the breeding ground of bacteria. Blood and pieces of gut are on and in the fish. The water quickly becomes a heavy culture of bacteria, which would do much more harm than good to a really fresh fish. Green (above referred to) says "finally, if fish, when gutted, can not be washed in *running* water they are far best left unwashed altogether."

Where a large volume of water is running vigorously and freely over and among the fish it does more good, especially in ungutted fish. There is also the question of washing off slime, which is not always desirable. A fresh eel, for example, if frozen with the slime on will look more natural after defrosting than it would if it had been washed thoroughly. It is the view of some, also, that the slime constitutes a natural protection for the fish. These arguments have some force when applied to perfectly fresh, ungutted fish. In fact, if the fish could be frozen round immediately after coming from the water, without washing, they would be best of all; but after they have become infected heavily and have been gutted and contaminated with intestinal bacteria there seems to be no escape from the necessity of thorough washing, even though it does remove the slime.

Halibut when slimy are sometimes scrubbed with a brush before they are frozen. This practice is to be recommended, as old slime is of no value, and only serves to detract from the appearance of the fish. Eels should not be washed entirely free of slime. When

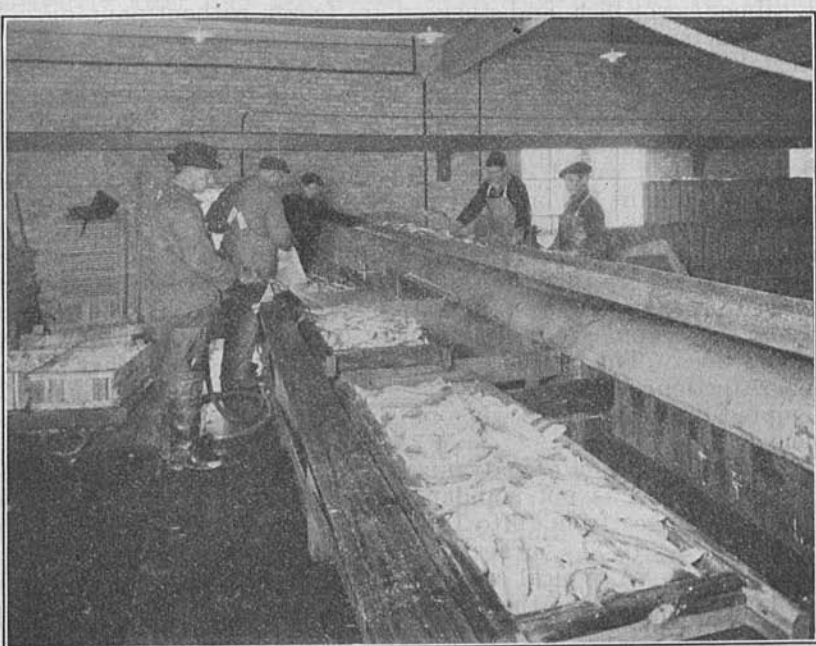

FIG. 12.—Washing. The fish in this case are in trays with slat bottoms. They are washed with a spray of water that runs through. In this freezer the wash water is maintained at 32° F., which serves to precool the fish. The fish may also be washed in the tanks, a more common practice. Courtesy, Bay City Freezer

perfectly fresh, the slime is desirable for the German smokers; but when the eels are a few days old the slime becomes ropy and unsightly and should be washed off. The glaze does not stick well over a heavy slime, but if not too heavy or ropy some of it may be left on by washing only lightly.

The water used for washing fish is usually, though unfortunately not always, pure, clean drinking water. The practice of using harbor, lake, or river water that has not been filtered or otherwise purified and that may contain bacteria that not only promote decomposition of fish but are a menace to health, is wholly bad. If there is any doubt about the quality of the water used, it is, of course, a duty that the proprietor owes to the public to have samples examined by a competent bacteriologist or the city or State board of health that has jurisdiction. It is always best, where possible, to use the city water that has been purified for drinking purposes.

On the Pacific coast halibut are washed with a hose. In some freezers the halibut are laid out on the floor, white side up, heads all in the same direction. A strong stream of water is played on the fish by means of a hose and is directed as much as possible into the belly cavities. In other places each fish is raised from the floor and given a momentary squirt of water with a hose.

PANNING

Smaller fish nearly always are panned. (See fig. 7, p. 531.) Halibut, salmon, swordfish, and sturgeon are frozen without panning.

The practical advantages of packing the smaller varieties of fish in metal pans and freezing them in cakes have made the practice almost universal. By this means the fish are handled conveniently before and after they are put into the sharp freezer. The labor of handling and glazing the frozen fish is greatly reduced and simplified; boxes that would contain only about 125 pounds of singly-frozen fish contain 150 or more pounds frozen in cakes. In storage, exposure of the fish, as well as drying and rusting, is reduced. In shipment, breakage and abrasion are diminished. The disadvantages of pan freezing are that the rate of freezing is retarded because the surface of fish exposed to refrigeration is reduced. It has been shown already that rapid freezing produces better frozen fish than slow freezing does. The pressure of the fish against each other causes some distortion, and damage frequently is done to the fish when it is attempted to break a cake when only a part of it can be used at one time.

The pans are made of galvanized sheet iron, usually of 22 to 24 gauge. The size is not standardized, but custom has established a pan that ranges from 16 to 18 inches in width, 26 to 28 inches in length and 2½ to 3½ inches in depth. They hold from 25 to 35 pounds of fish. A typical example, taken from measurements made in a large freezer, has the following dimensions: Bottom of pan, 15¾ inches wide, 25 inches long; top, 17½ inches wide, 26¾ inches long; depth, 3 inches. The edges are of rolled wire.

Four ⅜ or ½ inch holes are made in the bottom of the pan to permit water and slime to drain off. In most freezers no lid is provided for the pans, in which case the sides of the pan slope outward, so the cake can be removed easily. In a few cases the sides of the pan are vertical and a lid is used to cover it. These lids keep drip out of pans that rest upon one another, keep "snow" from falling on the fish in the freezer, and undoubtedly prevent some loss of weight from drying in the freezer. Pans with lids have plain-cut edges.

The panning operation is most often done on tables attached by brackets to the side of the washing trough, usually 4 to 8 in number and about 2 feet apart. Moderate-sized fish are alternated, heads and tails, in one or more rows so as to fit nicely into the pans. Eels are bent around; large fish are arranged as orderly as possible. Some ingenuity is required to place the fish neatly. The heads point outward, if possible, so that the tails may be protected against breaking off. Gutted fish are panned bellies downward, so that the water may run out of the belly cavity. Round fish are packed bellies up. Usually the fish are not panned in two layers, because a two-layer cake is difficult to break, if a part of the cake is wanted, without separating the whole. The bellies are left exposed, as the appearance of the belly of a fish is often indicative of the quality. Squid and butterfish are not arranged definitely in the pans but are dumped in promiscuously. Shrimp are better scattered thinly over the bottom of the pan, as otherwise they entrap so much air as to freeze slowly. Sometimes mackerel and shad roes are placed alone on the bottom of the pan, so that they can be wrapped separately after they are frozen. The time required for panning ranges from ½ to 4 minutes for each pan, depending on the size and style of arrangement of the fish and the skill of the operator. For example, a skilled worker can fill a pan of Spanish mackerel, small lake trout, or ciscoes in 1 to 1½ minutes. It is generally desirable to put as nearly as possible the same weight of fish in each pan, but nowhere are the pans weighed as they are packed. When the pans are filled, they are stacked on trucks, sometimes 8 or 10 deep. The pressure exerted on the fish in the bottom pans obviously does the fish no good and by crushing and bruising may promote autolysis.

FREEZING IN THE SHARP FREEZER

DESIGN AND CONSTRUCTION

Sharp freezers are usually small and several in number. The sizes most commonly found have a capacity ranging from 15,000 to 40,000 pounds at a charge. Usually they are long, narrow rooms, side by side, with doors at the ends.

Small rooms usually are preferred to large ones, because such rooms can be filled and left unmolested until the charge is frozen. In large rooms the temperature is more stable because of the large reserve of brine in the coils, but this advantage is offset by the disadvantage of frequent opening and closing of doors to put in and take out small lots of fish.

The side-by-side arrangement reduces the necessity for heavy insulation, except on outside walls, which should be covered with 6 or 8 inches of corkboard. It is always advisable to have storage rooms, glazing rooms, or chill rooms, rather than warm rooms or outside walls, adjacent to the sharp freezers. The same applies to rooms above and below the sharp freezers. Anterooms also are desirable to prevent excessive loss of cold air when the doors are opened. Sometimes a narrow corridor is built, into which all of the sharp freezers open. Often this is used as a glazing room.

PIPING IN SHARP FREEZERS

Along each side is a bank of refrigeration coils made of 1½ or 2 inch iron pipe, arranged to make shelves on vertical centers of 6, 8, or 10 inches. Direct-expansion ammonia or calcium-chloride brine from the refrigeration system circulates in these coils. If ammonia is expanded directly into the coils the expansion valves preferably should be located at or near the low point of the coil, either inside or outside the room, and the coils kept well flooded with ammonia, with a trap to prevent the liquid ammonia from returning to the compressor. The "flooding" of the pipes with liquid ammonia secures the advantages of superior conduction of liquid in the coils as compared with gaseous ammonia. The "flooded" system, however, requires certain features of design and installation that, for the sake of safety, must not be overlooked.[26]

Where brine is used it is important to have a brisk circulation forced by an efficient pump. A mistake in arrangement of the circuits of pipe may greatly reduce the efficiency of the freezers. Where a main brine header is used, with many parallel circuits branching off, the flow of brine may be rapid in the header but slow in some rooms, especially when circuits in other rooms are open. This difficulty is avoided if the circuits are all in series, or, if more convenient, in two or three parallel series. When this arrangement is made, a by-pass connection is made to bridge each room coil, so that cutting off one room coil does not stop the flow through the entire system.

TEMPERATURE MAINTAINED IN SHARP FREEZERS

It has already been pointed out that the more rapid the freezing of fish the better. In fact, slow freezing is the one great defect in the method of freezing now being described and which is in common use. It is to be remembered also that the rate of freezing is proportional to the difference in temperature between the fish and their surroundings. If the fish on entering the freezer are at 32° they will freeze 50 per cent faster at 16° below zero than they will at 0°. The desirability of flooding the pipes with ammonia or briskly circulating brine is therefore of as much importance as the degree of temperature of the ammonia or brine, good insulation, and tight doors.

In this connection it is desirable to define what we mean by temperature of the air in the room. This temperature changes with the opening of doors and the loading and unloading of the room. When a freezer is filled with fresh fish and the door is closed the temperature rises because the fish are giving up their heat to the surrounding air. As the air warms, the difference between its temperature and that of the brine pipes increases, and, according to our rule, the rate of absorption of heat by the brine increases. The brine, flowing at a constant rate, warms, and the difference between its temperature and that of the ammonia increases, again giving up heat faster, in accordance with the rule. The ammonia warms, and the pressure shown by the suction gauge in the engine room rises. These changes continue until the whole system is in equilibrium—heat is being given up by the fish as fast as it is being absorbed by the brine (or ammonia) in the pipes, and the machine removes the heat at this same rate. The temperature in the sharp freezer

[26] See H. Rassbach, "The value of the flooded system, and its application to ice making and refrigerating plants." Paper read before the American Society of Refrigerating Engineers, Chicago, Oct. 18 and 19, 1909. Also published as Bulletin, L. A., by the Vilter Manufacturing Co., Milwaukee, Wis.

will now remain approximately constant for some time; that is, until the fish are so frozen that they give up heat at a diminishing rate. Then a series of changes in the opposite direction occurs. The brine pipes absorb heat from the air faster than the fish give up heat; the air becomes colder. The ammonia absorbs heat faster than the brine gets it from the air, so the brine grows colder, likewise the ammonia, and the pressure on the suction gauge drops. This continues until the fish are frozen through and until there are only small differences in temperature all around. The temperature at the finish may be 10 or 20° below zero, but it is not proper, for practical purposes, to call this the temperature of the room. It would do the fish no good to cool them to 50 or 100° below zero after they are frozen; in fact, there is little doubt but that it would do them harm. The important thing is not how cold they are eventually, but *how fast they freeze.* As the rate of freezing, as we have seen, is determined by the difference between the temperature of the air and the temperature of the fish while the freezing is going on, we may say that the speed with which they freeze is determined by the coldness of the air around them *while they are freezing.* The temperature of a sharp freezer thus may be defined as the maximum, approximately constant, temperature of the room after it has been loaded and the doors have been closed.

Failure to understand this principle often leads to difficulties and poor operation. A case that recently came to the writer's attention may well illustrate the point. A new freezer, approaching its maximum fish production of the season, contains a room with piping designed for a storage temperature of about 0°. When closed and empty it had a temperature of about 5° below zero. The management, anticipating a shortage of freezer space, reasoned that as a temperature of 5° below zero was as good as that of a sharp freezer (when it is loaded) the room might be used as a sharp freezer during the rush of fish production by the aid of wooden frames for the pans of fish. The management was surprised, of course, to find that the temperature of the loaded room rose many degrees above zero, and that the fish froze very slowly and were greatly damaged thereby. There was not enough pipe in the room to absorb the heat from the air as fast as the air absorbed it from the fish. The air grew warmer, the difference between the temperature of the air and that of the fish diminished, and the rate of freezing was retarded. This brings out another important rule; namely, each square foot of pipe surface absorbs a definite number of thermal units per hour per degree of difference in temperature. Under the conditions pevailing in a sharp freezer this figure is about 5 B. t. u. From 25,000 pounds of fish approximately 3,480,000 B. t. u. must be removed in order to freeze it, and the required number of square feet of pipe surface must be available to carry this amount of heat away in the given time.

On the basis of this definition we have few exact data regarding the degrees of temperature maintained in sharp freezers. Final temperature in freezers ranges as low as 20° or 25° below zero, and during the heavy load it runs as high as 20° above zero. The temperature actually prevailing at any time in the sharp freezer depends on the piping, temperature and rate of flow of brine, quantity and initial temperature of fish, insulation, opening of doors, air circulation, etc. It is highly desirable to maintain a maximum temperature not above 0° F. during the freezing process.

There are also few data on the amount of time required to freeze fish in air. Pans of fish usually are allowed to remain on the sharp freezer for 24 to 36 or even 48 hours when the temperature is not low. Panned fish, small, and large fish freeze in about the same length of time, but if frozen separately small fish freeze much more rapidly than large ones.

In rooms refrigerated by direct expansion it is a common practice to stop flow of the ammonia while the rooms are being loaded. After the fish are on the shelves the doors are closed and the expansion valves opened. The room begins to cool and reaches a fairly constant temperature at several degrees above zero, where it remains for several hours, until the fish are nearly frozen. The temperature then drops gradually until it reaches, say, 10° below zero, when the fish are considered to be frozen. The ammonia is again turned off and the fish taken out. If the doors are left open, the snow on the coils thaws and there is much drip. The coils, being clean, absorb heat faster but also appear to take up moisture faster.

In rooms refrigerated by brine the brine is allowed to run continuously and the rooms are always cold. In such a case freezing begins at a lower air temperature and probably progresses more rapidly. As the snow on the pipes rarely thaws, it becomes very dirty from drip from the pans. It should be removed occasionally by shutting off the brine and warming up the room, or by an accessory circulation of warm brine through the pipes.

PLACING THE FISH IN THE SHARP FREEZER

In most cases the fish are trucked into the freezers, where the pans of fish are transferred from truck to coils. Sometimes a small door is let into the large freezer door, through which the fish may be passed without entailing a great loss of cold air. A few freezers have a roller conveyer leading from this small door along the corridor of the freezer. Operators receive the pans from the roller conveyer and place them on the shelves. (See fig. 7, p. 531.) The pans should rest directly on the coils. Sometimes, when freezer space is limited the pans are placed one on another; but this practice is obviously bad because, it will be remembered, the heat must pass out through the surface of the fish. Stacking pans two deep eliminates the bottom of one and the top of the other as available surfaces—nearly half the total surface—and retards freezing in the same proportion.

For large fish, where pans are not used, there are provided galvanized-iron sheets that are laid on the coils. (Fig. 14.) The fish are laid on these metal sheets in such a way that they do not freeze together. Still larger fish, such as whale halibut, swordfish, and sturgeon, are laid on the floor or on boxes or battens to freeze or else they are suspended. Large fish like these freeze in 2 to 4 days at a sufficiently low temperature.

Herring for bait are not panned but are dumped en masse on wooden flakes. If on iron sheets they stick and are difficult to remove.

Shucked oysters in 1-gallon tin cans are simply placed in the sharp freezers on the shelves or floor and allowed to freeze. Clams and scallops are treated in the same manner, the latter sometimes being frozen in muslin bags.

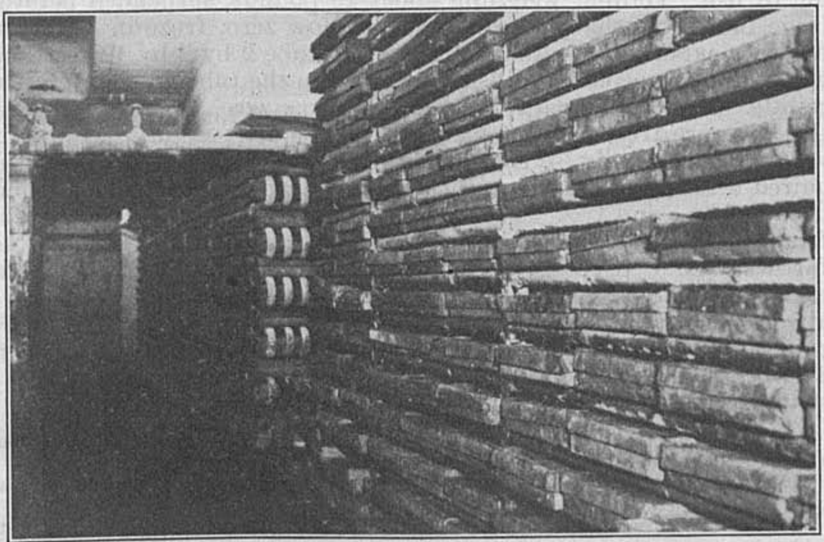

FIG. 13.—Fish pans in sharp freezer. In this freezer the pans are fitted with lids. Courtesy, Booth Cold Storage Co.

FIG. 14.—Salmon being individually frozen. The pipe shelves are provided with sheets of galvanized iron on which the fish are laid. Courtesy, Canadian Fishing & Cold Storage Co. (Ltd.)

Circulation of air, especially if rapid, greatly facilitates the freezing of fish. Halibut weighing about 15 pounds, suspended before a large fan in the sharp freezer at 9.5° below zero, froze in 3½ hours. Another experiment with a long wooden tube 2 by 2 by 12 feet long, with a fan at one end and fish suspended in the tube, gave interesting results. The air temperature was 10° below zero. Whitefish nearest the fan were frozen in one-half hour. The air passing over the fish was warmed rapidly, so that fish at the opposite end of the tunnel required three hours to freeze. At 7° above zero smoked fillets of haddock before a fan froze in 30 to 40 minutes, according to the distance from the fan. The nearest were 6 inches from the fan and the farthest about 18 inches. This method of freezing dries the fish excessively, and, because of the large volume and high velocity of air necessary, seems impracticable for commercial use. About 33 cubic feet of air are equivalent in cooling power to 1 pound of brine. The preferred practices to be recommended in the freezing of fish in sharp freezers may be summarized thus:

1. The sharp freezers should be adjacent to each other or to other cold rooms, and exposed walls, floors, and ceilings should be heavily insulated.
2. Tight doors should be provided, and the air circulation should be locked with anterooms.
3. Fish are preferably passed into the freezers through small doors in the main doors.
4. The freezers should be very heavily piped.
5. If ammonia is directly expanded in the pipes the latter should be kept flooded with ammonia.
6. If brine is circulated in the pipes, pipe circuits should be so arranged and pump capacities provided to give very brisk circulation.
7. The rooms should be cold when the fish are put in.
8. The fish in pans should not be stacked, but each should rest directly on the pipes.
9. The temperature of the air in the room should, if possible, never be higher than 0°.
10. To obtain the proper temperature of the room the brine should be at from 10° to 20° below zero.

GLAZING

When frozen fish are to be stored, they are exposed more or less to the air. If they are not protected, the oxygen of the air will act on the fats, turning them rancid, and the moisture and perhaps odor and flavor principles will evaporate. To protect the fish from these untoward happenings they must be glazed; that is, the frozen fish must be dipped in cold water, some of which adheres and freezes as an envelope or glaze of ice, completely surrounding the fish.

REMOVING CAKE FROM FREEZING PAN

Fish that have been frozen in metal pans stick fast and must be warmed slightly by spraying with or immersing them in water to loosen them. In most cases this is done in one operation by passing the pan containing the frozen cake into the glazing bath. (Fig. 10, p. 533.) In this bath the fish thaw just enough to loosen the pan, which is then taken off. The cake, remaining a moment in the water, is covered with a glaze and is then removed for boxing. When this operation is done carelessly the side of the cake that was on the bottom of the pan is not wetted and therefore not glazed.

In one freezer a rectangular shower bath is provided at one end of the glazing tank. The pan is passed, upside-down, under this bath, and upon emerging from the bath the cake slides into the bath and the pan is removed at the same time.

GLAZING TANKS

The glazing trough usually consists of a shallow wooden tank, 6 or 8 feet long, with curved runners that pass under the water and out lengthwise of the tank. (See Fig. 10, p. 533.) In some tanks the

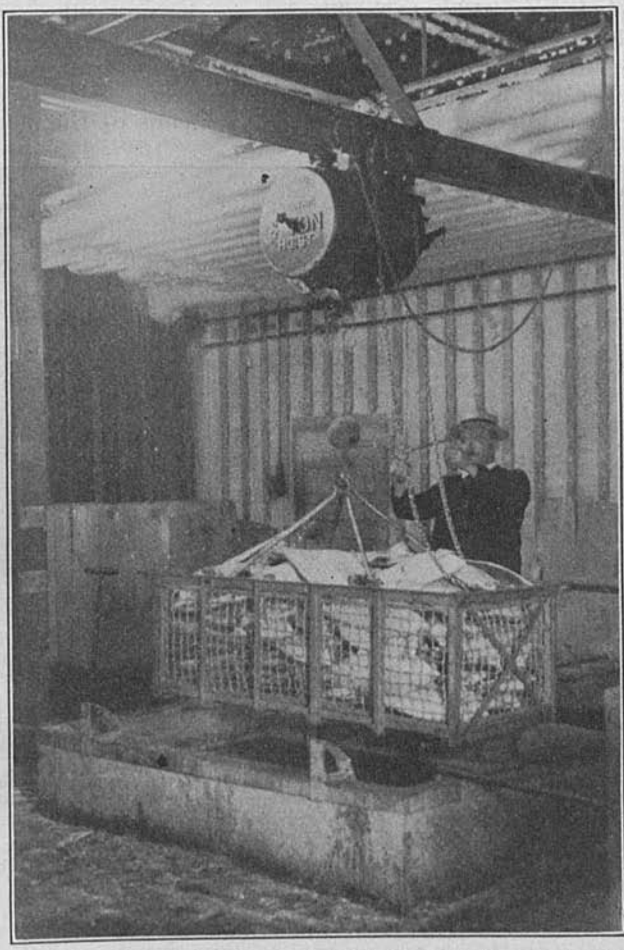

FIG. 15.—Improved type of glazing tank for salmon and halibut. The tank is of concrete. Courtesy, Seattle Port Commission

bottom is curved. The tank may be stationary or on casters. When no special room is provided for glazing, a movable glazing tank is placed near the sharp freezer doors.

On the Pacific coast, where halibut and salmon are frozen in large quantities, the glazing tank in common use is a stationary wooden or concrete tank provided with a movable wooden slat platform suspended by ropes to a windlass or lever, by which it is moved up and down in the tank. (Fig. 15.) The salmon or halibut are piled on this suspended platform, which, when loaded, is lowered into the water. One to four dips are given, separated by a moment out of the water for draining off excess water and freezing the glaze. An improvement on this type of glazing tank is a concrete tank partly below the floor level. Instead of the wooden platform a large rectangular, heavy, galvanized-wire basket is suspended by a one-half-ton electric hoist. (Fig. 15.) The hoist rides on trolleys on an overhead rail leading from the sharp freezers to the glazing room and from the latter to the elevator, and into the several storage rooms. The wire basket is loaded in the sharp freezer, conveyed into the glazing room, lowered into the water by means of the electric hoist,

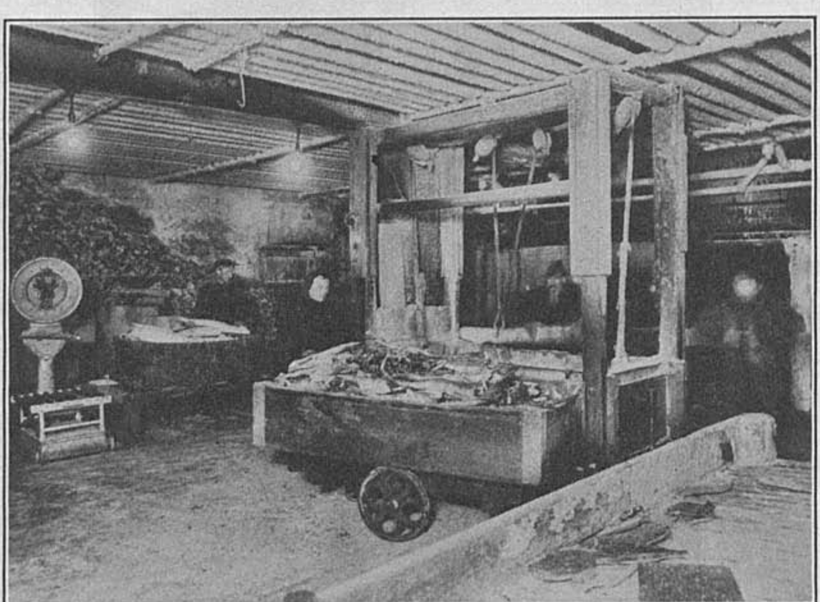

FIG. 16.—Glazing room of a Pacific coast freezer. Halibut, black cod, and salmon are being glazed in the dipping tank. Roller platform scales at left for weighing the glazed fish. Courtesy, Canadian Fishing Co. (Ltd.)

then raised and conveyed to the elevator and into the storage rooms. From 500 to 750 pounds of fish are handled at a load.

TEMPERATURE OF GLAZING ROOM

A fish that is not thoroughly frozen will not glaze properly, especially in warm air, because the fish is of itself not cold enough to freeze a good glaze. A simple calculation will illustrate the point. A 2-pound fish will take, say, a 5 per cent glaze. Assume that the glazing water is at 35°. The fish is 80 per cent, or 1.6 pounds, of ice. As the specific heat of ice is 0.5, then 0.5×1.6, or 0.8 B. t. u., is required for each degree of increase in temperature of the fish. One-tenth of a pound of glaze is frozen on the fish, requiring 14.4 B. t. u. of latent heat and 0.3 B. t. u. to cool the water from 35 to 32°, or 14.7 altogether; $14.7 \div 0.8 = 18.4°$ rise in temperature of the fish to freeze the glaze. This calculation is only illustrative, however, and does not necessarily represent what actually happens within the fish. It is more probable that at the beginning not all the water in the fish is frozen; the ice present is in equilibrium with concentrated fish juice. As the fish absorbs heat from the freezing glaze, some of the internal ice thaws, absorbing latent heat, with a corresponding dilution of the juice and rise in temperature.

At any rate, it is much better to derive part of the refrigeration from the surrounding air for freezing the glaze. While glaze will form on the thicker parts of the fish in comparatively warm air by warming the fish, the thin parts—fins, tail, and snout—will not glaze at all, because these parts do not contain sufficient refrigeration. They can be covered with glaze only in air cold enough to freeze the water. The freezing point of water being 32°, it might seem that air slightly below this temperature would be sufficient; but water drains off rapidly when fish are withdrawn from the water, and at too high a temperature too much of the water runs off before it has frozen, consequently the glaze is thin. Several quick dips with short intervals between in the cold-room air are better than one long dip in the trough. These several dips allow freezing of the glaze partly by the cold air rather than entirely by the fish.

The temperature in the glazing room should be low, therefore, and might be very low as far as the glazing itself is concerned; but workers object to remaining for long periods in very cold rooms. A temperature of from 12 to 15° has been found to be satisfactory, producing a good glaze and being not too cold for the workers if they remain vigorously active.

It is contended by some that because when fish come from the freezer they are not of uniform temperature throughout, further freezing of the inner portions occurs after they are placed in the cold-storage room, which causes further expansion that cracks the glaze. They should not be glazed at once but allowed to come to a uniform temperature in the storage-room air before the glaze is applied. There may be something in this objection to the practice now followed, but it is academic, for it would be commercially expensive to store loose or boxed fish and then handle them all over again for glazing.

TEMPERATURE OF GLAZING WATER

The glazing water should be clean, wholesome water of 35 to 40° temperature. In some plants warmer water is used. If operations are begun with warm water, ice is added to cool it; in this case snow from pipe coils should not be used, as it forms a mush that sticks to the fish, making a rough surface. However, as glazing proceeds, the water is chilled rapidly by the cold cakes of fish passing through it. When the water approaches the freezing point, a pebbly glaze is produced. The water must therefore be kept slightly warmer, preferably at about 35° F., by the continuous flow of a small amount of warmer water into the glazing tank.

THICKNESS AND AMOUNT OF GLAZE APPLIED

The cakes of fish are left in the water for from a few seconds to a minute at a time. It is inadvisable to leave them in longer. The conductivity of the fish is not any too good, and the fish is surrounded by water warmer than itself. The heat given up by the water in freezing is taken up by the outer part of the fish, but is conducted inward rather slowly, so that if the fish is left in the water too long the outer part of it is thawed. It is better to lift the fish out of the water in order to give the heat time to be conducted into the interior of the fish and also, if the air of the room is cold, to take advantage of the refrigeration in the air. If a thicker glaze is required, the fish may be dipped a second or third time. Excessively thick glaze is usually undesirable because customers may object to the undue increase in weight; and, also, too thick a glaze may crack on handling. The ideal glaze is clear, smooth, comparatively thin, free from roughness, and uniformly adherent to all parts of the fish, including snout, fins, and tail. The ice glaze usually has bubbles or tubular holes in it, probably caused by the air dissolved in the water. Water heated to the boiling point to drive off the air and then cooled off probably would produce a better glaze.

Tables 7, 8, and 9 give some idea of the amount of glaze put on fish. In general, it varies from 2 to 7 per cent. Fish frozen singly take a larger percentage of glaze than pan fish take, because there is more surface to be glazed. Small fish, individually frozen, take a larger percentage than large ones for the same reason. Soft, smooth fish, like eels, mackerel, and lake trout, take a better and heavier glaze than heavily scaled fish, like carp, drum, or red snapper, because heavy scales act as insulators, preventing the water from freezing quickly. Table 9 gives the amount of glaze on several individual cakes of squid, showing that, though the average amount of glaze is 2.5 per cent, that on the individual cakes varies from 0.8 to 3.9 per cent. It would be desirable for trade reasons to make cakes of uniform weight and glaze, but so far this has never been accomplished in practice.

TABLE 7.—*Glaze on blue pike, cakes frozen in pans*

Weight of cake—				Amount of glaze		
Before glazing		After glazing				
Pounds	*Ounces*	*Pounds*	*Ounces*	*Pounds*	*Ounces*	*Per cent*
33	0	34	1	1	1	3.1
39	12	41	1	1	5	3.2
34	9	36	3	1	10	4.5
38	14	40	3	1	5	3.3
33	14	34	15	1	1	3.0
38	0	38	13	0	13	2.1
34	9	35	12	1	3	3.3
38	8	40	3	1	11	4.2
38	12	39	13	1	1	2.7
Average						3.4

Halibut usually are trimmed before they are glazed. The side fins are chopped off with a large butcher knife or sharp hatchet, and the nape usually is smoothed with a little trimming. As will be seen in Table 9, the loss of weight in the trimming is about the same, on the average, as the amount of glaze, so that an untrimmed, unglazed halibut weighs about the same as a trimmed and glazed one. Fins if left on do not glaze well, dry out rapidly in the freezer, and act as a wick to draw out the moisture from the adjacent tissues.

TABLE 8.—*Gain in weight on glazing squid*

Pan No.	Weight frozen		Weight glazed		Gain in weight		
	Pounds	*Ounces*	*Pounds*	*Ounces*	*Pounds*	*Ounces*	*Per cent*
1	35	0	35	12	0	12	2.1
2	33	8	34	8	1	0	2.9
3	34	0	35	0	1	0	2.9
4	30	0	30	12	0	12	2.5
5	35	12	36	4	0	8	1.4
6	32	8	33	4	0	12	2.3
7	31	12	33	0	1	4	3.9
8	32	8	32	12	0	4	.8
9	33	4	34	4	1	0	3.0
10	30	12	31	12	1	0	3.2
11	40	0	41	0	1	0	2.5
12	25	8	26	8	1	0	3.9
13	27	8	28	8	1	0	3.6
14	33	0	33	8	0	8	1.5
15	35	0	35	8	0	8	1.4
16	29	0	30	0	1	0	3.4
17	32	0	32	8	0	8	1.5
18	32	8	33	0	0	8	1.5
19	27	8	28	0	0	8	1.8
20	25	12	26	8	0	12	2.9
21	25	8	26	8	1	0	3.9
22	34	8	35	8	1	0	2.9
Average							2.5

TABLE 9.—*Trimming and glazing halibut*

No.	Weight frozen		Weight after trim		Loss in trim			Weight glazed		Amount of glaze	
	Pounds	*Ounces*	*Pounds*	*Ounces*	*Pounds*	*Ounces*	*Per ct.*	*Pounds*	*Ounces*	*Ounces*	*Per ct.*[1]
1	16	15	16	4	0	11	4.1	16	14	0–10	3.7
2	15	11	15	2	0	9	3.6	15	12	0–10	4.0
3	13	10	13	3	0	7	3.2	13	11	0– 8	3.7
4	14	6	13	11	0	11	4.8	14	5	0–10	4.3
5	26	5	25	5	1	0	3.8	26	0	0–11	2.6
6	16	0	15	7	0	9	3.5	16	2	0–11	4.3
7	21	11	20	14	0	13	3.7	21	11	0–13	3.7
8	31	9	30	4	1	5	4.1	31	4	0– 6	1.2
9	23	3	22	4	0	15	4.0	22	14	0–10	2.6
10	14	13	14	7	0	6	2.5	15	1	0–10	4.2
11	24	15	24	2	0	13	3.2	24	13	0–11	2.7
Average	19	15	19	3	0	12	3.67	19	14	0–10	3.36

[1] Based on original or unglazed weight.

OTHER PROTECTIVE GLAZES

Materials other than ice have been used to cover fish, but apparently without commercial success. Paraffin has been tried, but is too brittle at low temperatures and can be applied in a perfect film only with great difficulty. Another substance tried with more success in Germany is called "Jela," a proprietary mixture of linseed oil, resin, paraffin, and carnauba wax. It is more flexible and more easily applied than paraffin, and undoubtedly keeps the surface of fish in almost perfect condition during long periods of storage. Being impervious to water and air, it prevents the slow evaporation, oxidation, and absorption of cold-storage odors that take place where impervious protection is not used; but at best it is expensive and troublesome to apply.

Gelatin in 3 or 4 per cent solution has been tried. This holds the moisture even when the fish is defrosted, but is not impervious to water or to gases soluble in water. While the gelatin film remains on the fish water can diffuse through it slowly and evaporate. Tests recently made with a gelatin glaze indicate that it offers no advantages.

BOXING, MARKING, AND WEIGHING

Before frozen fish are placed in the cold-storage room they are boxed or not, as the case may require. Boxes, as will be seen later, afford a certain amount of protection to fish and make for more expeditious handling. Breakage of fins, tails, and snouts is prevented, and drying and rusting are not extensive. Boxes also provide an easy means of marking weights, dates, names, and lot numbers. Boxed fish also are more economical of space, for they make it possible to fill to the ceiling a room that otherwise could not be so filled with assorted varieties and lots for which bins would have to be built. Pan-frozen fish usually are boxed, especially in public freezers. Large fish, such as halibut, salmon, carp, sturgeon, cero, king mackerel, red snapper, cod, and shad, which are frozen singly, often are stored unboxed. The maximum economy of space is attained in private freezers where pan-frozen fish are stored not boxed, the rooms being filled entirely with the cakes, closely stacked.

BOXES

The boxes are made of any suitable wood—spruce, pine, fir, etc. They are generally constructed as the "Style 4" standard of the box manufacturers. This style has the cleats on the ends of the boxes and is preferred because, when the boxes are stored on end, the cleats serve as battens to keep the boxes separated by spaces in which the cold air can circulate. Salmon and halibut boxes to be used for long-distance shipments usually are reinforced with a triangular strip nailed in the corners. For packing cakes of pan-frozen fish the boxes are made of a size just large enough to accommodate 4 or 6 cakes—that is, 100 to 150 pounds. Some inside dimensions of boxes in use are as follows:

TABLE 10

Length, inches	Width, inches	Depth, inches	Capacity
26.5	16.5	16	Four to five cakes.
26.5	14.25	18.5	150 to 165 pounds, winter-caught fish.
27	17	17	150 pounds cake frozen fish.
34.5	18	9.75	California shad.
51.5	25	16.5	Western halibut.

The thickness of wood is 3/8, 7/16, or 1/2 inch in the smaller boxes and 3/4 or 7/8 inch in the larger ones. In public freezers, where each lot of fish must be kept strictly intact, use is made of shallow extra, or "ex" boxes. These are made to fit one, two, or three cakes of pan-frozen fish and to accommodate odd numbers of cakes left over from the larger standard boxes.

The boxes usually are bought as shooks for convenience in shipment and are stored in a convenient dry room, attic, or shed. Nailing machines sometimes are used in the larger freezers, but in many freezers the management finds that fluctuations in the volume of business often leave the laborers with little to do, at which times they can be turned to nailing boxes by hand. The boards are nailed together as snugly as possible to avoid air circulation between the inside and outside. The boxes cost, in shook form, of North Carolina pine, from 40 to 55 cents each, in carload lots. White-pine boxes are considerably more expensive.

WRAPPING FISH AND LINING BOXES

Some fancy varieties of fish, such as mackerel, salmon, and whitefish, are wrapped with vegetable parchment paper before they are packed. The wrapping improves the appearance of the fish and may carry a printed trade-mark or advertising matter. It is further useful in protecting the fish from drying and rusting. Sometimes, usually for export, the boxes are lined with vegetable parchment paper. Parchment is used because it resists the action of water when the fish defrost. This lining paper also may bear a printed trade-mark. Fancy grades of frozen salmon and halibut are sometimes labeled individually. A paper label, not gummed, bearing the trade-mark, guarantee, and name of the producer, is wetted and applied to the side of the fish before the latter is glazed. After the glaze is applied the label can not be removed without damaging the glaze or defrosting the fish.

PRECOOLING AND WETTING BOXES

In freezers where the best and most careful work is done the boxes are wetted before they are filled and are also precooled for several hours in a cold room. The weighing and packing is done in the glazing room or other cold room. A dry box absorbs some of the moisture from the fish, but if it is wet the absorbed water later freezes, to make an icy box that helps substantially to reduce drying. By packing and weighing in a cold room a low temperature of air in the box is assured at the start, though this factor is of comparatively little importance because of the very low heat capacity of the small quantity of air in the box.

WEIGHING AND MARKING

The customary weight of fish in a freezer is the frozen weight. This, of course, is usually greater than the fresh weight because of the glaze. As the boxes are of approximately uniform weight, the boxes are weighed after they are packed and closed, and the tare weight of box is deducted from the gross to give the net weight. The gross, tare, and net weights are then marked or stenciled on the box, together with the lot number and date, variety, and size of fish, which are stamped on. Box numbers, where they are used, also are stenciled on. These markings are put on the end of the box. Some freezers put the markings on both ends for convenience. Trade-marks are put on the sides.

In several of the States there are cold-storage laws that regulate the conditions of storage of fish. Most of them prescribe a limit to the length of time frozen fish may be kept in storage, and it is for this reason that it is important that these markings be accurate and plain.

For shipment, boxes are greatly strengthened by strapping with metal straps or tying with wire. For tying with wire handy and efficient little machines are available that tie a box in a few seconds. For export the steamship companies require that the boxes be strapped or wire-tied.

FREEZING IN ORIGINAL CONTAINERS

Some fishery products are frozen in the wooden boxes or other containers in which they were originally packed. Finnan haddies, smoked fish, smoked fillets, squid, pulpo or octopus, and smelts often are placed directly in the cold-storage rooms without the advantages of the lower temperature of the sharp freezer. Examination of the frozen products shows that such products, especially the fillets (smoked or fresh), are seriously injured by internal crystallization when frozen by this method. Smelts do not seem to be injured so much by this treatment.

STORING FROZEN FISH

The very best quality in fish after it has been frozen, stored, and finally defrosted can be expected only if the best practice has been followed throughout the entire process, at each stage of which poor practice may easily result in more or less serious impairment of quality. While it may be true that the freezing proper is the most important stage of the process, holding more possibilities of injury or good preservation than any other, it is only little more important than the methods followed in storage; for many pounds of fish reach the storerooms in excellent condition, only to emerge dried, rusty, and insipid. Good storage is much more than merely putting frozen fish in a room below freezing in temperature and keeping them there until they are wanted. Activities if not prevented will be going on slowly but steadily 24 hours a day, until in a few months the best edible qualities have departed and a mere dry and fibrous ghost of the original fish remains.

Briefly stated, the two great enemies of frozen fish in storage are rusting and drying; the principal combatives are low temperature and heavy glazing. Low temperature arrests rusting and promotes drying; glazing, aided by other protective means, prevents drying and helps to prevent rusting. These have been the governing factors in the development of methods of storage now practiced. Some reference books on refrigeration give the "proper" temperatures for storing different varieties of fish, and the idea seems to prevail elsewhere that different kinds of fish require different storage temperatures. General experience in cold storage as now practiced indicates that the temperature should be as low as is possible and economical for all kinds of fish, preferably from 0° to 5° F. The temperature is not likely to be too low, as far as the quality of the fish is concerned, provided they are protected from drying and the temperature remains constant.

Cold-storage rooms are usually large and are located on the upper floors of the house. They are insulated, of course, in keeping with the temperatures to be maintained—usually 4 or 6 inches of cork, or the equivalent insulating value in other materials. The piping usually is suspended from the ceiling or placed on the side walls, or both, and in ample amount to insure the required low temperature.

FIG. 17.—Storeroom of boxed frozen fish. Here the boxes are stacked on bottoms. It is more general practice to stand the boxes on end. When Style 4 boxes are used and stacked on end the cleats separate the boxes and allow circulation of air between them. Courtesy, Bay City Freezer

The walls usually are whitewashed. Freshly applied whitewash, however, appears to have a drying effect on fish placed near it.

TEMPERATURE OF STORAGE ROOMS

It has been pointed out already (see Glazing, p. 546) that low temperature is the only sure means of avoiding rust or rancidity of fat fish, though a heavy glaze helps. The approximate maximum temperature is 8° F., if the fish are to be kept more than three or four weeks. It is safer to maintain 5° or even 0°, as some of the best freezers do regularly. Even at these temperatures some fish, particularly prone to rust, such as smelts, may rust unless they are otherwise protected.

Although there seems to be no mention of it in the scientific literature of fish cold storage, there appears to take place a change in the protein of fish on long cold storage, called "souring" by the practical freezer man. The activities of bacteria are greatly retarded by freezing but apparently are not absolutely arrested, for some fish on long storage develop a sour odor. Pickerel, especially if frozen

FIG. 18.—Storage room in a public freezer. For separately frozen fish, not boxed, bins are provided to keep the lots separate, so that they are accessible for delivery at any time. Tags for lot numbers and dates are attached to each bin. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

round, are prone to sour and may do so in a few months at 0° F. Ciscoes also are subject to this trouble, especially if round, but the trouble is slow to develop. Perhaps the intestines or contents of the alimentary canal are chiefly concerned in souring.

The temperature must not only be low but also as constant as possible. Fluctuating temperature promotes drying of the fish. The vapor pressure (that is, the tendency to evaporate) of water or ice increases with rising temperature. The tendency of water vapor to condense increases with a lowering temperature. Water will evaporate, therefore, from warm objects and condense on cold ones. The pipes are usually the coldest objects in the room—perhaps several degrees colder than the fish. The ice slowly evaporates from the fish and condenses as snow on the pipes. When the temperature of the room and the fish rises a few degrees temporarily, evaporation is increased. Therefore, provision is made to prevent warm air from entering the storage room when the doors are opened. Sometimes a canvas curtain is used at doors and elevator openings. The brine or ammonia is kept at a temperature as nearly uniform as possible.

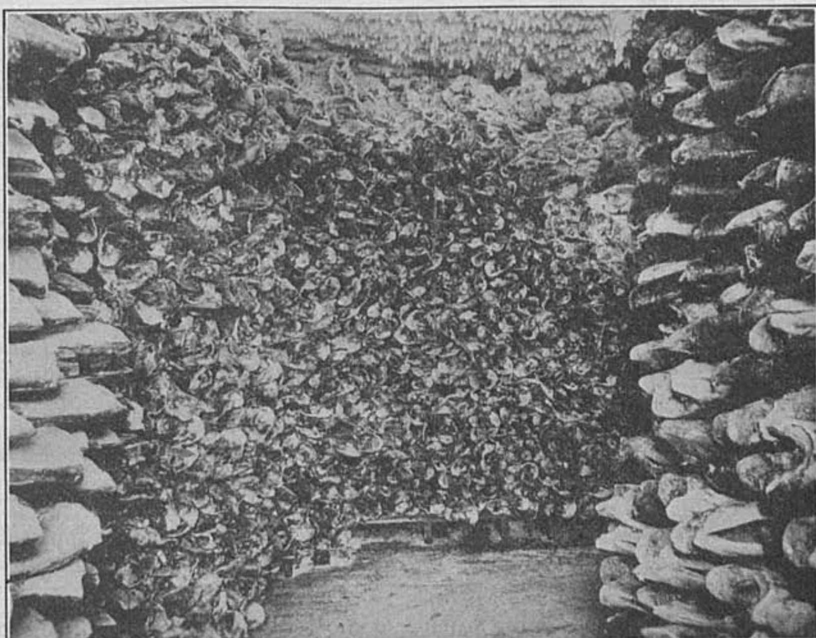

FIG. 19.—Halibut and salmon frozen and stored in bulk in a private freezer, Pacific coast. Courtesy, Canadian Fishing Co. (Ltd.)

PLACING FISH IN STOREROOMS

In public freezers, where the fish are boxed, the boxes are placed in the rooms, usually standing on end, and stacked to the ceilings. Dunnage is often, though not always, put on the floors to permit circulation of cold air under the boxes. Bins usually are built for fish not frozen in cakes. Such bins serve to hold the fish and to keep lots separate. Bait herring are dumped without arrangement into large bins.

In private freezers, especially those used chiefly for halibut and salmon, the frozen fish are stacked in an orderly way without boxing. One method of arrangement is to put dunnage on the floor, then pile the fish to the ceiling in a solid rectangular block, leaving only a narrow passageway adjacent to the four walls for inspecting and reglazing. The tails all point inward and heads or shoulder ends outward. Halibut are piled white side up, except the four or five nearest the top, which are arranged black side up. Another arrangement is to stack the fish, filling the room completely, with a wooden framework placed near the wall pipes to hold the fish away from the pipes. A space is left so that the door may be opened. It is best to arrange the fish so that all those exposed to the air will be accessible for reglazing. When rooms are so filled, the fish well glazed, the doors kept closed, and the temperature kept at 0° or thereabouts, the conditions for keeping are excellent. This solid formation of loose fish economizes space and obviates a larger investment for boxes.

REGLAZING

As already stated, exposed fish in a cold room gradually dry. The glaze first evaporates; then the skin, fins, tail, and snout become dry. The following tabulation, taken from Ehrenbaum and Plank [27] illustrates the rate at which certain fish, hanging free, will dry at a storage temperature of 19.6° F.

TABLE 11.—*Loss of weight of glazed fish hanging in a storage room at 19.6° F.*

Fish	Original weight	Loss of weight— After 10 days	After 20 days	After 40 days	After 60 days	After 80 days	After 100 days	After 120 days	After 140 days
	Grams	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Pollock	3,827	5.9	8.9	15.0	21.0				
Cod	2,674	7.4	11.0	18.2	25.5				
Sole	858	11.4	18.2	28.6	37.3	43.0			
Do	318	17.0	27.6	42.7	52.0	57.5	60.0	61.6	62.3
Haddock	570	9.6	16.6	28.1	37.2	44.8			
Do	179	15.1	26.2	43.3	54.2	62.0	65.0	66.5	66.5
Mackerel	421	3.3	7.8	14.9	19.9	24.2	27.1	29.4	31.1
Eel	349	8.3	12.3	17.7	20.9	22.6			

Table 12, from the same authors, shows the effect of boxing on reducing evaporation. Two haddock of about the same size were kept in storage, one hanging free and the other inclosed in a wooden box.

TABLE 12.—*Effect of boxing or loss of weight in storage*

Date	Weight— Hanging free	Packed in a box	Date	Weight— Hanging free	Packed in a box
	Grams	*Grams*		*Grams*	*Grams*
Aug. 13 (fresh)	449	473	Sept. 21	368	423
Aug. 14 (frozen)	477	452	Oct. 4	339	422
Sept. 1	411	430	Oct. 25	305	413

[27] See footnote 15, p. 518.

Table 13, also from Ehrenbaum and Plank, shows the amount of time found by them to be required for various fish to lose a very heavy glaze. The fish were suspended in the storeroom.

TABLE 13.—*Time required for ice glaze to evaporate from the surface of fish*

Species of fish	Weight of fish	Weight of glaze	Weight of glaze as percentage of weight of fish	Time that glaze lasted
	Grams	*Grams*	*Per cent*	*Days*
Mackerel	434	56	13.0	18
Do	365	56	15.3	18
Haddock	964	142	14.7	22
Do	428	50	11.7	14
Coalfish	4,270	472	11.1	33
Cod	2,588	252	9.8	28
Plaice	293	64	21.9	20
Do	184	46	25.0	15
Eel	296	41	13.8	14

These tables are all illustrative but do not represent conditions that prevail in American freezers. Our storage rooms are held at a very much lower temperature, the fish do not hang, and the glaze is not so heavy.

It is always the fish that are exposed on the outer parts of piles or cake that dry most. Those inside, especially in closely packed piles and boxes, dry least. Proximity to the cooling pipes hastens drying, and pipes freed from adhering snow cause much more rapid drying than those covered with snow.

When fish in storage are inspected the glaze is often found to have departed. When necessary the fish are glazed again. This may be accomplished in any of several ways depending on circumstances. The fish may be taken to the storage room and glazed in the usual way by immersing in water. If the fish are boxed considerable labor and damage to boxes is entailed by opening the boxes. In this event a portable tank is taken to the storage room and the boxes themselves are immersed in the tank and held under the water until they fill with water. They are then removed and suspended above the tank until the excess water drains out. To facilitate handling a davit is mounted on one end of the tank with block-and-fall and grapple hooks.

Fish piled loose may be reglazed conveniently by spraying them with water without moving them. A spraying tank and pump is used, such as horticulturists use for spraying shrubbery. The water freezes quickly on the fish. This is a quick, convenient, and satisfactory method.

REMOVING RUST

Where fish are rusty they may be freshened and improved by the following treatment: Two vats or tanks of tepid water (about 100° F.) are provided. Some sodium bicarbonate (ordinary baking soda) is dissolved in the water in the first tank, and two sticks are laid across the top. The cakes of fish, or large single fish, are laid on these sticks. The water is taken up with stiff scrubbing brushes, narrow enough to reach into crevices, and the fish are scrubbed vigorously to remove the glaze. The fish are rinsed in the soda solution and then in the other tank of fresh tepid water. They are then placed in the sharp freezer for a short time to harden the surface and finally are glazed as usual and returned to the storage room.

TRANSPORTATION OF FROZEN FISH

RAILWAY TRANSPORTATION

In cool weather frozen fish may be transported in small lots in ordinary cars for short distances. For this purpose the boxes may be wrapped with several thicknesses of heavy wrapping paper, tacked

FIG. 20.—Delivery of frozen fish to trucks. Courtesy, Brooklyn Bridge Freezing & Cold Storage Co.

on. The shipment of frozen fish in warm cars is not very satisfactory, however, if the fish are to be kept frozen after arrival at their destination. For the great bulk of frozen fish shipped, refrigerator cars are used. These are railway freight cars with double wooden walls, with 1 to 4 inches of felt between the wood facings, which are lined with tar paper. There are cars with only 2 inches of air space or 1 or 2 inches of felt insulation in the walls, but these, and also cars with metal roofs and steel braces in the sides, which are heated in the sunshine, are less suitable for frozen fish. Refrigerator doors are provided with compression bolts for tight closure. In each end of the car is a space or "bunker" for ice, or ice and salt. Each bunker is provided with a hatch at the top for charging with ice, and drain-pipes with traps at the bottom for discharge of brine. To allow circulation of cold air, there is an aperture about 1 foot wide at the top and bottom of the partition between the bunker and the body of the car. A heavy wire screen prevents the ice from falling through these openings. When the bunkers are charged with ice, or ice and salt, the cold air flows from the bunker to the car, through the lower opening, and is replaced with warm air from the car through the upper.

For dunnage the floor of the car is provided with heavy slat boards mounted on 2 by 4 timbers. These floor racks often are hinged down to prevent their removal from the car. Where "permanent" floor boards (slats nailed directly on the floor) are provided circulation is insufficient, and frozen fish may be partially defrosted.

Cars vary in all their dimensions. Table 14 shows the dimensions and capacities of several American and Canadian refrigerator cars. If the dimensions of these cars were standardized, it would be possible to standardize boxes for more economical packing, but as it is shippers must pack as best they can, often with much waste space. Pan-frozen fish usually occupy about 4 cubic feet per 100 pounds when boxed. The minimum car shipment is 24,000 pounds. In the larger cars as much as 33,000 to 35,000 pounds, or even more, can be packed.

TABLE 14.—*Inside dimensions of some refrigerator cars*

Railroad	Length		Width		Height		Capacity
	Feet	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Cubic feet*
Michigan Central	33	0	8	4	7	7	2,084
N. C. & St. L.	29	1	8	2	7	3	1,721
New York Central	39	11	8	5	7	6	2,518
Do	28	9	8	4	7	6	1,718
Canadian National	[1] 38	9¾	8	2	7	2½	2,713
Canadian Pacific	34	0	8	7	6	8	1,943
Soo Line	32	3	8	0	7	2	1,849
American Refrigerator Transit	33	4	8	4	7	7	2,105
Grand Trunk Pacific	33	2	8	1	6	5	1,719
Fruit Growers' Express	33	0	8	3	7	6	2,042

[1] Equipped for connection in passenger trains.

Usually the cars are refrigerated by packing the ice chambers with cracked ice and salt. The capacity of the bunkers is from 6,000 to 7,500 pounds of ice each, or 12,000 to 15,000 pounds for the car. Salt is mixed with the ice in the proportion of 10 to 15 pounds of salt to 100 pounds of ice, this figure being referred to as "percentage." Thus, 10 pounds of salt to 100 pounds of ice is referred to as "10 per cent" salt. (A true 10 per cent mixture would, of course, be 10 pounds of salt to 90 pounds of ice.) In winter the 10 per cent mixture is used. Some shippers increase the proportion to 12 per cent in spring and 15 per cent in summer. Other shippers use a 10 per cent mixture all year round. For oysters, which require a cool temperature above freezing, a 5 per cent mixture is used. Winter shipment, of course, is most satisfactory, as summer shipments, especially in the more southern latitudes and in warm periods, sometimes partially defrost and lose their glaze. The drainage valves remain open, so that the brine formed flows off.

Shucked oysters in cans and fresh fish in boxes often are stowed in the car and covered with cracked ice. The boxes of fish also contain ice with the fish.

PREPARATION OF CARS

In order to prevent the boxes of fish from coming in direct contact with the outside walls, where heat may be conducted directly to them, it is advisable to nail battens along the side walls. Two, or, better, three thicknesses of lath nailed on, vertically or inclined at a slight angle, with eight-penny nails, are sufficient. As an extra precaution the entire cargo is sometimes wrapped by laying building paper on the floor (if the floor battens are removable) and tacking it under the lath on the sides. The free ends are tacked temporarily to the ceiling while the car is being loaded. After the load is all in the ends of the paper are freed from the ceiling and brought around over the boxes, entirely surrounding the contents of the car.

PRECOOLING CARS

Best results are obtained if refrigerator cars are precooled before they are loaded. A common way to do this is to ice the bunkers 24 hours before the car is loaded. Some of the meat-packing houses bring the cars alongside the freezer platform and attach a large canvas duct or " tunnel " to the door leading from a cold room in the freezer. A large fan blows cold air into the car for a number of hours to precool the air and walls of the car. It is advisable to use a canvas cover over the passageway from freezer to car, in any event, to prevent the circulation of air during the loading.

Where quick precooling is necessary in an emergency, a 20 per cent ice and salt mixture is used in the bunkers during the loading. This strong mixture thaws more rapidly, reaches a lower temperature and chills the car more quickly. When the car is loaded, the bunkers are brought up to capacity with the 10 per cent mixture.

Where ice and salt are used in the bunkers it is unsafe, especially in warm weather, to pack the car entirely full of fish. Usually the car is packed to within 1 or 2 feet of the top. When the goods are all in, the boxes should be bracked tight to prevent shifting in transit.

It is highly important that the doors of the refrigerator cars should fit tightly so as to prevent the entrance of warm air into the car. The threshold should be cleaned carefully before the door is closed.

The cars are reiced in transit as required. This service is performed by the carriers at a comparatively low cost for ice and salt, usually plus a switching charge.

Refrigeration of cars with carbon-dioxide ice will be discussed in connection with the ice.

REFRIGERATOR-TRUCK TRANSPORTATION

In cool weather frozen fish may be transported for short distances in an ordinary open truck. Usually a tarpaulin is thrown over the load to cut off the direct sunshine. A closed van is preferable, however, where a longer haul is necessary, or in warm weather, refrigeration is required. For this purpose there are now in use truck bodies refrigerated by cold-brine circulation on the principle followed in the brine-refrigerated freight cars already described.

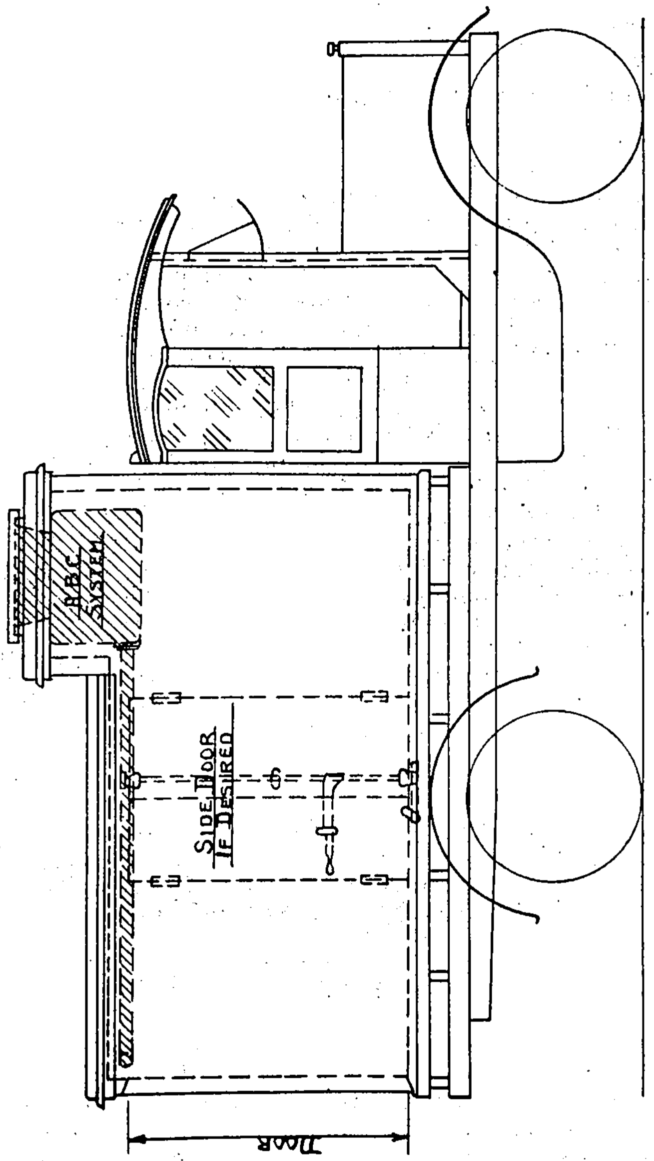

FIG. 21.—Construction of brine-refrigerated truck. Courtesy, Anheuser-Busch

There is a single bunker or tank at the top with brine pipes in the top of the freight body. An arrangement of valves causes the brine to circulate in the pipes when the truck is in motion. Ice and salt are put in the bunker in proportion to give the desired temperature (which may approach zero if necessary). Such a truck is shown in Figure 21.

Dry ice or carbon-dioxide ice, next to be described, also may be used. A closed van should be loaded and from 100 to 200 pounds of crushed dry ice thrown over the boxes. A very rapid fall in temperature occurs, and the fish keep, frozen hard, for several hours in hot summer weather.

SOLID CARBON-DIOXIDE REFRIGERANT FOR TRANSPORTATION

As a means of refrigeration of cars for the transportation of fish, solid carbon dioxide has shown promise in trials. Although the application of this substance to the preservation and transportation of fish in commercial practice is still (August, 1926) too recent and experience is too limited to justify a prediction of its possibilities in the fish industry, yet it is being used for other products, and its possibilities for fish warrant a description of its properties.[28]

Carbon dioxide is familiar as the gas used in soda water. It is of widespread distribution, being present in small amount in air. It is produced by combustion of coal, wood, gas, etc., and may be recovered from flue gases. It is a noncombustible, nonpoisonous, invisible, heavy gas. When compressed to about 1,000 pounds per square inch it liquefies at about 80° F., and if the pressure is suddenly removed from the insulated liquid carbon dioxide some of it evaporates, and in doing so absorbs so much heat that the remainder freezes to a white, snowy substance having a temperature of about 109° F. below zero. This white "snow" is then compressed into bricks or other desired shapes. This compressed carbon-dioxide "ice," as its manufacturers have named it, weighs 70 pounds per cubic foot, as compared with 57 pounds per cubic foot of water ice. It contains about 1.7 times as much refrigeration per pound as water ice, or about 2.1 times as much per cubic foot. The amount of refrigeration available in this solid carbon dioxide, expressed in B. t. u. per pound of gas evaporation, and the gas warming to various temperatures is shown in Table 15.

TABLE 15.—*Refrigeration available in solid carbon dioxide*

Final temperature of gas, ° F.	Refrigeration available, in B. t. u.	Final temperature of gas, ° F.	Refrigeration available, in B. t. u.
−10	249	32	274
0	255	75	300
+20	267		

Eight cubic feet of the gas weigh 1 pound. The gas, at 32° F., has a specific heat of about 0.18. If this gas is at 109° below zero, F. as it comes from the ice, it absorbs only about 25 B. t. u. in being warmed to 32°. But this same gas, in passing from the solid to the gaseous state, absorbed 255 B. t. u. The refrigerating effect of the gas is therefore only about one-tenth of the ice from which it was produced.

[28] Elworthy, British patent 7486 (1895), U. S. patent 579866, Mar. 30, 1897; Slate, T. B., U. S. Patents 1511806, Oct. 14, 1924, 1546681, 1546682, July 21, 1925, 1563112, Nov. 24, 1925, and 1595426, Aug. 10, 1926.

The heat absorbed by the ice in its changing state must therefore reach the ice by direct conduction from objects in contact with it or by convection of the gas current. These facts have a significant bearing on the applications of this "ice" to refrigeration.

The term "dry ice" is used advisedly, for it does not melt to a liquid as water ice does, but, in absorbing heat, is converted directly into the gaseous state, the gas formed being also very cold until it, too, absorbs more heat. This gas is about one and one-half times as dense as air and consequently will sink to the bottom of an inclosed chamber, displacing the air. If sealed tight it will exert a powerful pressure, but if a means of escape is provided it passes out into the atmosphere.

Solid carbon-dioxide "ice," though very cold, may be insulated and transported for short distances, but with some loss, of course. It may be used for chilling a chamber, the temperature being regulated by insulating the solid to control the rate of evaporation. If blocks of it are placed in the upper part of a chamber they rapidly absorb heat and give off cold gas, which displaces the warm air, sinking to the bottom and gradually filling the entire chamber and surrounding contents. If much of the solid is used, with little or no insulation, the chamber may be chilled to an extremely low temperature; but if a small quantity is used, with heavy insulation, the chamber may be kept cool without freezing.

This gas has other useful properties. By displacing the air it arrests oxidation completely. This fact is probably of advantage in fat fish in preventing oxidation of fat (when air is present, oxidation actually produces heat). Many kinds of bacteria require oxygen, and when oxygen is displaced by carbon dioxide they either die or become inactive. By dissolving in the juice of the fish carbon dioxide produces a mild, harmless acid (carbonic acid), which also combats some bacteria. Carbon-dioxide ice is thus not only a refrigerant of valuable properties but its gas is an aid to preservation as well. It evaporates and disappears when the fish are taken out of it, leaving no taste or other objectionable trace.

USE OF CARBON DIOXIDE ICE IN THE SHIPMENT OF FISH

The pioneers in the manufacture and application of solid carbon dioxide to refrigeration and preservation of food[29] arranged, at the request of the Canadian Department of Marine and Fisheries, to send a trial car of fish from Halifax to Montreal, the distribution of the fish to the trade being arranged by the Canadian Fisheries Association.[30] A refrigerator car was equipped at the four corners (outside the ice bunkers) with cylindrical metal containers 12 inches in diameter and 70 inches high, in which cylinders of solid carbon dioxide were placed, the entire charge weighing 850 pounds.

The car was packed at Halifax with an assortment of frozen fish and fish on ice and sent to Montreal, being four days en route, and allowed to stand on the tracks two days—six days from the time of sealing. When the car was opened the air (or gas) temperature was 33° and all the fish were in excellent condition.

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[29] The Dry-Ice Corporation of America, 50 East Forty-second Street, New York City.

[30] For full report on this shipment, see reports in Canadian Fisherman, Vol. XI, May, 1924, pp. 111–120. Gardenvale, Province of Quebec. There are numerous technical errors in the report.

Following upon the favorable results of tests in its research laboratory, the Atlantic Coast Fisheries Co. made several shipments, under the immediate supervision of the writer, of packages of frozen fillets of fish from New York to Kingston, Jamaica, on ships without re-

FIG. 22.—Solid carbon dioxide or dry ice being loaded on a truck. Courtesy, Dry Ice Corporation of America

frigeration. The frozen blocks of fillets, with dry ice between, were packed in corrugated strawboard boxes for insulation. The shipments arrived in seven days, all in perfect condition. In April, 1926, following the above preliminary shipments, the first car of frozen fish was shipped from New York to Detroit—a three-day trip.

Twelve hundred pounds of dry ice was used, contained in wooden fish boxes and distributed in the upper layer of boxes of fish. Bunker openings were sealed with building paper nailed on with lath, likewise the doors. The car arrived in good condition. Two more cars followed in June and July, 1926. Numerous shipments then were undertaken from Provincetown, Mass., to St. Louis and Kansas City and from New York to the same points in the hottest summer weather, the time of transit being five to six days. These cars arrived in excellent condition, except when insufficiently insulated cars were used. Recording thermometers in two of the cars showed virtually constant temperature of 26° to 28° F. throughout the trips.

In the three-day shipments 1,200 pounds of boxed ice were included and 200 pounds of granulated ice were scattered over the load just before the car was sealed to effect rapid cooling of the car. In the five and six day shipments 1,500 pounds boxed and 200 pounds granulated were used at first. All the ice was gone on the arrival of the cars, which were tight and well insulated, but the fish were frozen hard. In the later cars of five and six days the amount was increased to 1,800 pounds boxed and 200 pounds granulated, and at the end of five days about 200 pounds remained in the boxes. In other cases 2,400 pounds, all in boxes, were used. Where 1,800 pounds were used, the ice was contained in 10 boxes of 180 pounds each. In some of the cars rather serious defrosting had occurred; in others the fish were held perfectly. In the unsatisfactory instances the trouble apparently was caused by insufficient insulation and leaky doors and bunkers.[31]

In the shipments from Provincetown the ice was shipped by express in boxes of sawdust.

Practical experience in these shipments has yielded information that may be summarized as follows:

It is practical to ship frozen fish in the hottest summer weather, up to six days on the road, as the fish remain frozen by the use of dry ice alone.

A tight car with heavy insulation should be ordered without precooling. Movable floor racks, 4 inches deep, should be on the floor. The bunker openings into the car should be sealed with building paper and lath. Strips of 1-inch wood (or three thicknesses of lath) should be nailed vertically on the sides of the car to prevent any possibility of the boxes coming in direct contact with the walls. The door not used for loading should be similarly sealed inside. The car should be filled as full as possible—up to within 2 to 4 inches of the ceiling—with frozen fish, in boxes, as a full car is more favorable to refrigeration with dry ice than a part car. Dry ice, in 8 to 10 wooden boxes, should be distributed in the top layer so as (1) to come next the ends and sides of the car, (2) not to come next to one another, and (3) to be uniformly distributed over the load. There should be no sawdust or insulation around the dry ice, but the boxes may to advantage be lined with heavy paper.

The dry ice should be delivered to the car with the fish, and loading should be prompt. When the load is in, or during loading,

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[31] Solid Carbon Dioxide, or Dry Ice, in the Fish Industry. By Harden F. Taylor. Ice and Refrigeration, vol. 71, 1926, pp. 211–218. Chicago.

200 pounds of crushed dry ice should be thrown over the top of the load. (Handle quickly with a shovel or dry cotton gloves.) The door should be sealed with a strip of putty or a rubber tube against all facings. The bunker hatches and the brine vents in the bunkers should be closed tight. Do not open the car, once it is closed, until it reaches destination.

One of the reasons for preferring a well-filled car of fish when dry ice is used is, for one thing, that it reduces cost, for no more dry ice is needed for a full car than one-half full, whereas with ordinary ice it is usually unsafe to pack the car entirely full. Another reason, however, is not so obvious. A pound of dry ice produces 8 cubic feet of gas. In an empty car of, say, 2,000 cubic feet capacity, 2,000

FIG. 23.—Frozen steelhead in refrigerated hold of a steamer from Pacific coast ports to New York, via Panama Canal. For transoceanic shipments the boxes must be strapped

pounds of dry ice will fill the car eight times with gas; that is, the gas will be changed eight times as the ice evaporates. If half the space is occupied with fish, the gas will be completely changed 16 times; if the car is seven-eighths occupied by fish, the cold gas will be changed 64 times, insuring a cold atmosphere in the car at all times.

Carbon dioxide ice may also have possibilities in the refrigeration of individual packages of fresh or frozen fish, oysters, and other perishable sea foods. Its dryness and cleanness are desirable properties for this purpose and make possible the use of paper or fiber containers for express or even parcel post. At the present writing, however, though numerous trial shipments have been made, one is unable to speak with confidence as to its ultimate usefulness in this field.

OCEAN TRANSPORTATION

Refrigerator ships provide facilities for storage aboard similar to those in cold-storage warehouses, with those differences that are made necessary by the construction and operation of the ship. The holds are insulated with cork, with pipes overhead and on the walls. Battens usually are provided on the floors. The temperature commonly maintained ranges from 18° to 20°, which is high for long storage but answers the purpose for the short time of a voyage. The machinery is either the carbon dioxide or ammonia compression type. Ships usually have one or two spare machines, complete, and a full supply of spare parts to be used in case of a breakdown, which would be diastrous if spare parts were not available.[32]

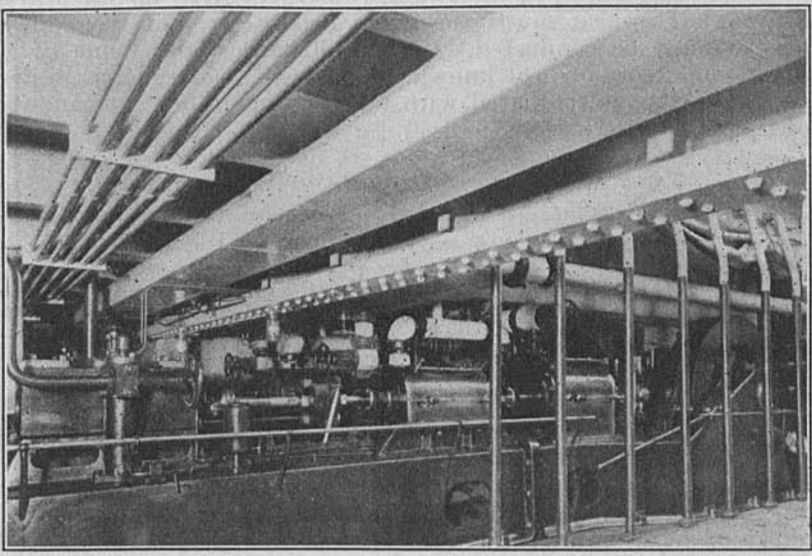


FIG. 24.—Carbon dioxide refrigeration machinery aboard a steamship

Boxes for ocean transportation should be strong, well nailed together, and are required to be strapped or wired. Transportation from freezer to ship is usually effected by trucks. This practice affords some opportunity for the fish to receive some heat, especially if there is any delay in transferring them to the refrigerator hold of the ship. When there is a railroad track alongside the freezer, connecting with a track on the wharf, it is excellent practice to pack the fish in a refrigerator railroad car, with bunkers iced, and have the car shifted to the wharf. In handling large lots this is cheaper than transfer by truck.

[32] For discussion of practical details see "The design and construction of refrigerated ships," by Llewellyn Williams. Paper read at thirty-second general meeting of the Society of Naval Architects and Marine Engineers, New York City, Nov. 13 and 14, 1924. Also, "Ship's refrigeration," by Robert F. Massa. Cold Storage and Produce Review, vol. 20, No. 227, February, 1917, p. 40; No. 228, March, 1917, pp. 62–64; No. 230, May, 1917, p. 104.

OTHER METHODS OF FREEZING

The method already described in detail has come into widespread use because it is simple, practical, and is equally applicable to all varieties of fish. The chief and only serious objection to it is the slow rate of freezing. In connection with the discussion of the operation of sharp freezers numerous suggestions were made, intended mainly to increase the rate of freezing, and if these were all applied general improvement would result. But after everything possible is done, sharp freezers are still far too slow to produce all that could be desired because of the insurmountable difficulty of an exceedingly poor heat conductivity and the low specific heat of air.

In a sharp freezer most of the heat from the fish is absorbed by air surrounding the fish, and the air in turn gives up its heat to the pipes. The heat must pass from fish to air and from air to pipes—it must be conducted. Of all substances, air is one of the poorest conductors of heat known. Expressed in the metric system, its conductivity, as compared with that of some other substances, is shown in Table 16.

TABLE 16.—*Heat conductivity of various substances*

Substance	Conductivity, in calories per ° C. per second	Substance	Conductivity, in calories per ° C. per second
Air at 0° C.	0.0000568	Mercury	0.01479
Water at 4.1° C.	.00143	Iron	.152
Ice	.00568	Copper	1.079

The specific heat of air likewise is exceedingly small; that is, a relatively small quantity of heat causes a relatively large rise in the temperature of air. The specific heat of a substance is defined as the number of heat units required to raise a unit weight of that substance 1°. The specific heat of water is the standard, its specific heat being taken as unity. The specific heat of air, as compared with that of some other substances, is shown in Table 17.

TABLE 17.—*Specific heat of various substances*

Substance	Specific heat	Substance	Specific heat
Air	0.24	Brine, salt, 100 per cent saturation	0.783
Water	1.00	Sea water	.94
Brine, salt, 80 per cent saturation	.829	Ice	.50

The above figures are on the basis of weight and heat units, say, pounds and British thermal units. That is, 0.24 B. t. u. would be required to raise the temperature of a pound of air 1° F., while 1 B. t. u., or four times as much heat, would be required to raise the temperature of a pound of water 1°. But a pound of air occupies 11 cubic feet while a pound of water is approximately a pint. Only a very small weight of air is actually in contact with the fish at one time—perhaps not more than a few thousandths or ten-thousandths of a pound—and this of only one-fourth of the heat capacity of water. The temperature of air rises markedly when the fish has given up only a very small quantity of heat. When its temperature rises, the rate of flow of heat is reduced, the rate of flow being proportional to difference in temperature. The heat given off by a 1-pound fish in freezing will raise the temperature of 310 cubic feet of air 10° F.

If the air in a freezing room should remain still, the fish might require weeks to freeze; it is only the circulation of air that makes ordinary sharp freezers practicable. Air in immediate contact with solid objects, however, moves very sluggishly, a sort of static film being formed. Blowing the air by a fan greatly increases the speed of freezing, as has been shown elsewhere; but this principle seems impracticable of application in freezing large quantities of fish because of the immense volume of air that would have to be moved.

It becomes evident, therefore, that if very much more rapid freezing is to be accomplished recourse must be had to a medium of higher conductivity and specific heat than air or any other gas. Any liquid is vastly better than any gas, hence the use of brine. The greater rapidity of freezing of fish in brine than in air is shown by the experimental results given by Stiles[33] in Table 18.

TABLE 18.—*Time required to freeze fish of various thicknesses in air at 14° F. and in solutions at 14° and 6° F. below zero*

Thickness of fish in—		Time required to freeze in—		
		Air at 14° F.	Brine at 14° F.	Brine at 6° F. below zero
Centimeters	*Inches*	*Minutes*	*Minutes*	*Minutes*
1	0.39	120	10	4
2	.79	248	21	8
3	1.18	361	35	14
4	1.57	490	54	19
5	1.97	620	78	29
6	2.36	748	112	40
7	2.75	877	148	50
8	3.15	1,000	190	67
9	3.54	1,130	230	85
10	3.94	1,260	275	101

These figures are illustrative only. In this country air temperatures much lower than 14° F. below zero are used regularly, and the brine temperature of 4° F. below zero is much more advisable and more likely to be used than 14° F. above, as in the table.

At this point it will be well to remember that the object of achieving more rapid freezing is solely to improve the quality of the frozen fish and not to increase the output of a freezer. In every case the amount of fish that can be frozen per day is limited by the capacity of the ammonia machine. Brine freezing will greatly increase the speed of freezing of any one fish, while other fish, unfrozen, await their turn. In sharp freezers all the fish are put

[33] See footnote 47, p. 583.

in at about the same time, while in brine the fish pass through the process in small lots; but, other things being equal, as much time would be required to freeze a day's capacity by one process as by another.

The means of freezing fish may be classified for the purposes of this discussion as (*a*) those methods in which fish are immersed directly in or exposed directly to brine, and (*b*) those methods in which fish are inclosed in molds, cells, or containers, the walls of which separate the fish from the brine but make good contact with both. These two classes of freezing methods will now be discussed at some length.

FREEZING IN CONTACT WITH BRINE

If the liquid to be used for freezing is to come in direct contact with the fish, we are limited virtually to sodium chloride or common salt brine. It is the only chemical substance that is tolerated by the human palate and stomach, while being cheap, harmless, and affording a solution of sufficiently low freezing point. Calcium-chloride brine has an acrid, disagreeable taste, and any trace left on the fish would be objectionable. The same may be said of magnesium chloride. Glycerin and alcohol are excessively expensive and are otherwise objectionable. A mixture of salt brine and glycerin has been proposed and is being used to some extent.

STERILIZING EFFECT OF BRINE.

Strong brine has a distinctively destructive effect on bacteria, as is well known from its use as a preservative for meat, fish, etc. Coming in direct contact with the slime on the skin and gills of fish, where decomposition starts very easily, the strong brine used in freezing plasmolyzes and kills many putrefactive bacteria. Green has investigated, bacteriologically, the keeping quality of brine-frozen fish in comparison with those frozen in air. Her report on this work is as follows:

Samples of brine and dry frozen fish were brought out of store and placed on trays with an equal number of perfectly fresh herrings straight from the drifter. These were left away from the sun and wind at a temperature of about 60° F. for two or three days, and then bacteriological samples were taken from them and inoculated into fish broth.

Observations.—(*a*) Brine-frozen herrings produced the least amount of bacterial growth. (*b*) Dry-frozen herrings produced by far the greatest amount of growth. This experiment, like the first, shows that bacteria do continue to multiply at a temperature of 18 to 20° F., whereas the brine-freezing method not only inhibits growth but kills many of the forms of bacteria present before they have time to spore.

RAPIDITY OF FREEZING IN BRINE

Figures that show the speed of freezing in brine as compared with that in air already have been given (p. 571). The larger the fish to be frozen, the smaller the difference, as shown in Table 17. It is easily understood why the larger objects freeze more slowly than the smaller ones, when we remember that the volume of a solid object increases as the cube of its diameter, while its surface increases only as the square of the diameter. Thus, a ball 4 inches in diameter has four times the surface and eight times the volume of a 2-inch ball; or, that is, the 2-inch ball has twice as much surface in proportion to its volume as the 4-inch ball has. Likewise, a fish 1 foot long has twice as much surface in proportion to volume as a 2-foot fish of the same kind.

The amount of heat in a fish is proportional to its volume; but as the fish freezes the heat must pass through the surface, and this surface is proportionately smaller the larger the fish. In the table it is apparent that a fish twice as thick as another freezes only about half as fast in air; but the same ratio is not apparent when the freezing is done in brine, where doubling the thickness approximately triples the time required to freeze. The reason for this is that in air freezing, which is very slow, the heat has time to be conducted from the inner parts of the fish to the surface, and the amount of surface exposed will determine how long it takes the fish to freeze. But in brine the surface very quickly reaches the temperature of the brine, and the heat must then be conducted from some distance through a shell of frozen tissues; the area of surface thus has relatively less to do with the rate of freezing in brine, and the heat conductivity relatively more, than in air. Thus, a fish 2 inches thick will freeze in brine about 13 times as fast as it will in air, while a 4-inch fish will freeze only about 8.8 times as fast. A fish 10 inches thick would freeze only about 4.5 times faster in brine than it would in air, the air and brine being, of course, at the same temperature. These same remarks apply to the packing of small fish in pans or molds. This practice has the effect of making a larger fish of several small ones, reducing the surface exposed and lowering the rate of freezing.

The rate of movement of the brine is also highly important in determining the rate of freezing in brine, as illustrated in Table 19, taken from the work of Dunkerley.[84] As will be seen later, this fact is of the greatest importance in the design and operation of brine freezers.

TABLE 19.—*Time required to freeze fish in brine. (From Dunkerley.)*

Thickness of fish in inches	Still brine at 10° F.		Brine at 10° F. moving 3 feet per second		Thickness of fish in inches	Still brine at 10° F.		Brine at 10° F. moving 3 feet per second	
	Hours	*Minutes*	*Hours*	*Minutes*		*Hours*	*Minutes*	*Hours*	*Minutes*
1	0	25	0	14	4	4	10	3	0
1½	0	45	0	28	4½	5	0	3	45
2	1	20	0	50	5	6	0	4	37
2½	1	50	1	15	5½	7	0	5	30
3	2	35	1	45	6	8	15	6	30
3½	3	15	2	18					

Dunkerley also gives the following formula for calculating the time required to freeze fish at any temperature if the time required to freeze in brine at 10° F. is known. His formula is:

$$\text{Time} = \frac{(\text{Time at } 10^\circ \text{ F.}) \times 20}{30 - (\text{Brine at desired temperature})}$$

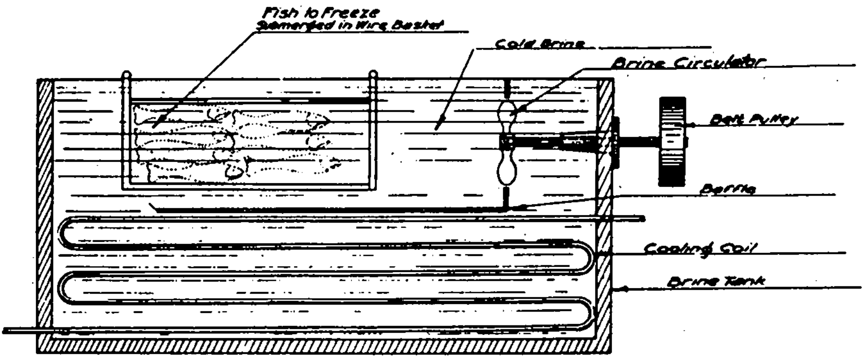
[84] "Fish freezing in brine," by H. M. Dunkerley. Fish Trades Gazette and Poultry, Game, and Rabbit Trades Chronicle, Mar. 30, 1918, p. 19. London.

Thus, a fish will freeze 20 per cent faster in brine at 5° F. than it will in brine at 10° F. He found that a fish is frozen solid when the temperature at the backbone is 25° F.

EARLIER METHOD OF BRINE FREEZING

It so happens that both freezing in brine and in freezing molds surrounded by brine originated with the same inventors. Hesketh and Marcet,[35] in 1889, patented the principle of immersing perishable articles directly in cold brine, with or without protective covering or container, or else inclosing the goods in water-tight cells with hollow walls in which brine is circulated. Nothing came of the invention. In 1898 Henry Rouart[36] obtained a patent covering very nearly the same ground. Rouart employed a tank of brine with cooling coils (in the bottom) and agitator to move the brine.

In 1899 H. W. Rappleye, of Philadelphia, patented[37] what appears again to be essentially the same thing as covered by Rouart and



Side Elevation - Cross Section.

FIG. 25.—Apparatus similar to Rouart's, used for freezing smelts at Seattle, Wash. Courtesy, Booth Fisheries Co.

more broadly by Hesketh and Marcet; namely, immersing the perishables to be frozen directly in a tank of brine refrigerated with an ammonia machine.

KYLE'S METHOD

In 1905 T. D. Kyle[38] devised a method of chilling and freezing fish by placing them in a tank of refrigerated sea water, which was filtered through charcoal and a sponge filter. When the fish had been cooled in this tank they were gutted and transferred to another tank of concentrated sea water for further refrigeration. Here they could be kept a time for sale or they might then be sorted, packed in pans, covered with pure filtered sea water, and frozen to a block. The same ground was again covered by J. R. Henderson[39] in 1910 and 1913,

[35] British Patent 6117, Apr. 9, 1889.
[36] British Patent 5378, Apr. 16, 1898.
[37] U. S. Patent 626771, June 13, 1899.
[38] British Patent 16916, 1905.
[39] British Patent 30221, Dec. 29, 1910; U. S. Patent 1055636, Mar. 11, 1913.

who also precooled the fish either in a cool room or in cool brine containing about 6 per cent salt held at 27° to 30°, after which precooling they were frozen in a tank of saturated brine at a low temperature—about 5° F. above zero. The brine was refrigerated by a cooler outside the freezing tank. Henderson also used a charcoal filter for purifying the brine after it had been in use.

All these inventions, appearing to be essentially the same thing, failed to come to practical application, and all the patents have expired except that of Henderson. It is not difficult to understand why these inventions failed. It is easy to demonstrate the freezing of a few fish quickly in a tank of very cold brine, the quantity of which is large in proportion to the amount of fish to be frozen, and the quality of the goods frozen in such a demonstration is easily

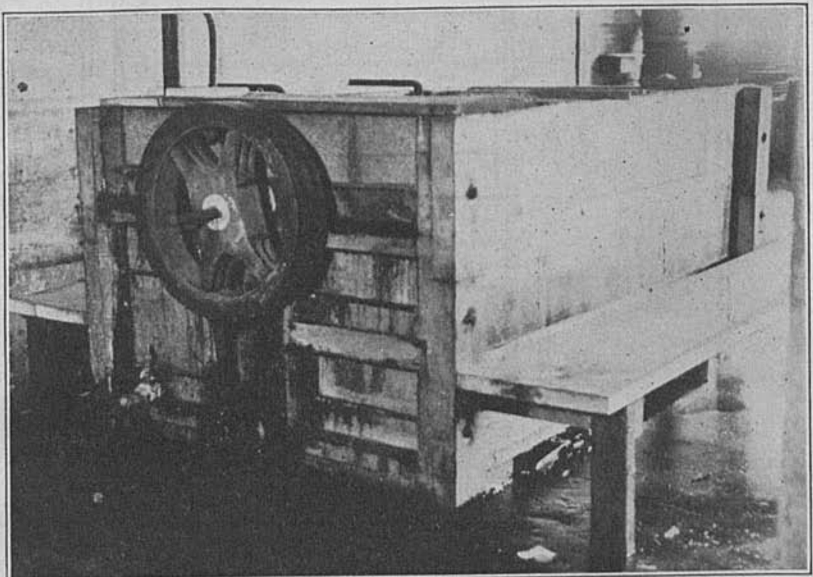


FIG. 26.—Brine freezer similar in principle to Rouart's, used for freezing smelt at Seattle, Wash.

apparent. It is by no means so easy, however, to freeze 25,000 to 100,000 pounds of fish a day, wash them, glaze, pack, and store when open tanks of brine are used, the fish being frozen singly, wet with brine, curled, and misshapen.

DAHL'S METHOD

The first brine-freezing method to be put into practice was that of Nekolai Dahl,[40] a fish merchant of Trondhjem, Norway.

The fish are packed in the containers in which they are to be shipped. A cover, with holes, is fitted on the box, and the boxes are stacked on a mass of cracked ice and salt in a chamber or hold of a vessel. A suction pipe is provided in the bottom of the cham-

[40] U. S. Patent 1123701, Jan. 5, 1915; Danish Patent 18844, 1914; British Patent 13760, Mar. 6, 1912.

ber, connected with a brine pump. The pump draws up the brine formed by the ice and salt mixture and forces it into pipes, which distribute the brine as a spray over the boxes of fish. The cold

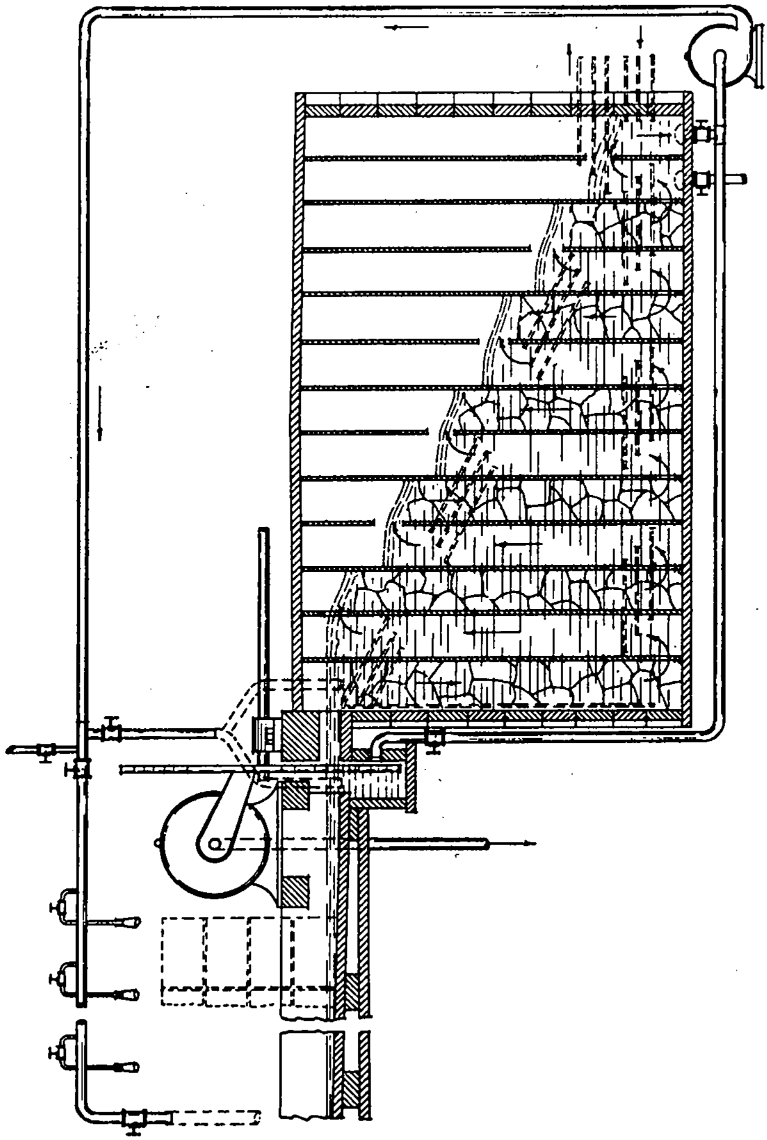


Fig. 27.—Dahl's method of forming brine for freezing fish

brine trickles down into the boxes, through the holes and apertures in the lids, and coming in contact with the fish, freezes them.

An improvement [41] on the original consisted in a tank divided into chambers, wherein the ice and salt mixture was placed. The brine formed passed through the pump without entraining the cracked ice.

[41] U. S. Patent 1177308, Mar. 28, 1916; British Patent 6711, Mar. 17, 1914.

(See fig. 27.) This brine was pumped over the boxes of fish as in the original invention.

In a later improvement Dahl [42] stood the cases on end and bored a hole in each end. The fish in the cases then standing parallel with the downward flow of brine afford a better flow and are more thoroughly exposed to the refrigerating action of the brine.

Dahl patented another improvement [43] by way of effecting a better distribution of brine among and contact with the fish. He first

FIG. 28.—Small plant for freezing by Dahl method. The fish are put in the boxes and brine pumped in through the hose

inserted a brine-discharge hose among the fish, for a short time, to stiffen them, after which operation they remain better separated during the subsequent freezing by the brine flowing among them.

The fish frozen by Dahl's process are not glazed and appear to be more suitable for shipment and consumption after a short time than they are for prolonged storage. Installations of apparatus for freezing on the Dahl principle have been made at Los Angeles, San Diego, and San Francisco, Calif. These consist of the brine-forming com-

[42] U. S. Patent 1235661, Aug. 7, 1917; British Patent 109238, Sept. 6, 1917.
[43] U. S. Patent 1367024, Feb. 1, 1921.

partments and several compartments for fish, wherein the brine is pumped through flexible hose.

A small plant, built after the Dahl design, for freezing with ice and salt brine, was built in Fernandina, Fla., for freezing shrimp. The ice and salt were put in chambers, and the brine formed was circulated by a centrifugal pump through the freezing chamber. Shrimp were dumped directly into the brine. They froze in a few minutes. They were left in it about three minutes, taken out, drained a few minutes on the floor, boxed, and stored at about 0° F. At first these shrimp appeared to be of excellent quality, but after a few months' storage they developed a bad appearance. The delicate pink changed to a less pleasing orange color, blackish in places, and the meat darkened. On microscopic examination the otherwise beautiful tentacled pigment cells were found to have disintegrated. Direct freezing in brine appears to be unsuited to shrimp. This criticism is, of course, no more applicable to Dahl's method of freezing than to others wherein brine comes into direct contact with the shrimp.

OTTESEN'S METHOD

A. J. A. Ottesen,[44] of Thisted, Denmark, patented in several countries a principle that has to do with the relation of the temperature and concentration of brine to the penetration of salt into the fish. As the question of salt penetration is an important one for all methods of freezing where the fish come into direct contact with brine, space will be taken here to discuss this subject at some length.

PENETRATION OF SALT INTO FISH IN BRINE FREEZING

It is a well-known fact, of course, that fish or other flesh substances when treated with salt absorb some of the salt that diffuses throughout the tissues. Likewise, some of the water in the tissues passes out and dissolves the salt, to form brine. When strong brine is used instead of dry salt, the same exchange occurs in a somewhat diminished amount—salt penetrates the fish and water comes out and dilutes the brine. This exchange of water and dissolved substance is called osmosis. Osmosis always occurs whenever a permeable membrane (in this case the cell membranes) separates a strong solution of a crystallizable substance from water or a weaker solution (in this case the fish juice). Osmotic pressure (the tendency to osmose) diminishes with diminishing temperature.

Salt penetration is a much slower process than the freezing of fish in brine. A fish that under the most favorable conditions would salt through in 24 hours will freeze in brine in one-half an hour. Nevertheless, even a small amount of penetration is objectionable. It interferes with glazing; for just as salt dissolved in water lowers its freezing point just so does it lower the freezing point of the surface tissues of the fish and prevents a glaze from sticking. Also, if salt is present in any considerable proportion the flavor will be

[44] U. S. Patent 1129716, Feb. 23, 1915; British Patent 24244, Sept. 4, 1913; French Patent 449815, Jan. 4, 1913. Patents were also issued to him in most of the other important fishing countries of the world.

affected. This was a difficulty, perhaps a fatal one, in the earlier attempts at brine freezing made by Hesketh and Marcet, Rouart, Rappleye, and Henderson. Ottesen discovered that if the proper relations of concentration and temperature are observed penetration of salt may be reduced to a minimum, so much that it ceases to be objectionable.

Warm water will dissolve more salt than cold water. If we saturate some warm water with salt and then cool the brine, some salt will precipitate out as small crystals, leaving the brine weaker. If we cool it more, some more salt crystallizes out and the brine is still weaker. We can continue to cool it with separation of salt until we get a temperature of 6.16° F. below zero, when the brine will freeze solid. At this temperature the liquid portion contains

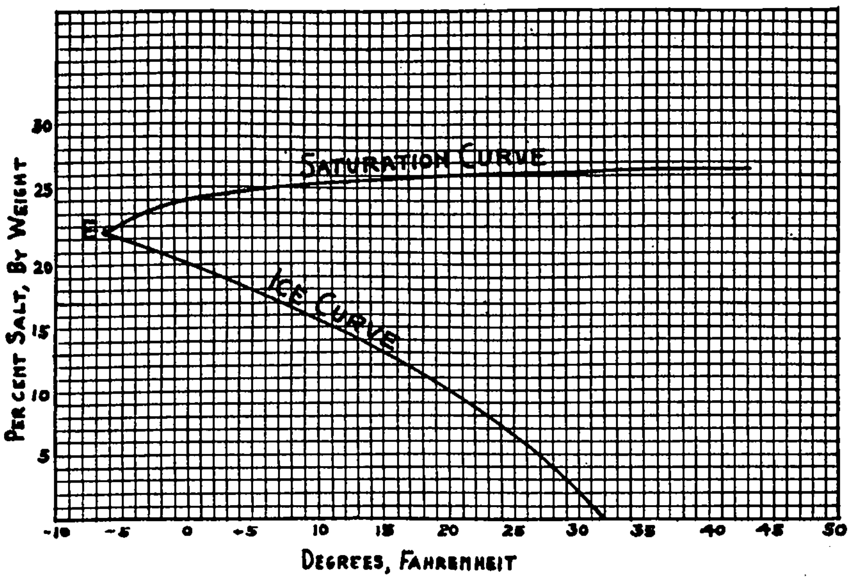


Fig. 29.—Temperature saturation curve of salt brine

22.42 per cent salt. If we begin with a brine of such strength that it is completely saturated with salt and immerse fish in it there will be penetration. The upper part of the curve in Figure 29 represents the concentration of the liquid portion, corresponding to the temperatures.

Now, if we begin with a very dilute solution of salt and cool it. what happens? The temperature drops slightly below 32° F., with no apparent change, because the salt has lowered the freezing point of the water. A degree or two below 32° crystals appear, but they are water ice and not salt. The separation of water in the form of ice leaves the brine more concentrated, and its freezing point falls. As we continue to extract heat more water separates out as ice and the remaining brine becomes stronger and stronger, as indicated by the lower part of the curve in Figure 29. When a temperature of

6.16° below zero is reached, enough water in the form of ice has been removed from the brine to leave the liquid portion at a concentration of 22.42 per cent salt. This is the same figure we arrived at when we began with the strong brine. That is to say, at a concentration of 22.42 per cent salt and 77.58 per cent water, by weight, and a temperature of 6.16° F. below zero, both ice and salt will separate together or the brine freezes as a mass. This concentration and temperature point is called the cryohydric or eutectic point, shown in Figure 30 where the two curves meet. It is the lowest temperature that can be had with liquid salt brine, whatever the initial concentration may have been. It is useless, therefore, to start with more than 22.42 per cent salt or a specific gravity of brine of 1.171 (about 84.64 per cent saturation at 60° F.)

Suppose the brine to be of a lower concentration, however, say, 20 per cent. The freezing point of such a brine is 0.14° F. above zero. It can be cooled to any temperature above this point without separation of either ice or salt. Ottesen discovered that if brine is less than saturated (that is, less than 22.42 per cent salt) and is cooled until water begins to separate, penetration of salt into the fish immersed in it is at a minimum as long as ice is separating, or as long as the conditions represented are on the lower ice curve in Figure 29. He reasoned thus: If water separates from the brine as ice at this temperature, certainly water can have no tendency to mix with it. A drop of water added to such a brine will not mix with it but will freeze as a pellet of fresh ice or a cluster of ice crystals. Therefore, the water on and in the fish will not combine with the brine or absorb salt, but will freeze without mixing with the brine. If, however, the quantity of warm fish is sufficiently great to warm the brine and thaw out all the separated water ice, penetration will take place. Hence the necessity for having an excess of free ice in the brine when freezing begins. He therefore claims that when the unsaturated brine is at its freezing point[45] and an excess of fresh-water ice is present the surface moisture and skin of the fish freeze immediately and thenceforth form an effective barrier against the further penetration of salt. Table 20 gives the cryoscopic properties of salt brine.

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[45] "Freezing point," to fit the use Ottesen makes of it, must be defined as the temperature at which water ice begins to separate from a brine of less than 22.42 per cent salt. An important distinction must be made between the use of the term "freezing point" for brine and for water, which has a true freezing point at 32° F. In this sense, only brine of 22.42 per cent salt has a true freezing point—6.16° F. below zero—at which temperature it will freeze solid without change of temperature.

TABLE 20

Specific gravity 60°/60° F.[1]	Degrees Baumé 60° F.	Degrees salometer 60° F.	Per cent salt by weight	Pounds salt per gallon solution	Freezing point °F.[2]	Changes in brine before solidification
1.00000	0	0	0	0	32.0	Ice separates.
1.00725	1.04	3.8	1	0.084	31.1	Do.
1.01450	2.07	7.6	2	0.169	30.0	Do.
1.02174	3.08	11.4	3	0.256	28.9	Do.
1.02899	4.08	15.2	4	0.344	27.9	Do.
1.03624	5.07	18.9	5	0.433	26.8	Do.
1.04366	6.07	22.7	6	0.523	25.5	Do.
1.05108	7.06	26.5	7	0.617	24.1	Do.
1.05851	8.01	30.3	8	0.708	22.9	Do.
1.06593	8.97	33.9	9	0.802	21.2	Do.
1.07335	9.90	37.5	10	0.897	19.8	Do.
1.08097	10.86	41.3	11	0.994	18.2	Do.
1.08859	11.80	45.2	12	1.092	16.5	Do.
1.09622	12.73	49.2	13	1.190	14.7	Do.
1.10384	13.64	53.0	14	1.289	13.1	Do.
1.11146	14.54	56.8	15	1.389	11.3	Do.
1.11938	15.46	60.6	16	1.493	9.1	Do.
1.12730	16.37	64.4	17	1.602	7.2	Do.
1.13523	17.27	68.2	18	1.710	4.8	Do.
1.14315	18.16	71.9	19	1.819	2.5	Do.
1.15107	19.03	75.5	20	1.928	−0.1	Do.
1.15931	19.92	79.1	21	2.037	−2.2	Do
1.16755	20.80	83.0	22	2.147	−5.3	Do.
1.17101	21.15	84.6	22.42	2.197	−6.16	Freezes solid.
1.17580	21.68	86.9	23	2.266	−5.3	Salt separates.
1.18404	22.54	90.9	24	2.376	−3.3	Do.
1.19228	23.39	94.7	25	2.488	+7.0	Do.
1.20098	24.27	98.5	26	2.610	21.5	Do.
1.20433	24.60	100.0	26.395	2.661	59.0	Do.

[1] Temperature correction 1° salometer for every 7½° F. added to reading for temperatures above 60° F., subtracted below. There is also a salometer scale in use with 1° equal to ¼ per cent salt 0 = 1.0000 sp. gr. 100 = 1.19228 sp. gr., or 25 per cent salt.
[2] The freezing point of a brine is commonly understood to mean the temperature at which ice begins to appear in it. In the solutions stronger than 22.42 per cent salt, salt, instead of ice, separates.

To conform to Ottesen's principle it is necessary to keep the brine in rapid motion. If agitation is not sufficient the mass of brine as a whole may be at its "freezing point," while the brine film in immediate contact with the fish may be so warmed up as to be several degrees above the "freezing point" and penetration may take place. For the same reason the quantity of brine must be sufficiently large, in proportion to the amount of fish present, so that the reserve ice is sufficient to take care of initial freezing. (Each pound of mush ice present will, in thawing, absorb 144 B. t. u. of heat from the fish.) Precooling the fish before they are immersed in the brine is also assumed to reduce the amount of penetrating salt.

Amount of salt penetration.—The amount of penetration of salt into fish has been studied experimentally by various investigators. Ehrenbaum and Plank froze large and small haddock in brine of 23.66 per cent salt, which dropped from 3.6 to 5.1° F. below zero during the freezing. Under these conditions crystals of salt were separating from the brine. Salt was determined in the surface tissues to a depth of 5 millimeters (1/5 inch) before and after freezing. The results are shown in Table 21.

TABLE 21.—*Penetration of salt in haddock frozen in brine*

	Salt in 5 millimeters of surface	
	Before freezing	After freezing
	Per cent	*Per cent*
Large haddock	0.11	1.57
Small haddock	.17	2.05

A similar trial was then made on fish in brine of 15 per cent salt at 11.1° F. above zero. Under these conditions crystals of water ice were separating from the brine. Salt was determined in the outer portion of the haddock before freezing, and one was wiped dry and immersed in the brine while the other was immersed wet. The results of this experiment are given in Table 22.

TABLE 22

	Not frozen	Frozen after wiping dry	Frozen wet
Per cent salt	0.09	0.38	0.45

Almy and Field[46] investigated the penetration of salt in brine freezing of several common American fishes. Their conclusions, supported by several tables of analytical data, follow:

Weakfish, flounders, herring, and whiting were frozen in chilled brine under different conditions to determine the various factors which influence the penetration of salt into the outer tissues of the fish. To assist in the determination of the degree of salt penetration, the skin and two successive layers of muscular tissue just beneath the skin were analyzed for their content of penetrated salt. The muscular layers examined were usually one-eighth of an inch in depth, a few being three thirty-seconds of an inch thick. It was found that:

1. Salt penetrated perceptibly into the skin and superficial muscular tissues of all the fish under all conditions, the amount not being sufficient, however, to affect the taste of the cooked product.
2. During the process of freezing the above species of fish under various conditions the outer muscular layer one-eighth inch in depth absorbed from 0.32 to 6.22 per cent of salt on the dry basis, the average being 2.88 per cent.
3. In a few instances the amount of salt absorbed by fish frozen in brine at its freezing point was slightly less than that which occurred when the brine temperature was several degrees above this point. In the majority of cases, however, no such temperature influence could be observed.
4. When fish were frozen in brines of different concentrations but at the same temperature, no consistent differences in the amount of salt absorbed by the fish could be noted.
5. Fish which had been precooled to near 32° F. before immersion in the brine did not take up as much salt as those which were at atmospheric temperature at this time, the absorption in the former case being 35 to 65 per cent of that in the latter.

[46] L. H. Almy and E. Field, "The preservation of fish frozen in chilled brine. I. The penetration of salt." Journal of Industrial and Engineering Chemistry, vol. 13, pp. 927–928. Easton, 1921.

6. The amount and rate of penetration of salt into the tissues of fish varies with the species. In weakfish and flounders the greater part of the salt which can be found in the superficial tissues at the end of a two-hour immersion in brine entered during the first 30 minutes. The absorption in the case of whiting and herring was more gradual, continuing rather uniformly during the two hours.

7. Inequalities in the fat content of the subcutaneous and body tissue of the fish are responsible in large measure for the difference in the susceptibility to salt penetration possessed by fish of the same species and by those of different species.

Stiles[47] gives several tables of analytical data, of which one is reproduced here as Table 23, showing the influence of the length of time of immersion on penetration of salt in different parts of pike.

TABLE 23.—*Influence of time of immersion on penetration of salt*

Region of fish	Salt in fish after immersion in 21 per cent solution at 2.3° F.	
	5 minutes	1 hou
	Per cent	*Per cent*
Near body cavity	0.17	0.76
Muscle tissue just under the skin	.22	.29
By the wall of the body cavity	2.51	3.51

When the fish are just removed from the brine any excess of salt will be in the skin and immediately underlying tissues. In time this salt seems to diffuse slowly throughout the fish and in this way becomes unnoticeable. Almy and Field observed that salt will even penetrate a block of ice and diffuse toward its center when the block is immersed for two hours in brine, even though the brine is at its freezing point.

Practical importance of salt penetration.—Salt, being a harmless substance, is of practical importance only insofar as, in penetrating, it (*a*) salts the fish excessively for taste, or (*b*) prevents glazing. It is not observed by any of the investigators that any fish have been too salty for taste except where flounders (a thin fish with large surface) were frozen in brine far too strong and too warm. Prevention of glazing, however, is of more consequence. It has been discovered independently by two or three investigators (including the present writer) that brine-frozen fish, if the penetration of salt is held to small proportions, can be glazed by washing the brine from the surface before the glaze is applied.[48]

This washing may be done either by moving the fish under fresh water or by spraying the suspended fish with fresh water.[49] It was found possible satisfactorily to glaze fish that had been frozen in brine without crystallization of ice. The Booth Fisheries Co. in Seattle, Wash., glazed smelt after freezing them in brine, washing them off, placing them in a cold room for awhile, then applying the

[47] "The preservation of food by freezing, with special reference to fish and meat," by Walter Stiles. Department of Scientific and Industrial Research, Food Investigation Board, Special Report No. 7, 186 pp. London, 1922.

[48] See "Refrigeration in the fish trade," by W. E. Warner. Cold storage and Produce Review, Vol. XXX, 1917, pp. 105–114. London.

[49] H. F. Taylor, U. S. Patent 1468050, Sept. 18, 1923.

glaze with fresh water.[50] Another effect of penetrating salt is to give the tissues of the fish a firmness superficially resembling rigor mortis. Fish may be soft and flabby before they are frozen in brine, yet after freezing and even after a long period of storage, when they are defrosted, they have a firmness or rigidity that might easily be mistaken for the rigor mortis of perfectly fresh fish. It may be distinguished from true rigor mortis by the fact that, while true rigor disappears after a short time, leaving the fish soft, firmness produced by penetrating brine persists for days, even until decomposition is well advanced.

PRACTICAL APPLICATION OF OTTESEN'S METHOD

In practical application Ottesen uses methods similar to those of Rouart, Rappleye, and Henderson—a tank of brine refrigerated by means of pipe coils connecting with a refrigeration machine. An agitating propeller keeps the brine in motion, and the fish are put in metal baskets and immersed in the brine. Ottesen's plants have been established at Esbjerg and Skagen, in Denmark; Henningsvaag, Norway; Gothenberg, Sweden; Åbo, Finland; and Ancona, Italy.

Two plants, operated under Ottesen's patents by Kühlfisch-Aktiengesellschaft Wesermünde, at Wesermünde and Cuxhaven, Germany, have been described by Walter Schlienz.[51] In the Wesermünde plant the fish are conveyed from the auction in boxes and dumped into washing tanks, where they are washed well in running water. The fish are then packed in wire baskets. By means of a crane these baskets are hoisted and placed in a shallow brine tunnel, or tank, 65 feet long, in which apparatus is provided to push the baskets slowly forward at a rate that is variable, so that the journey is made through the tank in from 1 to 3½ hours, according to the size of the fish. At the far end of the tunnel the crane again lifts the baskets and lowers them for a moment into a tank of running fresh water to wash off the adhering film of brine. The basket then passes through an aperture in a wall that separates the glazing room from the freezing room. A temperature of about 26½° is maintained in the glazing room. The glazing tank contains fresh water that is chilled to near the freezing point by the low temperature in the room. The fish, still in the basket, are immersed in this cold water for glazing and are transported to a storage room, where they are taken out of the basket, their heads cut off with a circular saw, and the fish packed 100 pounds to the box, the latter lined with paper. Ammonia compressors are used for refrigeration with electric motor drive. The plant has a capacity of 40,000 pounds per day, and provision is made for increasing this capacity to 160,000 pounds.

The Cuxhaven plant has the same capacity as that at Wesermünde and operates on the same general principles, with some differences in detail. The fish are packed in wire baskets that are rather long and narrow and suspended from both ends by a crane. The latter is

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[50] See also, Petersen, U. S. Patent 1388298, 1921.

[51] Die Tiefkühlanlagen für Fische in Deutschland und der Handel mit Kühlfisch. Jahresbericht über die deutsche Fischerei, 1925, 23 pp. See also, M. Hirsch, Das Kühlfischwerk Cuxhaven. Zeitschrift für die gesamte Kälte-Industrie, Heft 4, Jahrgang 23, April, 1926; W. Schlienz, Die Neue Wege im Fischhandel. Deutsche Fischhandel, Interessenblatt für die gesamte Fischwirtschaft, Nr. 20–21, November, 1925. Berlin.

similar to our ordinary ice-pulling crane. There is a preliminary dipping or washing tank with running water. The brine tank is divided into eight compartments, each with its individual circulating pump. The baskets containing the washed fish are lowered into their respective compartments and the covers are put on. Operations are so timed that when the last basket is put in the first is ready to come out. The baskets are then successively dipped into the eighth, or fresh-water, tank, after which dipping they go to the glazing and packing room, which is held at 14° above zero, F. The packed fish are conveyed by elevators to upper floors.

Schlienz does not describe any means for maintaining constant composition or temperature of the brine.

Another room in the plant is provided with woodworking machinery for removing skins, fins, and entrails from the frozen fish, which are dressed for the preparation of fillets and steaks. The fillets are made either as entire fillets or cut into portions of from 4 to 8 ounces.

Schlienz says that it is necessary to reglaze the fish every 4 to 6 weeks, and that if this is done they can be kept without damage for 9 months. He finds difficulties, however, with fat fish like halibut, turbot, mackerel, and herring, in which the fat becomes rancid on storage. This is an understandable difficulty, since the temperature of 14° maintained in the storage rooms is well known in this country to be too high for that purpose.

The present writer has had opportunity to examine cod fillets of the small size prepared by this process, as shipped. They are in a wooden box of 25 pounds net weight, wrapped in 30 packages. The wrapper is paper, not parchmentized, not waxed, not printed, and held with a rubber band. Each package contains one or two pieces of a size, shape, and thickness that depends on the part of the fish from which it comes.

The pieces themselves are skinless and are made by clean cuts of the fish in the frozen condition, the cut surfaces being flat or squarish, and not at all ragged. There is a groove where the backbone was, suggesting that the bone has been removed with a half-round chisel, such as is used in wood turning. In cross-section the internal structure is free from crystals and is in excellent condition. There is some development of yellow color outside, a condition that always develops in frozen cod and haddock fillets unless preventive measures are taken. On being defrosted the fillets are markedly juicy, indicating a change in the hydration of the protein. The elastic, gelatinous consistency of fresh cod muscle has disappeared. When cooked the flesh is somewhat dry and rather coarser than that of fresh cod because of the change just mentioned. The flavor is good and no saltiness is observed.

Ottesen also patented [52] a brine with an organic substance (glycerin) added in order further to reduce its freezing point.

Glycerin and water mixtures of low freezing point are well known for use; for example, for automobile radiators. When glycerin is added to a salt brine the freezing point of the mixture is lower than would be that of the glycerin or salt alone with the water. The

[52] U. S. Patent 1532031, Apr. 7, 1925.

mathematical formulæ for calculating the freezing points of such mixtures have been studied by Fawsitt.[53]

It is claimed for such a mixture that a temperature as low as 25° F. below zero may be attained in practice, and that fish and meat may be frozen in such a brine without impairment of appearance or quality. Ice crystals do not form in the brine under the conditions followed in practice.

BULL'S METHOD

H. J. Bull, director of the fisheries research laboratory of the Norske Fiskereies Fremme, at Bergen, Norway, devised a method[54] of freezing fish in a circular brine tank with an inner chamber, wherein ice is placed. Salt brine is drawn downward through this ice by means of a propeller, and rises in the outer zone. In this latter zone are placed the shelves or baskets of fish to be frozen. He later patented[55] a method of brine-freezing fish by incasing the fish in molds of net or with openwork sides so that the brine could enter and come in contact with the fish. He employed several kinds of molds. One was a shallow wooden frame with sides of wire screen. The fish were packed in the frame, held in place by the screen, and frozen in brine. When the freezing was complete the screens were removed and wooden boards nailed in their stead to the wooden frames, completing a shipping box. Several such frames could be fastened together, making one large shipping package. Bull also used sheet-metal molds and made them of different shapes. From these the frozen cakes were removed and packed in boxes for shipment or storage.

FYERS'S AND WATKINS'S METHOD

In most of the newer methods of freezing fish the aim has been to freeze as rapidly as possible, other considerations generally being subordinated to speed. A. Fyers and W. P. Watkins[56] state that the brine-freezing method involving immersion of fish directly in very cold brine has been unsatisfactory "apparently because of the sudden lowering of the temperature of the fish when immersed in the cold brine." In their method the fish are first thoroughly washed in water preferably at about the normal atmospheric temperature. They are then put in a revolving perforated cylindrical drum inclosed in a fixed cylindrical chamber. Around the drum are pipes adapted to spray brine radially inwardly on the drum, so that some of the brine goes through the perforations and strikes the fish. At the beginning the brine is at normal atmospheric temperature, but is gradually lowered until it is at about 15° F., at which temperature the fish are treated further until they are frozen. The time required to reduce the temperature to 15° F. is about 2½ hours, and the further treatment at 15° is, in the example cited by them, about 2 hours, a total of 4½ hours.

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[53] "The freezing point of solutions, with special reference to solutions containing several solutes," by C. E. Fawsitt. Journal of the Chemical Society, Vol. CXV, 1919, pp. 790–801.
[54] British Patent 23126, Apr. 16, 1913.
[55] U. S. Patent 1201552, Oct. 17, 1916.
[56] British Patent 127404, 1919.

We have seen from the theory of brine freezing that brine that would be liquid at 15° F., at normal atmospheric temperature is far above its freezing point. Under such conditions penetration of salt is bound to be severe. Furthermore, there is no evidence that very rapid freezing or sudden subjection to low temperatures does any harm to the fish.

MANN'S METHOD

For purposes of freezing fish in brine, particularly on steam trawlers, Robert Mann covered by patent[57] apparatus comprising a deep, upright tank, opening above the deck forward but extending through the deck below, where the accessory machinery is located. The tank is filled with refrigerated brine. Openwork cages are provided, in which the fish baskets or containers are placed. This cage is lowered into the tank of brine from the main deck. The brine is refrigerated by a suitable refrigeration machine and is filtered. The arrangement of apparatus permits the freezing operations to be conducted from the main deck without obstruction by machinery.

HIRSCH'S METHOD

It will be recalled that in Ottesen's invention it was brought out that when fish are exposed directly to brine for freezing there will be some penetration of salt unless the temperature and concentration of the brine conform to certain specified requirements; namely, that the brine of any particular concentration less than 22.42 per cent of salt be at such a temperature that free ice will exist in it. It was also pointed out that while the required conditions might be met in the body of the brine as a whole, that which is in immediate contact with the fish may be warmed by the fish until some penetration of salt occurs. Ludwig Hirsh[58] avoids the formation of a slow-moving film of brine in contact with the fish by suspending or loosely piling them and showering them with brine. By thus preventing penetration he claims that other brine, such as solutions of calcium or magnesium chloride, may be used. He further provides that the fish may be given a glaze by means of a preliminary bath or shower of fresh water, the adhering water film freezing at once when the cold brine touches it. It seems to the present writer unlikely that such a film would really freeze to a glaze under the circumstances. Ottesen makes a similar claim in his patent.

GOËR DE HERVÉ'S METHOD

The first method to be devised for continuous freezing of fish in brine was that of E. de Goër de Hervé,[59] who devised a long tank for brine through which the fish were moved by a combination of wire netting to hold the fish submerged and paddles to keep them in motion. The inventor describes the apparatus and its operation as follows:

> The apparatus consists of two endless chains on which is stretched an endless band of wire netting with a mesh small enough to retain the smallest fish

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[57] British Patent 144308, 1920.
[58] German Patent 335871, Apr. 16, 1921.
[59] La Revue Générale du Froid et des Industries Frigorifiques, October, 1920, pp. 291–292.

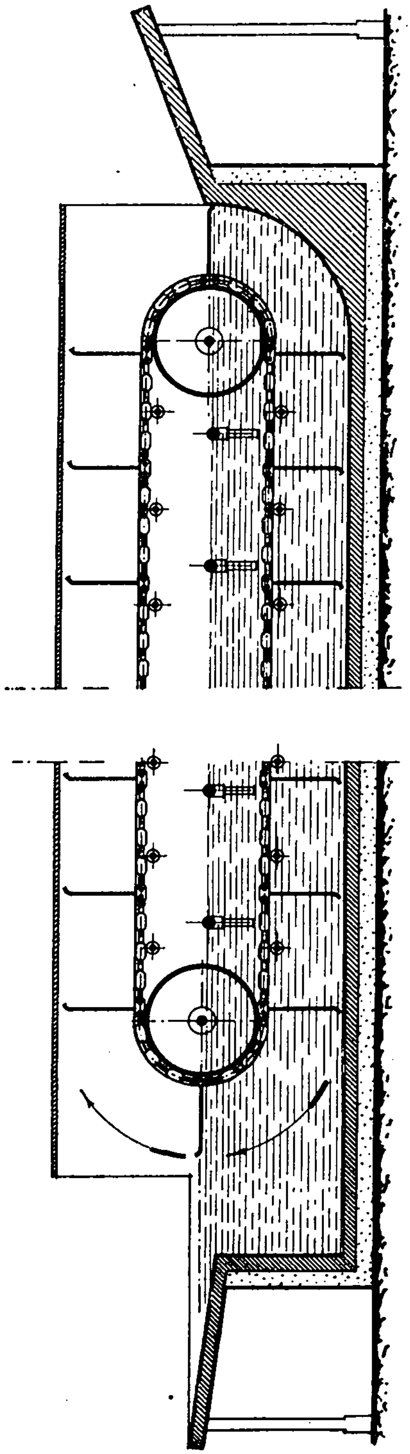

FIG. 30.—Goër de Hervé's method of freezing

without hindering the free circulation of brine. The endless chains and netting are supported by two drums, one of which is connected with a gear by which the whole system is set in motion.

At distances of 3 feet 6 inches the links of the chains carry light iron frames on which netting is stretched, thus forming a kind of paddle, the apparatus having to some extent the appearance of a caterpillar tractor, the paddles, however, being of exceptionally large size. The whole apparatus is immersed in a brine tank up to the axle of the drum.

At a small distance from the lower part of the endless net are placed lines of cocks with their apertures underneath, by which cold brine from a double-pipe brine cooler enters the tank at a certain pressure, causing sufficient agitation in the whole body of brine.

The drums, chains, and netting being set in motion at very slow speed, a crate of fish just landed from the trawler is emptied in the tank at one end; the fish are caught beneath a paddle and gently dipped into the brine. When the paddle has passed the vertical plane, the fish, on account of their density being less than that of the brine, begin to float in the liquid and adhere to the underside of the netting. The motion caused in the water by the lines of cocks prevents the fish forming thick masses from which heat could not be eliminated and spreads them thinly underneath the netting. The fish are thus slowly moved in gently agitated brine from one end of the tank to the other, where they arrive frozen hard; they are then taken out, packed in convenient cases, and placed in cold storage. The motion of the netting and the paddles is so slow and gentle that in no case can the skin or scales of the fish be injured, and special fittings are provided with a view to prevent any fish being caught and pressed between the paddles and the walls of the tank.

Except at the ends, where the fish are dropped in or picked out, the tank is covered to avoid any undue loss of cold, and, of course, the whole external surface of the tank is thickly insulated. The excess of brine coming from the tank is passed through a settling tank, then pumped through a filter to take out dirt, scales, or mucus, after which it passes through the brine cooler and back again to the freezing tank. The output of a tank supplied with fish up to 10 ounces in weight, with brine at 0° F., is about 1 ton per hour, the only hand labor needed being one unskilled man at each end, who can easily attend to three tanks, so that the cost of labor in this process is exceedingly small. The cost of refrigeration is reduced to a minimum, for if the insulation is good the only leakage is that at the ends, which is, of course, unavoidable. The speed of the drums may be increased in case the tank should be used for chilling fish instead of freezing, in which case the output is, of course, much larger. The standard tank covers a floor space of 83 feet by 7 feet.

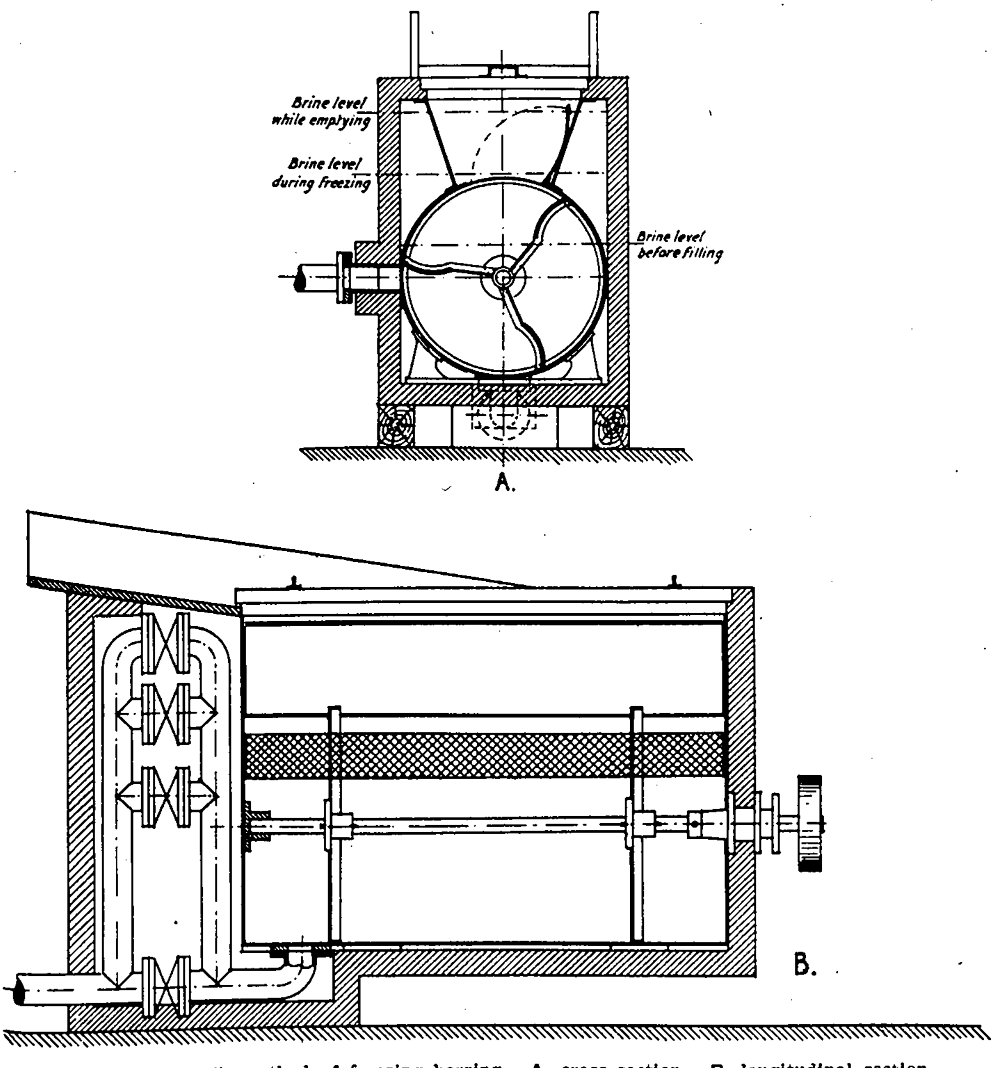

FIG. 31.—Piqué's method of freezing herring. A, cross section. B, longitudinal section

PIQUÉ'S METHOD

The British Fish Preservation Committee, under the Food Investigation Board, conducted extensive research work in methods of freezing fish, particularly by means of brine. One of the results of this work was the design of an apparatus for practical use in freezing fish, especially herring, in large quantities.[60] In this apparatus, as in that of Goër de Hervé, the fish are moved about in brine, but in a revolving motion rather than a forward motion. In its simplest form (fig. 31) the apparatus is a tank containing refrigerated brine. In the tank is mounted a cylindrical drum of wire netting or perforated sheet metal. Three baffles are mounted on a revolving spindle, arranged to revolve within the drum. A chute is provided for loading the freezer from the top when the door is open. Valves are provided so that the brine may be kept at any one of the three levels—one within the drum, another just above it, and the third near the top of the tank. To fill the freezer, the brine is lowered until its surface is within the drum, and with the door open the fish are put in at the top and dropped into the drum. The door is then closed and the brine level caused to rise by closing the lowest valve. When the brine is at this level, the drum is revolved by an external source of power. The baffles or paddles carry the fish around and around in the drum. When the fish are fully frozen the drum is stopped, the door opened, and the brine caused to rise farther in the tank by closing another valve. The fish now rise to the top from the compartments and are scooped out. Upon slow revolution of the revolving baffles the fish in the other compartments likewise rise to the top.

A larger apparatus makes use of three or more cylinders of netting or perforated sheet metal, 3 feet 3 inches in diameter and 7 feet long. The cylinders have a door that swings on hinges and extends part of the length. Inside the cylinder are three baffle plates of galvanized sheet iron. The cylinder is mounted on a spindle with a gear at one end. The cylinders are filled about five-eighths full of fish—that is, about 1,870 pounds to each—and are lowered into the tank containing the cold brine, when the spindle ends rest in bearings. They are now caused to revolve, when the baffles not only keep the fish in motion but also serve as propeller blades, which renew the brine in the cylinder. The cylinders are moved by an endless chain, and one may be removed without disturbing the others. This apparatus has a capacity of about 2½ tons, which, in the case of herring, freezes in 50 minutes. Floor space required is 16 feet 6 inches by 9 feet 8 inches. Such a plant was built and operated at Billingsgate, England.

Another form of the apparatus makes use of the cylindrical drums which are loaded at one end, conveyed mechanically downward and forward through the brine, revolving as they travel, emerging and rising at the other.

NEWTON'S METHOD

J. W. Newton, of Los Angeles, Calif., striving for a plant that could be inexpensively constructed and simply operated, designed a

[60] Department of Scientific and Industrial Research, Food Investigation Board. Special Report No. 4, Interim Report on Methods of Freezing Fish, with special reference to handling large quantities in gluts. 50 pp. London, 1920. Piqué, J. J., and the Imperial Trust for the Department of Scientific and Industrial Research, British Patent 154250; Piqué, U. S. Patent 1431328, Oct. 10, 1922; and W. B. Hardy, Canadian Patent 212879, June 19, 1923.

tank[61] divided into compartments. The larger compartment is the brine chamber for freezing fish; another compartment with a screen at the bottom is for cracked ice. Adjacent to this is a salt compartment with perforated bottom. The brine is drawn from under the ice in the ice compartment, and the greater part of it is pumped through a distributing feeder into the fish-freezing compartment. A branch of this discharge line passes into the bottom of the salt chamber and delivers brine upward through the salt. This brine spills over into the ice compartment, as does also the overflow from the freezing compartment. The brine flowing through the ice[62] is thus made up of (*a*) the warmed, and therefore unsaturated, brine returning from the fish compartment, and (*b*) a smaller quantity of approximately saturated brine from the salt chamber. The mixture of these two brines then passes through the pump and to the fish. By this means the brine striking the fish can not be saturated, and the maximum rate of

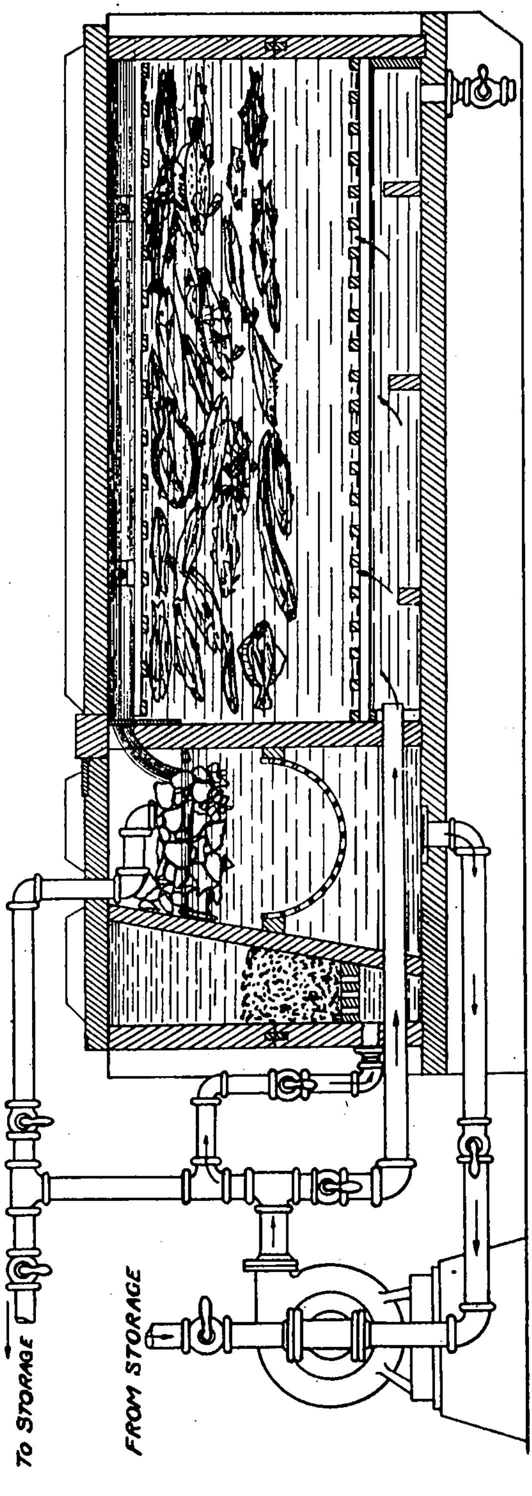

FIG. 32.—Newton's method of freezing fish in brine

[61] U. S. Patent 1547258, July 28, 1925.
[62] See also Dahl, U. S. Patent 1177308, Mar. 28, 1916.

liquefaction of ice and consequent absorption of heat can not be attained, as it could more nearly be attained if all the warmed brine returning from the fish passed through the salt before it struck the ice and after its passage through the ice chamber went to the fish again.

In operation ice and salt are put in their respective chambers and the apparatus is filled with brine. The valves are adjusted to provide the flow of brine and the pump is started. When the proper freezing temperature of brine is reached the fish are put in the freezing tank, where they remain until they are frozen.

TAYLOR'S METHOD

It is now some 36 years since freezing of fish in direct contact with brine was first proposed. In that time a dozen or more ways of doing it have been brought forward, and activity has been particularly marked in this field in the past 10 years. The advantages and difficulties of brine freezing are now apparent.

Fish frozen in brine, or by any sufficiently rapid method, undoubtedly are far superior to air-frozen fish in internal quality, because damage by internal crystallization is avoided, juices are saved on thawing that would be lost from air-frozen fish, autolysis is not so great, and the general appearance of the fish is better. By direct contact of brine with the fish the rate of extraction of heat is greater than it is in indirect contact, where the fish are inclosed in containers. Plank[63] has pointed out theoretical reasons for securing rapid freezing by direct contact with brine at a moderate temperature with the goods to be frozen, in preference to the very low temperatures of brine not in contact. Also, where contact with brine is immediate there is a sterilization of the surface tissues of the fish that is of practical value. The difficulties arising from penetration have been largely overcome by discovery of the physical principles that govern it and methods of reducing it to a minimum.

The barriers in the way of widespread adoption of direct brine freezing are largely mechanical. Where tanks are used for immersion of fish the volume of brine in proportion to volume of fish is large, almost prohibitively so where very large quantities of fish must be frozen. When fish are immersed in a tank of brine circulation of the main body of brine may be brisk, yet a very slowly moving film of brine will be in immediate contact with the surface of the fish, warming and causing excessive penetration of salt. Fish are of lower specific gravity than the brine, consequently they float and get out of the main movement of brine, crowding close together in a mass through which the brine does not circulate freely. In doing this they may also suffer considerable rubbing together, with consequent damage to snouts, fins, scales, and tails. Floating massed in brine, the fish assume curved shapes and do not pack advantageously when so frozen. Where fish are frozen in batches (as they are in all tank-freezing methods except Goër de Hervé's) the sudden charge of a large quantity of fish with rapid transfer of heat from fish to brine, unavoidably raises the temperature of the brine, with consequent penetration of salt, difficult or impossible glazing, and lack of uniformity of operation. Brine is corrosive, rapidly accumulating rust

[63] See p. 598.

from metal parts, and this rust may seriously discolor the fish. To the labor necessary for freezing must be added labor for washing and glazing, which, altogether, may be excessive.

If ice and salt are used as a source of refrigeration, it is impossible to maintain uniform temperature and concentration of brine, and refrigeration is wasted by discarding the excess of accumulating cold brine.

The present writer, while on the technical staff of the Bureau of Fisheries, after study of the theories involved and all the methods proposed for practice, approached the problem by first setting out the requirements that must be met by any entirely satisfactory brine-freezing method and then attempting to design a machine that would meet these requirements. The requirements for an entirely satisfactory brine freezer were conceived to be as follows:

1. Mechanical refrigeration should be used.
2. The brine should be maintained uniformly as near its cryohydric point as possible—that is, as near 6.16° F. below zero, and 22.42 per cent, by weight, salt.
3. To secure uniform operating conditions, operation must be continuous and not by batches.
4. The maximum rate of heat transfer should be secured by (*a*) exposing all the surface of the fish to the brine without obstruction, (*b*) flowing the brine with great rapidity, and (*c*) avoiding a sluggishly moving film in immediate contact with the fish.
5. The fish must be held straight until they become rigid.
6. Abrasion of fish by rubbing together must be avoided.
7. The quantity of brine used must be at a minimum and must not be wasted.
8. The brine must not be contaminated rapidly.
9. The fish must be washed thoroughly preliminary to freezing, preferably in running water.
10. The brine must be washed off and the fish glazed.
11. The machine must be capable of nice adjustment to fishes of different size, speed of freezing, etc.
12. It should be flexible—that is, applicable to as large a variety of fishes to be frozen as possible.
13. Metal working parts should avoid contact with corrosive brine, and rusting, in general, must be reduced to a minimum.
14. Labor for all operations should be at a minimum.
15. The machine must be suitable and practical for operation on a large scale.

The approach to the solution of these problems is as follows:

1, 2, and 3. If mechanical refrigeration is used, and if operation is continuous—that is, if the fish are fed continuously into the apparatus and are continuously withdrawn—maintenance of brine at or near its cryohydric point becomes possible. To secure continuity of operation the fish must be conveyed mechanically through the process from beginning to end.

4, 5, and 6. If the fish are suspended and sprayed with a violent spray of the brine, we secure all the desired conditions of exposing all the surface of the fish to the brine, flowing the brine with great rapidity, avoiding sluggish film on the surface, holding the fish straight as they freeze, and avoiding abrasion. 7. By using a spray the quantity of brine is very small—only enough is required to keep a pump primed and fill all pipes. It can be discarded frequently without serious loss.

8 and 9. If a spray is used and the fish are conveyed mechanically through it, we need only add a fresh-water spray at the entrance of the apparatus, the entering spray to clean the fish of slime, blood, and surface bacteria and to avoid contamination of brine and minimize foaming.

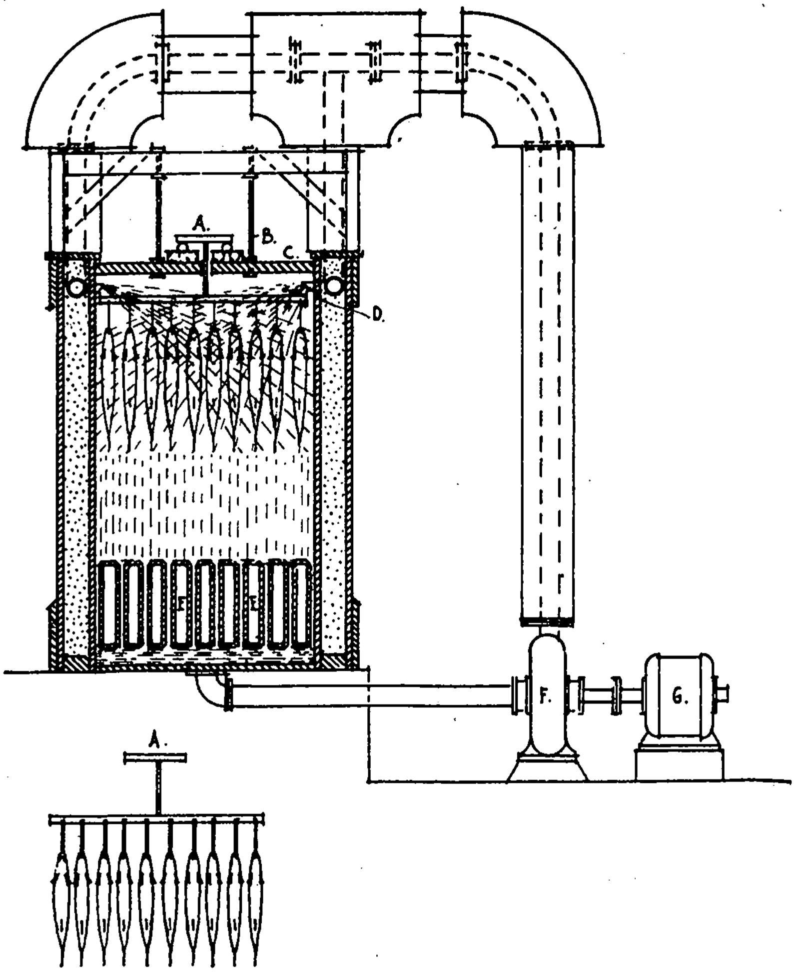

FIG. 33.—Taylor's freezing method. Cross section

10. To glaze the fish we need only to add a second fresh, cold water spray, or sprays, at the emergence end of the apparatus to wash off the brine and apply a glaze.

11 and 12. To secure flexibility and adaptability to different sizes of fish, the mechanical conveyer should be arranged for variable speed and the apparatus designed to take the largest varieties. Very small varieties can be inclosed in cans or other containers.

13. Avoidance of exposure of working parts to the brine is a matter of machine design and composition of brine to minimize formation of rust in the pipes, the same material, not galvanized, being used throughout.

14. By conveying the fish mechanically through the successive sprays of water, brine, and water, all necessary operations of washing, freezing, and glazing are done automatically, the only labor required being to put the fish in at one end of the apparatus and to remove them from the other.

The apparatus[64] takes the form of an insulated tunnel, say, 40 feet long by 4 feet wide, the dimensions being determined by the desired capacity. A mechanical conveyer operates in the top of the tunnel to convey horizontal bars through. On these bars the fish are suspended by head or tail. They hang thus and are frozen straight. The conveyer is adjustable for speed, so that large fish may be made to travel more slowly than small ones.

At the entrance end of the tunnel are provided sprays that give a violent shower of fresh water, washing the fish in clean running water. The fish then travel through a shower of brine at 5° or 6° below zero for, say, 32 feet, at a speed so adjusted as to freeze them by the time they reach the other end. When they emerge from the brine spray they pass under two fresh-water sprays. The first washes off the brine and, after draining a moment, the second applies the glaze. The fish then emerge washed, frozen, and glazed, and are ready to be packed.

The brine is pumped by a centrifugal pump and is cooled preferably outside the tunnel by a thermostatically regulated cooler, though it may be cooled in the tunnel, as shown in Figure 34. The time of travel of fish through the complete process varies from 15 minutes for smoked fillets of haddock to 3 hours for large salmon and halibut. Small fish, fillets, shrimp, oysters, and squid may be frozen by putting them in a can or other container and treating the containers like fish. Thus the flexibility of the apparatus is great.

A plant of this design and with a capacity of 15 tons of fish in 24 hours was constructed and operated in the Fishery Products Laboratory of the Bureau of Fisheries in Washington, D. C. It operated entirely satisfactorily under the experimental conditions.

FOAM IN BRINE

There is a tendency for foam to form in any brine freezer. The violent spraying of brine in this machine causes considerable formation of foam, a phenomenon that has required some study. The slime and blood on the fish, and other substances from the fish, if not washed off, are contributory causes. It was found also that the cruder grades of sea salt that we used in brine freezers contain a considerable quantity of an oily substance like petroleum. If the foam is collected, drained, and dried, a dark, sticky mass remains, partly soluble in ether and smelling like petroleum. It may be derived from decaying animals in the sea or may possibly be derived from ships.

[64] H. F. Taylor, U. S. Patent 1468050, Sept. 18, 1923; Canadian Patent 236588, Dec. 25, 1923.

The writer found by experiment (*a*) that the ratio of thickness of foam layer to depth of liquid brine obtainable with any particular brine is constant—that is, no amount of agitation of any particular specimen of brine will make a foam thicker than a definite maximum—and this ratio usually does not exceed 1 to 1; (*b*) that increasing contamination increases the ratio of foam thickness to brine depth; and (*c*) the constituents that cause foam remain in the foam. If the maximum foam is produced in a brine by agitation, and if the liquid brine is drawn off from the foam and this process is repeated two or three times, the foam-producing constitutents are removed and the brine does not foam until it is again contaminated. These facts point out a way to overcome difficulties from foam in brine freezers. The surface materials—blood and slime—that cause foam should be washed off. The brine vessel should be at least twice as deep as would be necessary for the liquid brine alone to allow for the gathering foam, and provision should be made for this foam to be carried away, draining free of the brine meanwhile. The contaminating impurities are thus automatically and continuously removed from the brine. In the case of the spray freezer this foam overflows into the washing compartments at each end.

RUSTING OF METAL PARTS

This highly complicated subject has received much study by chemists, electrochemists, and engineers and can not be discussed at length here.[65] Briefly, the brine should, if possible, be kept slightly alkaline with lime or a small amount of caustic soda. This may not be practicable in the spray freezer because of the intimate contact of the brine spray with air and consequent rapid absorption of carbon dioxide. Neither is this treatment effective in tanks where fish are in contact with brine, because these alkalis react and combine with the fish flesh and with the slime and fats coming from the fish. The composition of the metals of which the apparatus is composed has much to do with corrosion, and there are several resistant alloys on the market that eventually may be used for making freezing apparatus. Among these alloys are Monel metal, duriron, and an aluminum silicon alloy.

RAPID FREEZING IN CELLS OR MOLDS

In the foregoing methods of freezing, the fish are in immediate contact with the brine during the freezing process. Immediate contact secures the advantage of the greatest possible effective surface and the best possible rate of transfer of heat for a given difference in temperature. On the other hand, as has been seen in the discussion, the composition of the brine is limited practically to a solution of salt in water, with which the lowest possible temperature attainable is 6.16° F. below zero, though by addition of small amounts of other substances this temperature might be lowered a few degrees. Also, difficulties arising from the penetration of salt into and interaction with the tissues of the fish have necessitated serious considera-

[65] For a full discussion of corrosion see "Symposium on corrosion," papers by 19 authors, Industrial and Engineering Chemistry, vol. 17, April, 1925, pp. 335–392, Easton. See also "The corrosion of metals by refrigeration brines," by E. P. Poste and Max Donauer. The Milk Dealer, February, 1923; "The chemistry of the brine tank," by B. S. Hull. Ice Cream and Refrigeration, March, 1923; "The chemical treatment of refrigeration brines to prevent corrosion," by E. P. Poste. The Dairy World, December, 1924, pp. 41–46.

tion. Lower temperatures are possible with solutions of other substances. With calcium-chloride brine a temperature of 67° below zero is possible, and 28.5° below zero may be attained with magnesium chloride. These brines and other liquids of low freezing point can be used provided the fish are protected from direct contact with them by being inclosed in some impervious container, preferably a good conductor of heat. When fish are so frozen, the surface is free from any trace of foreign salt and may be glazed as easily as air-frozen fish. Numerous methods based on these facts have been proposed or practiced from time to time, and some of the more promising ones are in successful practical use.

As will be seen in the discussion, the difficulties in freezing in cans or molds arise from (*a*) less perfect contact of the fish with the brine than is obtained in direct brine freezing, and (*b*) lack of flexibility because of difficulty of making cans or molds that conform to the shapes of many varieties of fish.

Usually several fish are packed close together in the mold. The surfaces in contact with one another are, of course, not effective for heat transfer, only the outer surfaces of the mass as a whole serving this purpose. This outer surface, not being uniformly flat, generally has incomplete contact with the walls of the mold. The rate of freezing in molds, therefore, is considerably lower for the same brine temperature than it is where the fish are in direct contact with the brine. To overcome this difficulty, recourse is had to the lower temperatures that are possible with calcium chloride brine. An objection to this procedure lies in the diminished efficiency of refrigeration machinery as lower temperatures are reached, expressed in terms of tons of refrigeration per horsepower, as it is generally recognized that refrigeration machinery becomes less efficient as the temperature lowers.

In ideal refrigerating machines the amount of work done is proportional to the difference between the temperature at which heat is absorbed and that at which it is rejected. We may say that the steeper the grade up which the heat must be pushed the more work is required to push it. The efficiency is expressed mathematically by the ratio $T_1 \div (T_2 - T_1)$ where T_1 is the cold side and T_2 the warm side, expressed in absolute temperature units. Table 24 shows these ratios for several temperatures commonly dealt with in refrigeration.

TABLE 24.—*Ideal efficiency of refrigerating machines*

Temperature at which heat is absorbed (evaporating ammonia), degrees Fahrenheit	Temperature at which heat is rejected (ammonia going to condenser), degrees Fahrenheit, and ratio of cold produced to work done by machine					
	50	60	70	80	90	100
−30	5.5	4.8	4.3	3.9	3.6	3.3
25	5.9	5.1	4.6	4.2	3.8	3.4
20	6.4	5.5	4.8	4.4	4.0	3.6
15	7.0	5.9	5.2	4.7	4.2	3.8
10	7.5	6.4	5.6	5.0	4.5	4.1
5	8.5	7.0	6.0	5.3	4.8	4.3
0	9.2	7.7	6.6	5.8	5.1	4.6
+10	11.7	9.4	7.8	6.7	5.9	5.2
20	16.0	12.0	9.6	8.0	6.8	6.0
30	24.5	16.3	12.2	9.8	8.2	7.0
40	50.0	25.0	16.7	12.5	10.0	8.3

To take an example: If brine is to be maintained at 25° F. below zero, the temperature of the evaporating ammonia may be 30° below zero. This, expressed in absolute units (238.59°), is T_1. If the condensed water is 75° F., we must maintain a temperature of, say, 80° in the compressed ammonia gas. This, also expressed in absolute units (299.64°), is T_2. The efficiency, $T_1 \div (T_2 - T_1)$, is 3.9; that is, 3.9 times as much energy will be handled in the form of heat as is expended in the form of work. If a temperature of 5° F. below zero is to be maintained, we may evaporate the ammonia at 10° below zero. If the condenser water is still 75° and the compressed ammonia 80°, the efficiency by ratio will be 5.3. At 25° below zero brine temperature the ideal efficiency is only about 74 per cent of what it would be at 5° below zero brine. This neglects actual inefficiency in the machine itself, friction, losses, and smaller amount of gas handled per piston stroke.

Apart from the diminished efficiency of the machinery and the economic factors involved, it has been pointed out by Plank [66] that these lower temperatures are objectionable in their effect on the tissues of the fish. The juices of fish contain mineral salts and colloid substances. Because of their presence a very low temperature [67] (around 75° C.) is necessary to cause all the water to freeze solid. At a temperature warmer than this more and more of the water is left in the tissue substance. If a fish originally containing 75 per cent of water is frozen at 5° F., there remains about 13 per cent water of the 75 per cent still in the tissues unfrozen; while if frozen at 31° F. below zero only 2 per cent would remain—that is, the tissues would be almost completely dehydrated and would return, if at all, with much more difficulty to their original condition on defrosting. For these reasons Professor Plank recommends that speed in freezing be secured by direct contact and brisk circulation rather than by very low temperatures with less perfect contact.

Opposed to these objections are the advantages of compactness, convenience, and cheaper handling of cakes or blocks instead of individual fish, and the ease and perfection of glazing. Freezing in molds is particularly well suited to the freezing of fillets or steaks of fish, which readily conform to the shape of a mold and are more seriously affected by penetration of salt than round fish.

EARLIER METHODS

Among the earliest methods of freezing fish were those that involved the packing of fish in pans with lids,[68] which were embedded in cracked ice and salt. Hesketh and Marcet, who were also pioneers in brine freezing, covered in their patent [69] the freezing of perishables by placing them in compartments, boxes, or cells surrounded

[66] R. Plank, "Theories concerning the changes taking place in the cell membranes of animal flesh during the process of refrigeration." Ice and Cold Storage, October, 1925.

[67] H. W. Foote and Blair Saxton ("The effect of freezing on certain inorganic hydrogels." Journal, American Chemical Society, Vol. XXXIX, pp. 1103–1125. Easton, 1917. See also ibid., Vol. XXXVIII, p. 588, 1916.) have shown that the jellylike consistency also has an effect of lowering the freezing temperature, the contained water being in the capillary condition.

[68] D. W. and S. H. Davis, U. S. Patent 161596, Apr. 6, 1875. Referred to, also, in D. W. Davis, U. S. Patent 709751, Sept. 23, 1902.

[69] British Patent 6117, Apr. 9, 1889.

by a cooling medium. In the same year Douglas and Donald[70] invented the freezing of fish and the like by inclosing them in bags, which were put in ice cans and surrounded by water. The whole was frozen together, so that the fish were incased in a block of ice.

FRIEDRICHS' METHOD

This idea of freezing fish by putting them in tapered cans and lowering the cans in cold brine, according to the well-known practice of making ice, was revived in 1915 by Martin Friedrichs[71] in Hamburg, Germany. Friedrichs adapted it particularly to the freezing of eels. The eels were hung on a support and lowered into

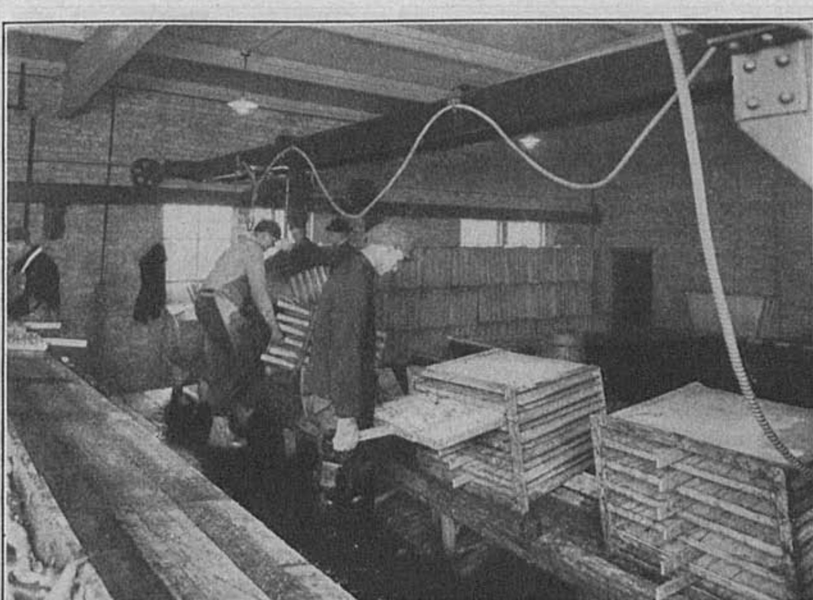

FIG. 34.—Petersen's method of freezing. The panned fish are transferred to the freezing molds. Courtesy, Bay City Freezer

a deep, narrow, tapered can and were surrounded by water. The can was then lowered into an ice-brine tank and the contents frozen solid. When the contents were frozen the can was withdrawn from the brine and the block was removed and stored at a temperature a few degrees below the freezing point of water. It was reported that eels frozen and protected in this way kept perfectly for a year or more. Provided a lower temperature was used in storage, they should keep almost indefinitely.

PETERSEN'S METHOD

P. W. Petersen, of Chicago, using a tapered freezing can, worked out many details of its application to the commercial freezing of

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[70] British Patent 20614, 1889 (Feb. 8, 1890).
[71] Die Friedrichs'che Aal-Gefriermethode. Die Kälte-Industrie. XII Jahrgang, Heft 1/3, pp. 3–4. Hamburg, 1915.

fish.[72] The method applies to freezing fish in cakes and to freezing them singly.[73]

FREEZING IN CAKES

For this purpose Petersen uses a narrow, deep, tapered can, constructed of heavy sheet metal, of various dimensions to suit different sizes of fish. For fish from 1½ to 10 pounds the dimensions are such as to produce cakes 28 inches long, 18 inches wide, and 3¾ inches thick. For smaller fish cans of the same length and depth but 2 inches thick are used. The can is somewhat deeper than the width of the cake, and when it is partially immersed in the brine

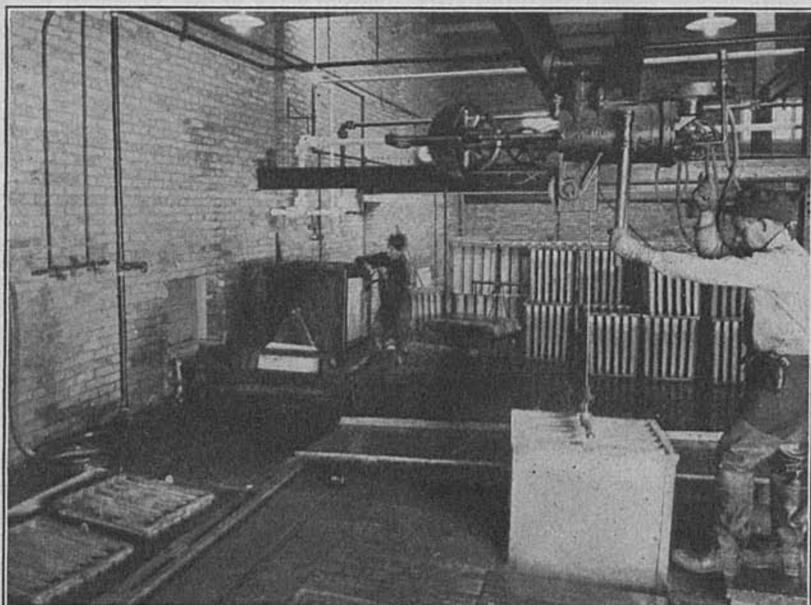

FIG. 35.—Petersen's method of freezing. The freezing molds are lowered into the brine tank. The dump for removing the cakes in center background. Here they pass through the glazing trough into a cold packing room. The pan with wheels on a rail is to catch brine drip from the freezing molds when they are brought up. Courtesy, Bay City Freezer

the contained fish are all below the brine level. To facilitate handling the cans are attached to iron frames in batteries of 4 of the larger cans or up to 8 of the smaller.

For packing fish in the cans scoop-shaped temporary receptacles are used—shallow pans suggesting a dustpan or snow scoop, provided with a handle. These scoops are designed to fit in the freezing pans. The fish after being washed in the usual way are packed in these scoops. A frame of cans is turned on its side and the scoops of fish put in the cans. The frame is then upended and the

[72] P. W. Petersen, U. S. Patent 1422126, July 11, 1922; reissue 15083, Sept. 24, 1923. C. J. Thompson and P. W. Petersen, U. S. Patent 1509850, Sept. 30, 1924. P. W. Petersen, U. S. Patents 1528890 and 1528891, Mar. 10, 1925.

[73] See "A modern fish-freezing plant," by P .W. Petersen. Refrigerating Engineering, June, 1924. New York; also "Modern methods of freezing fish." Same journal, July, 1922.

scoops pulled out, leaving the fish in the cans arranged in an orderly manner. In this position the fish in the bottom of the can are under pressure from those above. This has the effect of reducing the space occupied by the fish, with consequent saving of storage space, and also secures the good contact with the can necessary for rapid freezing. It has the disadvantage, however, of distorting the shape of the fish.

When the frame of cans is filled with fish, it is lifted, by an electric hoist that moves on rails over the freezing tank. This is a tank that resembles in all essentials an ice-making tank. It may be provided with refrigerating coils or an external shell cooler for refrigerating the brine, the brine being kept in motion among the cans by an agitator. The frame of cans is lowered into the brine so that

FIG. 3C.—Petersen's method of freezing. The fish emerge from the glazing tank into a cold room, where the glaze sets and the cakes are boxed. Courtesy, Bay City Freezer

the open ends project above the brine level. A hatch lid covers the can.

As calcium chloride brine is used, the temperature may be very low, with consequent rapid freezing. Peterson maintains a temperature as low as 25° or 30° F. below zero, but as brine is not in contact with the fish any suitable temperature may be used. Cakes 4 inches thick, in brine at 20° to 25° F. below zero, freeze in about 2½ hours. If allowance is made for time of dumping, glazing, and interruptions, 8 freezing cycles may be made in 24 hours, each frame of cans holding about 250 pounds. The capacity of a freezer is measured, of course, by the number of cans the tank will accommodate.

When the fish are frozen the hatch lid is taken off, the hoist attached, and the frame of cans pulled out. To prevent any drip of brine to the floor, with possible entrance into the fish cans in the tank, a pan, mounted to roll on rails over the tank, is brought under the lifted frame of cans. The frame is then conveyed to the dump. It is first immersed in a well of water (the warm water from condensers is recommended for this) to loosen the cakes and is then placed in a swivel-mounted dump and turned over. The cakes slide out into the glazing trough. This arrangement allows the frozen cakes to fall directly into the glazing water, which breaks the impact and avoids the damage that would be done the fish if they should fall on the floor.

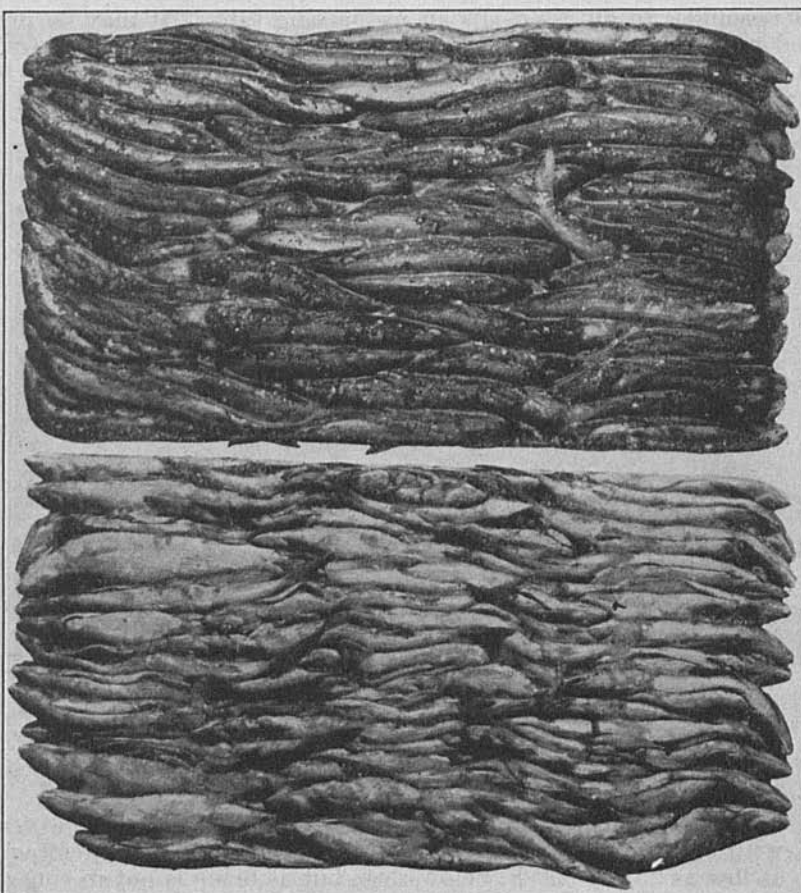

FIG. 37.—Petersen's method. Cakes of fish frozen in molds. Courtesy, Bay City Freezer

The glazing trough is built through an opening in the wall that separates a cold packing room from the freezing room, one end being in the freezing room and the other in the cold packing room. The fish cakes float through the glazing trough, take on a glaze, and are removed in the cold room and packed.

The entire operation is practicable and simple and undoubtedly produces frozen fish of excellent quality. Where the sizes and shapes are not excessively varied, a limited number of cans should serve; but where these vary greatly, as often occurs in public warehouses, especially those that freeze sea fish, a variety of sizes and shapes would be necessary. The larger kinds of fish do not pack to advantage in these cans, the difficulty being to secure contact with the sides of the cans. For this work Peterson has designed specially shaped freezing receptacles.

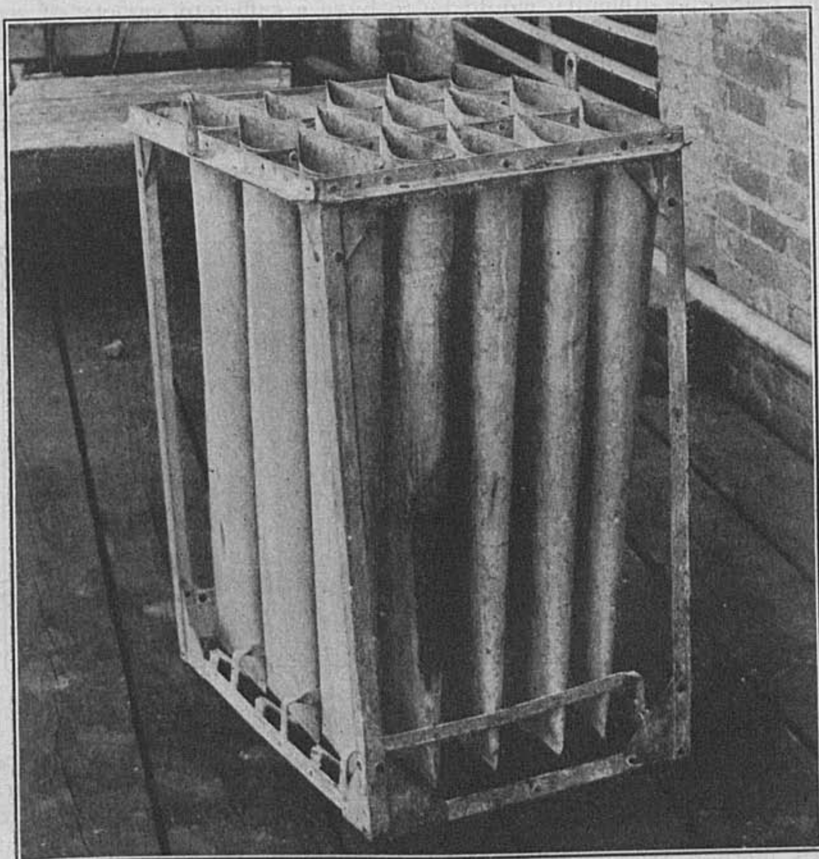

FIG. 38.—Petersen's method for freezing fish singly. The fish are slipped, tails downward, into the thin metal sheaths

INDIVIDUAL FREEZING

Instead of cans for a number of fish, a sheathlike, sheet-metal container is used for individual large fish. The container is made by bending around a thin metal sheet after the fashion of a starched cuff and crimping and riveting the edges together. The bottom is made narrower than the top and is also sealed. This arrangement makes a sheath somewhat resembling the shape of a fish, the round side fitting the back and the sharp side the belly. The fish is put in, tail down, the metal being sprung open so as to exert a slight pressure on the contained fish. For halibut a two-edged container is used. These sheathlike containers are mounted in batteries and otherwise handled in the same way as the cans for cake-frozen fish.

Fish frozen by this method (for which Peterson has coined the word, "keenkooling") are trim, straight, and, of course, take an excellent glaze. The bellies of dressed fish are closed. Here, again, the principal difficulty would be to have a sufficient variety of sizes and shapes to accommodate the general run of fish received at a fish freezer. There could scarcely be objection to the internal quality of fish so frozen unless on the academic ground suggested by Plank (p. 598) of freezing at excessively low temperatures. An excessively low temperature, of course, is not essential to Peterson's method of freezing, because any temperature may be chosen. The only reason for the low temperatures actually used is to secure the benefit of the

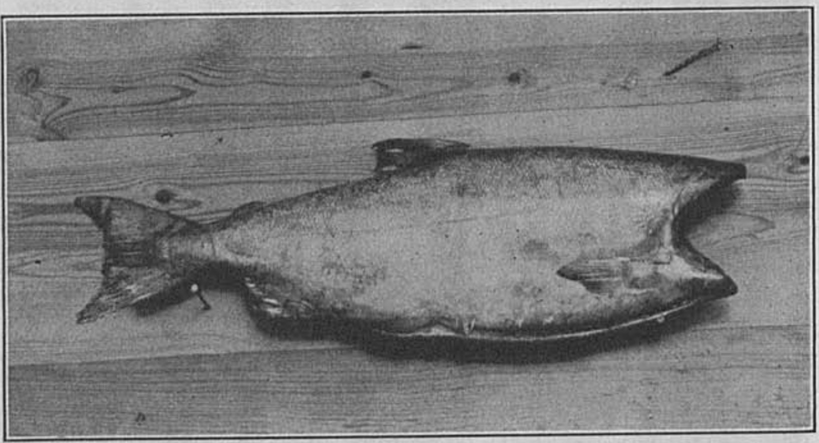

FIG. 39.—Petersen's method for freezing fish singly. Lake trout frozen in a thin metal sheath. Courtesy, Bay City Freezer

most rapid freezing possible. In this connection it may be noted that Peterson secures the necessary rapid freezing, not by particularly good contact with the refrigerant brine, but by a low temperature. It appears, in the absence of actual figures for comparison, that this method freezes at about the same rate in brine at 20° below zero as direct brine freezing does at 5° below zero. Refrigeration, as pointed out above, generally costs more per ton the lower the temperature.

Direct brine freezing seems to give the best possible contact but introduces difficulties of brine penetration, while indirect brine freezing avoids penetration but requires lower brine temperature to secure the necessary speed. The advantages or disadvantages are thus not all on one side.

KOLBE'S METHOD [74]

R. E. Kolbe, of Erie, Pa., has made an adaptation of the ordinary freezer pan to immersion in brine freezing without contact of brine

[74] "Brine freezing of fish," by Robert E. Kolbe. Ice and Refrigeration, vol. 70, pp. 205–206. Chicago, 1926.

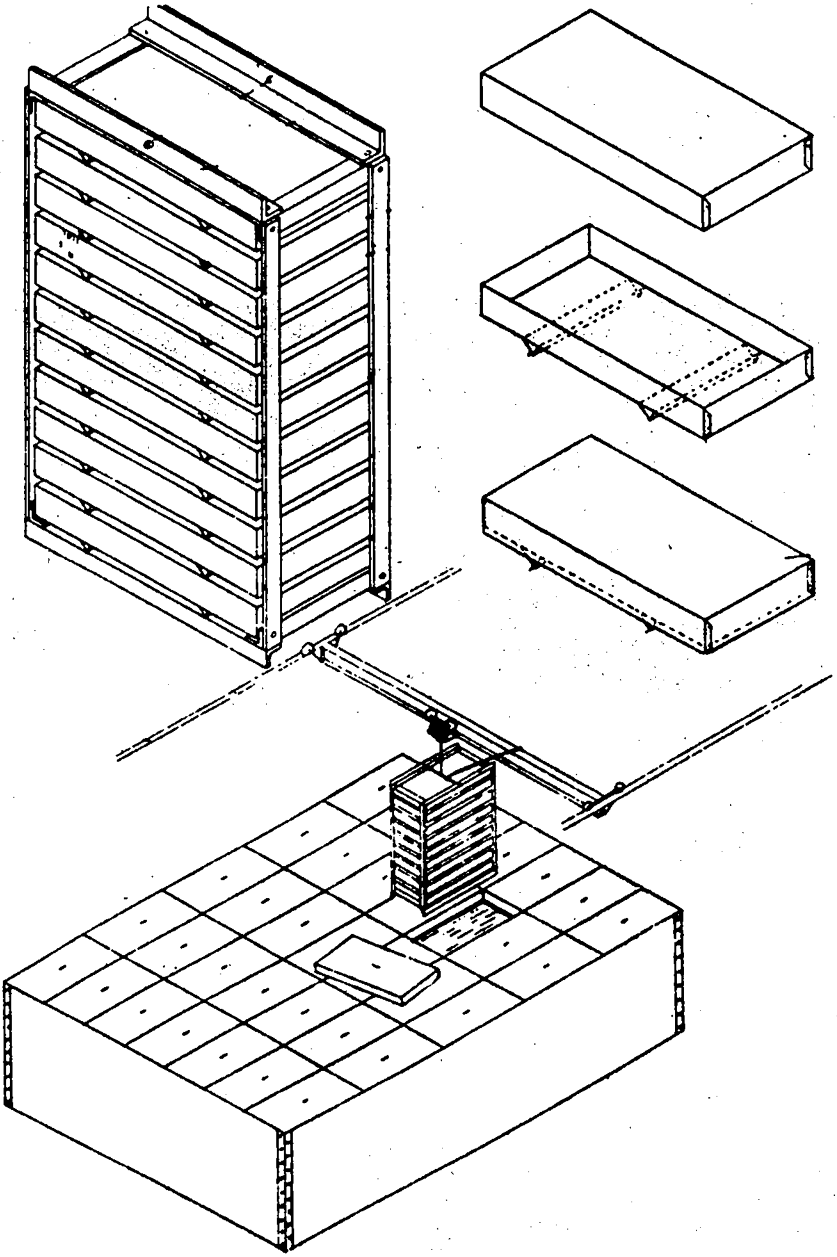

Fig. 40.—Kolbe's method of freezing. The fish are panned in metal pans, stacked in frames, and lowered into the brine tank. Courtesy, Kolbe Fish Co.

with the fish.[75] A plant is in operation at Port Dover, Ontario, on Lake Erie, with a daily capacity of from 12 to 20 tons of fish a day. Shallow pans in shape and dimensions similar to the ordinary air-freezing pans for Lake Erie fish, holding about 17½ pounds each, are provided with lids somewhat deeper than the pans. The pan itself has two V-shaped metal strips fastened to the bottom, so that when the pans are stacked, one on another, they are separated by the thickness of this strip to allow circulation of brine between. Twenty such pans, after having been packed with 350 pounds of fish in the ordinary manner of air freezers, are placed in a frame made of angle irons. This frame is lifted by a traveling overhead electric hoist, moved over the brine tank as in Petersen's method, and lowered

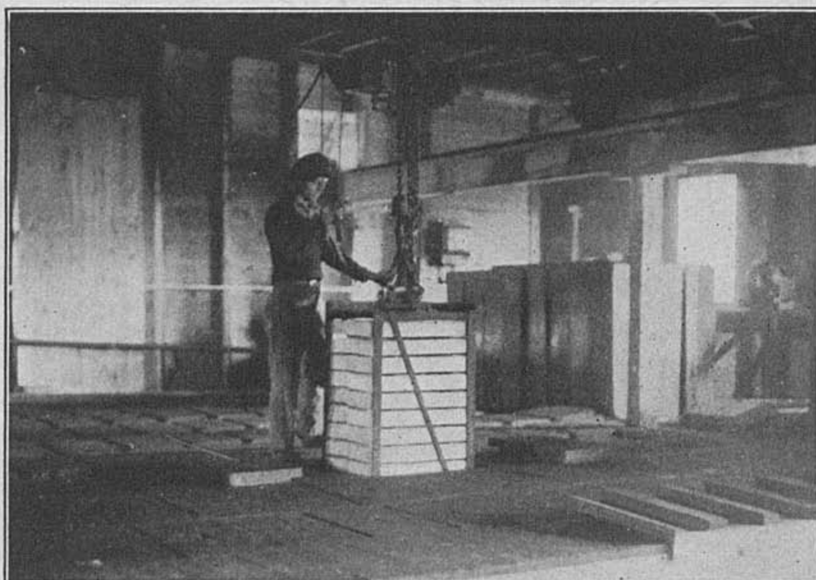

FIG. 41.—Kolbe's method of freezing. Frame of pans being lowered into brine tank. Courtesy, Kolbe Fish Co.

into the brine. The tank contains 9,400 feet of 1¼-inch pipe and 15,000 gallons of calcium chloride brine, chilled by ammonia and kept in motion by means of agitators.

The brine is prevented from entering the cans by air entrapped in each pan, as in the diving bell. The air entrapped is compressed in direct proportion to the depth to which it is lowered, and in direct proportion to the specific gravity of the brine. If, therefore, provision is made for a sufficient volume of air under the lid of each pan, the pan may be immersed to a considerable depth before the brine can reach the fish—hence a lid deeper than the pan.

Refrigeration is furnished by a 9 by 9 inch inclosed compressor driven by a 35-horsepower motor. When fish are not being frozen, some refrigeration is accumulated by mushing the large volume of brine. The brine, of course, may be chilled by pipes in the ice tank,

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[75] U. S. Patent 1527562, Feb. 24, 1925.

as above stated, or in a separate tank. Also, the pans may be lowered into an empty tank, which is then filled with the cold brine; or, with proper care, they may be immersed directly into the brine.

When the fish are frozen the cans are lifted from the brine tank, drained briefly, and conveyed to another part of the floor, where they are showered with water to remove the brine and loosen the cakes of fish. The cakes are then removed, glazed, and packed in the usual manner. This method of freezing is at present used by its inventor's firm, principally for freezing ciscoes on Lake Erie.

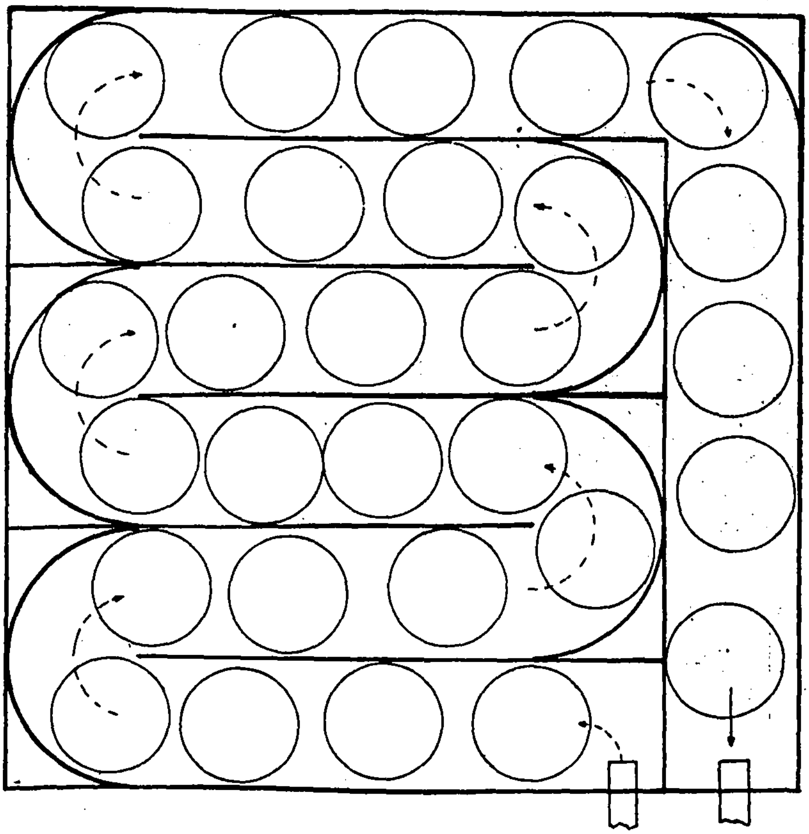

FIG. 42.—Kolbe's method of individual freezing for fillets and small fish. The circular pans float through the channel in the brine in directions indicated by arrows.

The advantages of simplicity and low cost of this method are at once obvious. While the writer has not had opportunity to see this plant, it seems that it requires some nicety of calculation in design to obtain best results. The buoyancy caused by entrapped air is overcome by the weight of the cans and the frames that hold them. The transfer of heat must take place through the top and bottom of the can, for the space on the sides between can and lid is occupied largely by air. If freezing is to occur on top, the pan must be well packed to obtain good contact with the lid. At the bottom of the can brine must be in contact. If the depth of the lid is calculated for this condition in the top can, the others also will be bathed on the bottom. Of course, a leak, even a tiny one, in the lid, would allow the air to escape and brine would strike the fish.

Kolbe has also devised[76] an ingenious method of freezing fillets and fish individually. The apparatus, consisting of a shallow, insulated tank, is fitted with galvanized sheet-iron partition baffles that divide the tank into a labyrinth or devious channel returning to a point near which it starts. Cold brine is pumped in and flows through this circuitous channel at a moderate rate of speed.

The fillets or fish are put in circular pans or boats made of galvanized sheet iron, 18 inches in diameter and 3 inches deep. These

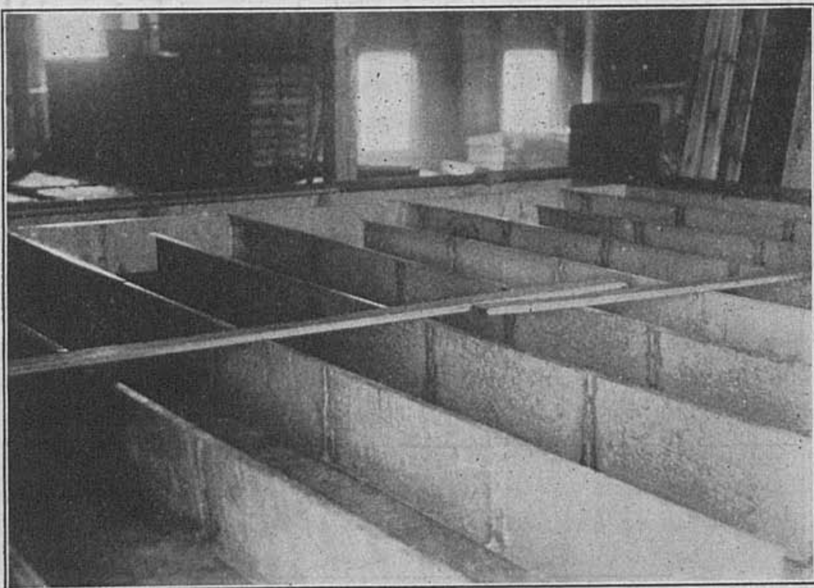

FIG. 43.—Kolbe's method for fillets and small fish. The maze tank, uncovered to show arrangement of baffles. Courtesy, Kolbe Fish Co.

boats are laid in the floating brine, whereupon they follow the stream through the channel, returning to a point near the starting point. The same operator loads the cans, starts them on their way, and receives them on their return.

At the completion of freezing the pans are removed, drained for a moment, inverted, and knocked against the wooden table. The tank is heavily insulated and has an insulated cover. The fillets or individual fish fall out and the pan is ready for repacking. The pans, being circular, do not jam in their course through the freezer, and the freezer may be filled to capacity with them without interference. Fillets of blue pike freeze in from 20 to 30 minutes with brine at about zero. Whitefish, being thicker, freeze in about 3 hours at this temperature. More rapid freezing can be obtained, of course, in brine of lower temperature.

[76] Patent pending (December, 1925.)

BIRDSEYE'S METHOD

Clarence Birdseye, of New York, adapted the can-immersion principle to the freezing of fillets of fish.[77] Because of exposure of much cut surface fillets must, almost of necessity, be frozen not in contact with brine. For convenience of handling it is also an advantage that they be frozen in bricks or blocks, to which form they

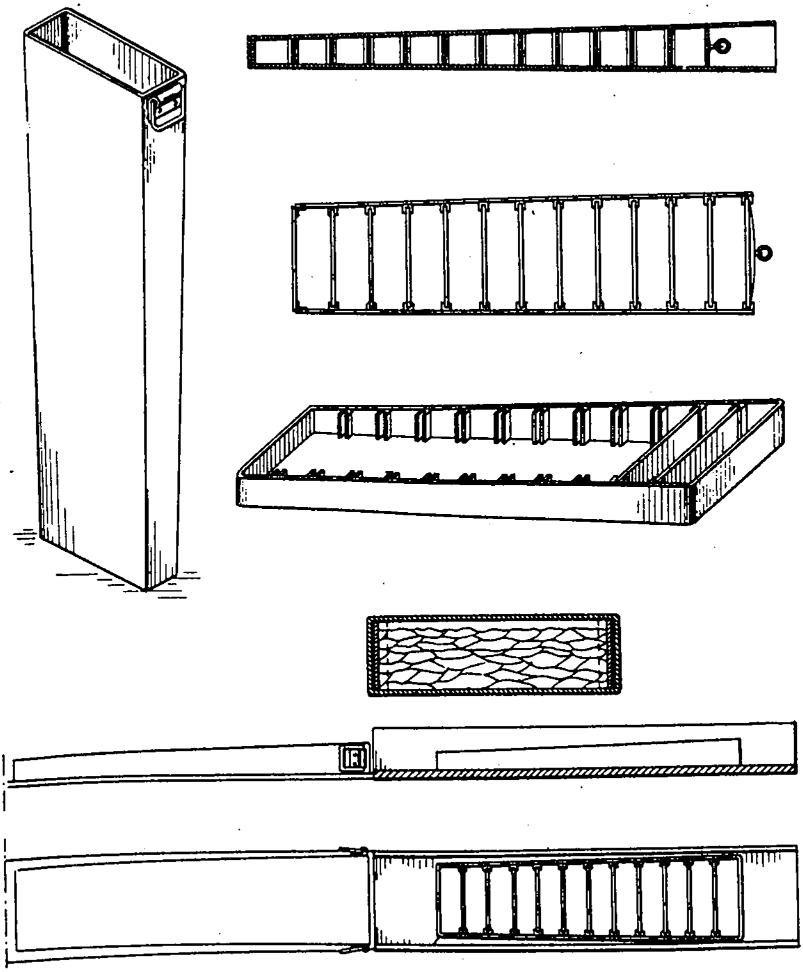

FIG. 44.—Birdseye's method of freezing.

are well adapted by their flabbiness.[78] The can is deep and narrow, with a slight taper. For filling the can there is provided a frame made of strap iron with removable cross partitions of metal. These cross partitions are arranged at such intervals that the interspaces will contain units of the desired sizes and weights—5 or 10 pounds.

[77] U. S. Patent 1511824, Oct. 14, 1924.
[78] The preparation of fillets of fish is described by Harden F. Taylor in "Modern methods of merchandising fish," published by the Patterson Parchment Paper Co., Passaic, N. J.

The can is laid upon its side on a working table. The frame, with partitions in place, is laid on a board with the end at the mouth of the can, the board raising the frame at such an elevation that it will slide directly into the can without disturbing the fillets. The fillets are packed and arranged in the spaces between the partitions of the frame, and the latter is slid into the can. The can is then upended and let down into the brine tank, the top protruding somewhat above the brine level, as in Petersen's system. The cans, being handled singly, are not heavy enough to require a mechanical hoist but are lifted by hand. When the fillets are frozen, the cans are withdrawn and dipped a moment in water, whereupon the frame is pulled from the can and the frozen bricks of fillets are released and packed.

Another form of Birdseye's freezing mold is a flat can opening at a large side instead of at the end. A side lid is arranged to be fastened on by means of thumb nuts and a gasket to prevent entrance of the brine. This mold is immersed bodily in the brine.

This method of Birdseye's was designed to meet a more specialized business than were most of the other methods hitherto described; namely, the dressing of fish and preparing fillets for cooking and freezing, all at or near the point of production of the fish, for shipment to consumers. The frozen bricks were packed in insulated containers and, containing their own refrigeration, went forward without ice as dry packages. Birdseye at first used a double-wall box made of corrugated strawboard, with dried eelgrass between the walls. He later adopted the simpler and less expensive practice of insulating ordinary corrugated strawboard boxes with two or more extra thicknesses of the same material cut in panels to fit the sides, top, and bottom of the box.

If the fish contain 75 per cent of water, all frozen, the package contains the equivalent of 60 or 70 per cent of its net weight in the form of ice for refrigeration. Ordinary shipments of fresh fish on ice usually have the same weight of ice as fish for refrigeration. Thus the contents of a box of 100 pounds net weight of fish would, together with the ice, weigh 200 pounds, only 50 per cent of the contents being fish. In the frozen bricks a shipment of 100 pounds of fish without ice would contain the equivalent in refrigeration of 60 or 75 pounds of ice, total weight of contents 100 pounds—an obvious advantage. Furthermore, the reserve refrigeration, being contained in rather than around the fish, is protected from loss by the insulating effect of the fish itself, for we have already seen that the thawed layer of fish around a frozen core during defrosting is a relatively poor conductor of heat. The economic soundness of this method of preparing fish for transportation is further substantiated by the removal of all nonedible parts of the fish and the use of a much lighter shipping package.

While Birdseye's business establishment was not a financial success, the methods he introduced appear to be economically sound and his freezing apparatus inexpensive and practical. As will be seen later, the fundamental ideas have been improved by others and are being applied in practice.

A simple experimental box, operating on Taylor's brine-spray principle, was put into practice by The Atlantic Coast Fisheries Co.

in New York in 1924. The apparatus is an insulated wooden chamber, 4 feet square and about 7 feet high, with a side door. A refrigerated coil was mounted in brine in the bottom of the chamber. A pump draws the brine from the tank and forces it through spray nozzles in the top of the tank. The fillets were packed in circular tin cans, $2\frac{5}{16}$ inches deep and $12\frac{1}{4}$ inches in diameter, holding 10 pounds and provided with lid. These cans were suspended in iron frames in the spray chamber and frozen, the temperature of the salt brine ranging from 5° below zero to several degrees above.

The fillets were stored and shipped in the cans. For shipping, the cans were packed in insulated strawboard boxes. While the tins afforded ideal protection against desiccation and rusting in storage, they were unsatisfactory because they were expensive and because of rust that developed during storage, which marred the external appearance of the cans and discolored the fish. Some brine entered the cans on which the lids did not fit perfectly.

In order to overcome the difficulties just mentioned molds of cast aluminum were made, $2\frac{5}{16}$ by 9 by 13 inches, with a flat lid fastened on with two thumb nuts. These are suspended on an angle-iron frame and conveyed into the brine-spray freezer. The frozen blocks are wrapped in parchment and a craft paper ("Safepack"), two sheets of which are cemented together by asphaltum, making it waterproof. These wrapped blocks are stored in wooden boxes and for shipment are put in paraffined cardboard boxes and packed in the insulated corrugated box. Such boxes have been shipped successfully 1,500 miles in summer weather. In cold weather they usually arrive at their destinations frozen.

This method also is subject to objections. The aluminum boxes are corroded somewhat by the salt brine (aluminum corrosion is harmless, however), and the lids of the molds become warped by repeated expansion of the fish in freezing, allowing brine to enter. An improved type of can is of similar shape but made of galvanized sheet iron, having an overlapping lid at one end, which is fastened on. The can is suspended by the lid and brine can not enter.

COOKE'S METHOD

A. H. Cooke, of The Atlantic Coast Fisheries Co. of New York, devised a method of freezing, particularly for fillets to be shipped after the manner of Birdseye, which is carried out in an apparatus consisting of aluminum pans of double wall.[79] Calcium chloride brine circulates between the walls equipped with temperature-collecting webs.[80] Instead of a lid on each can the cans are nested or stacked in such a way that the bottom of each can furnishes the refrigeration for the top of the fish in the can below. Two recesses are provided in each pan for two 10-pound blocks of fillets. Five such double receptacles, one above the other, form a battery that will freeze 100 pounds of fillets at a charge.

Such receptacle pans have calcium-brine inlet and outlet pipes on opposite sides of the middle of the pan, connecting by a swivel

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79 Patent pending.
80 See Hesketh and Marcet, British Patent 6117 (1889), for first disclosure of this idea.

joint. These pipes also connect by swivel joints with the brine-feeding and discharge headers, so that the pans can be raised, one at a time, turned up side down on the swivel joints, and the cakes dumped. The pans are counterpoised by weights on pulleys.

For loosening the cakes of frozen fillets in the pans a measured quantity of warm calcium-chloride brine is admitted from a tank into the wall spaces of the pan, forcing the cold brine out and back into the refrigeration system. When a quantity of warm brine just sufficient to displace the cold brine has been pumped in, a double-throw valve is operated to circulate the warm brine in a circuit of its own. Thus, the cakes are loosened and fall out. When the re-

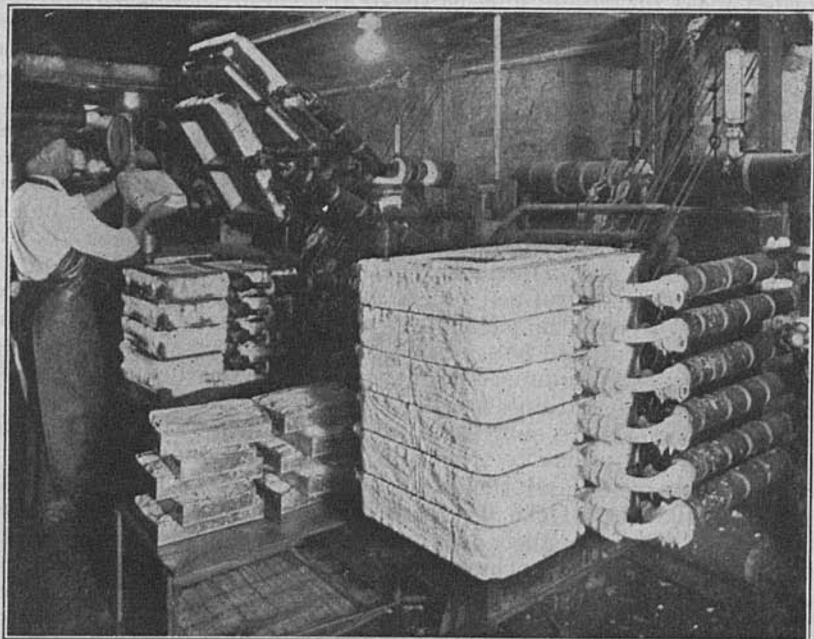

FIG. 45.—Cooke's method of freezing cakes of fillets. Machine in the foreground closed and freezing. Machine in background opened and being discharged. Courtesy, Atlantic Coast Fisheries Co.

ceptacles are empty the valves are reversed, driving all of the warm brine back into its tank, when, as the cold brine just fills the receptacle wall spaces, a valve is thrown, which puts the receptacles entirely in the cold-brine circuit again for freezing. An indicator guides the operator in operating the valves so as to loosen the cakes in the receptacles without mixing the hot and cold brine. The exposed surfaces of the freezing molds are insulated with corkboard.

While this apparatus is somewhat complicated and perhaps more expensive to construct than some of the others, it undoubtedly produces frozen fish of excellent quality, frozen rapidly and without contact with brine. With about one hour required, from the beginning of freezing of one batch to the beginning of the next when the brine is at 10° below zero, one battery of five double molds will freeze

800 pounds of fillets in an 8-hour day, or 4,000 pounds in five such batteries, one man being in attendance by rotation on the five batteries. There is some loss of refrigeration in repeatedly warming and cooling the apparatus, but this is not a large loss because of the low specific heat of aluminum (about 0.20).

The fillets are packed in temporary sheet-metal pans that hold 10 pounds each. From these pans the fillets are transferred to the freezing receptacles. When the calcium brine is 10° below zero, freezing is completed in about 50 minutes on cakes of the dimensions mentioned. Lower temperatures and consequently more rapid freezing is practicable, of course.

Fig. 46.—Cooke's method for individual filets. Frozen haddock fillets being taken from freezer. Courtesy, Atlantic Coast Fisheries Co.

INDIVIDUAL FILLETS

Cooke also has designed a freezer of somewhat similar arrangement for freezing individual fillets. The fillets are laid on aluminum plates about 30 inches square and $\frac{3}{16}$-inch thick. These plates are placed on hollow shelves contained in an insulated cabinet. The shelves are of cast aluminum with internal webbing that constitutes a labyrinth through which the cold calcium-chloride brine circulates. The webbing serves two purposes—namely, to distribute the cold brine uniformly throughout the shelf for uniform freezing, and to conduct the heat away from the surface of the shelf more rapidly than it would be conducted by a smooth surface. The brine inlet and outlet are attached to opposite edges of the shelf and are provided with double-throw valves, so that cold brine may be circulated for freezing and warm brine for slight defrosting so that the plates may be removed easily from the shelves.

The outside upper surface of each shelf is very slightly concave, so that when the shelves are warmed for removal of the plates the drip from the water condensed on the apparatus collects in this slight concavity. When the plates are again placed on the shelves, the water makes a physical contact between plate and shelf, which becomes ice when refrigeration is again turned on. This ice bond between plate and shelf serves to conduct heat rapidly and to insure rapid freezing. There are 12 shelves on each side, or 24 shelves in one cabinet freezer, taking about 250 pounds of fillets.

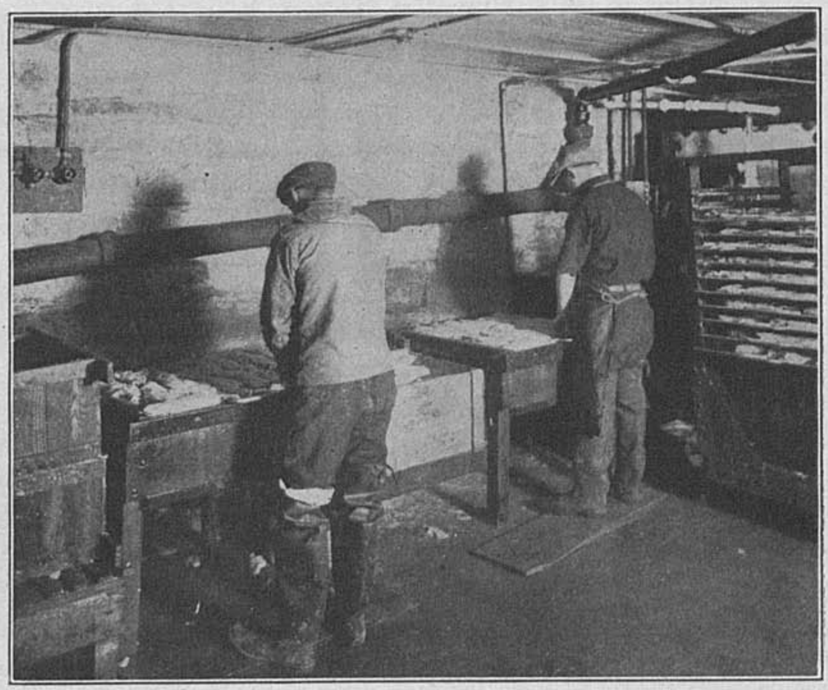

FIG. 47.—Cooke's method for individual fillets. Removing frozen fillets from plate and putting on fresh ones. Courtesy, Atlantic Coast Fisheries Co.

In operation, the fillets are laid, skin side down (the skins usually are removed), on the plates. The loaded plates are placed in a rack superstructure mounted on a flat truck and are moved to the freezer cabinet. They are put on the warm shelves, which, as stated, have water on their upper surfaces. The cabinet doors are closed and the cold brine is turned on. At a temperature of 10° F. below zero haddock fillets freeze in about 50 minutes; at 25° below, in less than 40 minutes. When fillets are frozen the warm brine is turned on, the plates are removed and transported back to the plating tables, and fresh plates are put in the freezer.

The plating table is really a frame to receive one plate at a time. It is provided with a series of perforated pipes connected with the city water supply. Water is turned on momentarily and is squirted from the perforations against the lower side of the plate and warms the plate so that the fillets may be removed. Fresh fillets are then placed on the plate.

The advantage of rapid freezing of fillets in this apparatus without contact with brine is obvious. It is also simple and practical. The advantage of compactness, which it embodies, is of importance, inasmuch as the surface required for individual freezing is relatively very large and will take up a prohibitive amount of space if spread out. Two cabinets of 24 shelves each can be placed on a floor area of about 3½ by 15 feet and will freeze about 500 pounds of fillets an hour with brine at 10° F. below zero. The fillets are flat and are frozen straight.

LIQUID AIR FOR FREEZING

Liquid air has been proposed as a refrigerant for fish[81] by Bailey. The inventor's container for liquid air was claimed to make practicable the control of temperature in a room by regulating the evaporation of the liquid. Even if liquid air were available at a moderate price (which it is not), it would scarcely be suitable for freezing fish. While liquid air has a temperature of about 342° F. below zero, the amount of refrigeration it contains is, pound for pound, actually less than that in ordinary ice. Ice has 144 B. t. u. per pound; liquid air about 122. It would freeze fish very quickly, but even if frozen in liquid air it would be impossible to hold the fish at anywhere near that temperature.

WINTER-FROZEN OR NATURALLY FROZEN FISH

In cold climates in winter fish are taken through holes in the ice and allowed to freeze in the cold winter air. This practice is followed in Canada, Russia, and other northern countries.

METHOD OF CATCHING FISH THROUGH HOLES IN THE ICE

The simplest way is to cut a hole through the ice and fish with a hook and line or a long-handled dip net. For commercial purposes a more efficient method is followed, as described by Robbins[82] Holes are cut through the ice at intervals. A long, light pole is lowered into a hole and extended to the next. By this means a line is run from hole to hole, on which a gill net is fastened and let drop into the water under the ice. The fish entangled in this net are drawn out with the net, taken off, and allowed to remain on the ice until they are frozen, or nearly so. The air may be, on occasions, as cold as 40° F. below zero. Snow is gathered, to be used in packing with the fish in wooden boxes, and the fish are packed, if practicable, while they are still slightly soft. The boxed fish are allowed to remain on the ice until the fish are frozen solid and a wagonload accumulates, when they are hauled to a railroad station and shipped.

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[81] Bailey, "Liquid air as a freezing agent." Canadian Fisherman, April, 1918. See also, O. Simonis, Liquid Air and Its Possibilities. Proceedings, Fourth International Congress of Refrigeration, London, 1924, Vol. II, Sec. III, pp. 1094–1102.

[82] C. C. Robbins, "The fish production of the Great Lakes of the United States and Canada, and the practical application of refrigeration and cold storage." Proceedings, Third International Congress of Refrigeration, Chicago, 1913, Vol. I, Sec. III, pp. 543–552. Chicago.

Sometimes winter frozen fish are packed in snow houses and not shipped at once. They may be held for months, packed in snow houses, frozen solid.

These fish are not glazed, but the conditions under which they are kept virtually preclude desiccation and rusting, so that glazing is scarcely needed. Fish frozen in this way are assured of one great point of superiority—they are absolutely fresh when frozen. The rapidity of freezing, however, may be highly variable, according to temperature and wind velocity. When the temperature is 40° below, the wind blowing a gale, and the fish are not piled, they should freeze rapidly and be of excellent quality. On a day with an air temperature of 10° above and no wind the fish would freeze slowly and would be damaged by internal crystallization. However, the conditions being entirely beyond our control, we may accept them as a bounty, enabling fishermen to earn something in such a winter climate and furnishing the public with an excellent product.

DEFROSTING AND COOKING FROZEN FISH

If, while the fish are freezing and during storage no changes take place other than mere solidification, they should, on thawing, return to their original condition; but we have seen that changes of a more or less serious nature may take place in freezing and storage. How may these changes be reversed on thawing and the fish restored to its original condition?

If fish are frozen rapidly, as in any of the newer rapid-freezing processes, and stored for a short time with a good glaze or covering to prevent drying, they may be defrosted rapidly or slowly, as desired, and will approach their original condition. In fact, a freshly brine-frozen fish may be put in the oven or frying pan while still hard, and it will be in every way indistinguishable from fresh fish.

EFFECT OF CRYSTALLIZATION AND COAGULATION

If during slow freezing some of the water separates from the tissues of the fish and freezes as crystals of water ice, on thawing these crystals turn again to water. If this water is to be reabsorbed into the tissues, it must have time. While it is absorbing the fish must not be squeezed or otherwise disturbed, else the water will exude and be lost. Likewise, if rapidly frozen fish on long storage undergo coagulation with separation of water, the water must be given time to be reabsorbed into the coagulated tissue on defrosting.

Slow defrosting is preferable, for the reasons given, to extremely rapid defrosting. The writer has observed that rapidly frozen fish that has been stored for more than a month is wet when defrosted in warm air and juice can be squeezed out; but within an hour the juice is reabsorbed and can no longer be squeezed out. Air-frozen fish on defrosting, especially if they have been stored for some time, are exceedingly juicy and will lose some juice with almost any kind of defrosting. This juice contains so much albumen that if heated it will coagulate like the white of egg. It represents not only a loss of weight but a loss of valuable nutrients and savory materials. For example, in a recent test made by the writer a sample of 15 pounds of a commercial brand of air-frozen fillets of haddock, individually wrapped, was defrosted in the original package. On defrosting the fish lost 16 per cent in weight, and on being taken from the box and unwrapped they lost 7.8 per cent, or 23.8 per cent loss between the frozen boxed fillets and the defrosted and unwrapped condition. If fish like halibut are steaked before defrosting, the loss will be greater than in fish not cut, because the skin of the latter helps to hold the juice until it can be reabsorbed.

If drying has been allowed to occur in storage, the fish will have lost some weight. Some of this lost weight can be restored to the fish as it defrosts, either by condensation of atmospheric moisture on the cold fish, by embedding the fish in ice, or by immersion in water.

METHODS OF DEFROSTING

These are (1) allowing the fish to remain in warm air, (2) putting it in cool air in a refrigerator, (3) embedding in cracked ice, and (4) immersing in water.

1. When fish are left in the air of a room at ordinary temperature a considerable amount of water will condense on the surface, and some of it will be absorbed by the fish, especially if the fish has dried in storage. This gain may be from 1 to 3 per cent. Air defrosting, like air freezing, is slow, and for the same reasons, but it allows time for the reabsorption of the separated juice. There may be some drying of the surface if the thawing time is prolonged, with consequent impairment of appearance. To prevent this, the fish may be covered with a damp cloth.

2. Defrosting in a refrigerator or cold chamber is similar to defrosting in a warm room, but is slower. It offers a slight advantage, perhaps, in protecting the fish from bacterial infection and from surface drying, to both of which it is exposed in a warm room. Otherwise there seems to be no particular advantage in this method.

3. The freezing point of fresh-water fish is about 31° and of salt-water fish about 30° F. Fish will therefore defrost slowly when embedded in cracked ice that has a temperature of 32°. This method is still slower than defrosting in a refrigerator. It exposes the fish to water from melting ice. Some of this water is taken up by the fish, with a consequent gain in weight, to a greater extent than when the defrosting is done in air. Also some of the soluble substance is dissolved from the superficial parts of the fish. Cut surfaces are blanched and their appearance is not improved. Still, the slowness of the method allows time for the reabsorption of the juices.

4. Immersion in cold water is the quickest method and perhaps the one in most common use. The fish absorb water up to as much as 10 per cent of the original weight, restoring loss if any occurred in storage. If the fish dried very much in storage, the loss may not be completely made good. In this method also some soluble substances are removed from the fish. This effect may be diminished by adding a small amount of common salt to the water. The amount of salt required would be about 0.7 pound to 100 pounds of water for fresh-water fish, or about 1.3 pounds of salt to 100 pounds of water for sea fish.

The reader who is interested in the theoretical principles involved in thawing is referred to Stiles[83] and to Plank, Ehrenbaum, and

[83] See footnote 47, p. 583.

Reuter.[84] The Dutch workers, Fortuyn and Van Driest, also carried out tests reported by Bottemanne.[85]

The conclusions from Plank's, Ehrenbaum's, and Reuter's experiments on loss of weight and on defrosting and cooking frozen fish may be summarized as follows: Fish that have been frozen for a week may be brought back to their original condition by either slow or rapid defrosting. In fish that have been kept frozen for a longer time the juice that has separated from the muscle substance is not reabsorbed.

The defrosting method followed (in cold water, ice, or air at room temperature) has, according to their experiments, no influence on the taste or keeping quality of the defrosted fish. Simple, quick, and convenient thawing in ice water seems preferable, while in air thawing some loss of weight may occur.

As soon as possible after the fish are defrosted they should be gutted. They will then keep as long as or longer than fresh fish held under the same conditions. Frozen fish, especially during defrosting, must be carefully protected from handling, bending, squeezing, or other mechanical disturbance that will press out any of the juice.

These conclusions seem sensible and practicable. Fortuyn and Van Driest, after some experimental work, recommended embedding the fish in cracked ice for defrosting. This is an extremely slow method, unnecessarily expensive, and not likely to be adopted generally.

COOKING FROZEN FISH

If the fish have been defrosted in accordance with the methods outlined, they may be treated as fresh fish in the kitchen. Joseph Bruna,[86] a French chef, recommends that frozen salmon be cooked without previous defrosting. His experience with frozen fish obviously is limited, for he says that salmon is the only fish suitable for freezing. Fish frozen in brine, or by any of the rapid-freezing processes, may be thawed before cooking, or they may be put in the oven or frying pan while still frozen. They will require a little longer to cook.

RATES CHARGED FOR FREEZING AND COLD-STORAGE OF FISH

The rates charged by fish freezers that do a public warehousing business vary, of course, with many conditions, such as the location of and investment in the plant, cost of power, water, and labor, kind of goods to be frozen, and volume and distribution of the business over the seasons of the year. Obviously, it would be unfair to make a comparison of the rates charged by various freezers without taking these factors into consideration. There are given here the published rates charged by three freezers separated by considerable distances geographically, which will give the reader a general idea of the rates charged in the United States and Canada.

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[84] See footnote 15, p. 518.
[85] See footnote 15, p. 518.
[86] Joseph Bruna, La cuisine des aliments frigorifiés. 40 pp. Association Française du Froid, Paris, 1919.

TABLE 25.—*Rates charged for freezing and cold storage of fish*

NEW YORK CITY

Goods received		First month	Second and subsequent months
Fresh, for freezing:			
To be pan frozen or spread—			
Lots of less than 12,000 pounds	per 100 pounds	$1.00	$0.30
Lots of more than 12,000 pounds	do	1.00	.25
To be frozen in packages—			
Large packages	do	.50	.30
Small packages	do	.70	.30
Clams, scallops, oysters, crab meat, etc., in cans	per gallon	.08	.08
Trunks of crabs	per trunk	.75	.35
Bait, barrels (200 pounds)	per barrel	.60	.40
Shad roes, season $0.10 per pair; monthly rate	per pair	.05	.01
Received frozen for storage:			
Lots of less than 12,000 pounds	per 100 pounds	.35	.30
Lots of more than 12,000 pounds	do	.35	.25
Small packages, smelts, etc	do	.40	.35
Smoked and dried fish, frozen temperature:			
Haddies, bloaters, etc	do	.35	.30

Goods received		10 days only	Second and subsequent months
For cooler:			
Barrels, 200 pounds	each	$0.50	----------
Boston boxes	do	1.00	----------
Salmon boxes	do	.50	----------
Fresh-water boxes	do	.40	----------
Scallops, tubs	do	.25	----------
Labor charges:			
Reglazing	per 100 pounds	.50	----------
Wrapping	do	.75	----------
Examination	do	.10	----------
Transfers that necessitate handling goods in storage	do	.125	----------
Minimum charge for any lot of fish		.50	----------
Boxes:			
Regulars	each	.90	----------
Mediums	do	.75	----------

BUFFALO, N. Y.

Goods received		First month	Second and subsequent months
Fresh, for freezing:			
Blue pike, 2,000 pounds or more	per 100 pounds	$1.00	----------
Blue pike, less than 2,000 pounds	do	1.25	----------
Other fish, 2,000 pounds or more	do	.75	----------
Other fish, less than 2,000 pounds	do	1.00	----------
Lots of 20,000 pounds or more	do	----------	$0.125
Lots of 10,000 to 20,000 pounds	do	----------	.15
Lots of 5,000 to 10,000 pounds	do	----------	.20
Lots of 2,000 to 5,000 pounds	do	----------	.25
Lots of less than 2,000 pounds	do	----------	.30
Fish received frozen in boxes for storage:			
Lots of 20,000 pounds or more	do	.25	.125
Lots of 10,000 to 20,000 pounds	do	.25	.15
Lots of 5,000 to 10,000 pounds	do	.30	.20
Lots of 2,000 to 5,000 pounds	do	.35	.25
Lots of less than 2,000 pounds	do	.40	.30

Buffalo, N. Y.—For fish received frozen in bulk 10 cents per 100 pounds is added to cover additional labor in handling. When possible, fish are boxed when frozen, and charge for box and labor is made in the first month's invoice. Empty fresh-fish boxes are subject to disposal at owner's expense after 24 hours unless shipping directions are given previously. The minimum charge is 5 cents per box.

Small fish, less than 12 inches average, are subject to a labor charge proportionate to the additional time required for handling. Reglazing and boxing is done at the cost of labor and material, plus 10 per cent. Fish are stored in bulk at the owner's risk of shortage, mixing, etc. For more than ordinary inspections goods are handled in the warehouse for weighing, sampling, or inspection at the customer's expense.

The monthly rate covers the period from the date of receipt to but not including the corresponding day of the following month, or any part of such period, excepting when the expiring day falls on Sunday or a holiday, in which case the next business day is deemed the expiring day. The storage rates specified include the labor of receiving, storing, and delivering the goods from and to the warehouse platform. Cartage to or from railroad depots and stores in the produce district and warehouses is charged at the prevailing rates of responsible truckmen. Deliveries requiring sorting for sizes are charged for extra.

Bay City, Mich. (*Petersen's method of freezing*).—The following is an excerpt from the freezing, keen-kooling, and cold-storage price list of a freezer in Bay City, Mich.:

Cake-freezing, glazing, and storage: One cent per pound (glazed weight) for cake-freezing, glazing, and storage until the end of calendar month in which received. Minimum charge for any shipment received for freezing, $5. Cakes will be marked with the words "Petersen frozen" and patent dates. Extra charge for freezing in divisible cakes, 15 cents per 100 pounds.

Keen kooling, glazing, and storage: Two cents per pound (glazed weight) for individual freezing (keen kooling), glazing, wrapping individually in special parchment paper or special parchment bags and storage until the end of the calendar month in which received. This price includes glazing boxes and lining boxes with parchment paper, as additional protection against evaporation during storage. Minimum charge for any shipment received for keen kooling, $10. All bags or wrappers will be marked with the words "Keen kooled" and patent dates.

Royalty: In addition to the above charges one-tenth of 1 cent per pound will be charged for all cake-freezing or keen kooling. This amount is the patent royalty charged us for the use of the superior Petersen rapid freezing systems which we have installed and are utilizing exclusively for all our freezing and keen kooling. Only articles in prime condition will be accepted for freezing or keen kooling. Boxes in which fish were received will, if desired, be returned to customer, transportation charges collect. All fish will be boxed before stored. Boxes are furnished at cost plus 10 per cent for overhead.

Storage on articles frozen or keen kooled: Twenty cents per 100 pounds per calendar month or fraction. Any lot on which this charge has been paid for six consecutive months will be held free of charges for any part of the subsequent six months. No handling charges are made on articles frozen or keen kooled.

Storage on articles received for general cold storage: Twenty-five cents per 100 pounds (gross weight) for storage per calendar month, or fraction thereof. Twenty-five cents per 100 pounds (gross weight) handling charges, including both "in" and "out," marking boxes, making out bills of lading, etc.

CHILLING AND ICING FISH FOR TEMPORARY PRESERVATION

For the temporary preservation of fish by chilling almost any of the methods described may be employed by removing the fish from the freezing process before they are frozen through. The freezing point of salt-water fish is about 30.7° F. and of fresh-water fish about 31°. The respective classes of fish may be chilled to these temperatures without freezing. At such temperatures putrefaction and autolysis are not arrested but are greatly retarded. Fish so chilled will keep in good condition for several days. Kyle's method was designed to chill in concentrated sea water, and later, if desired, to freeze the fish. Dahl's method chills or freezes according to the time allowed for pumping the cold brine between the fish. The methods of Ottesen, Goër de Hervé, Mann, Piqué, Taylor, and Newton also may be used for chilling.

LARSEN'S METHOD

J. M. Larsen, of Copenhagen, designed a method [87] particularly for chilling fresh fish. He uses clear filtered sea water chilled to about 32° F., or a little colder. The fish are kept in this bath until they are chilled to a temperature approaching their freezing point, but not frozen. He also specified salt water in lieu of sea water and of about the same concentration. In this mild brine he claims that penetration does not occur, and that after 10 days the eyes are bright and gills pink, while gutted fish keep from two to four weeks in a much better condition than fish preserved by the usual methods.

There is a widespread assumption that because sea water is the natural element in which fish live it is inert and harmless as a bathing medium for dead fish. The nearest to an ideally inert solution for this purpose would be water containing the same mineral substances in solution in the same proportions in which they occur in fish. This is not true of sea water for any common food fish. Sea water contains about 3.5 per cent salts and a larger proportion of magnesium chloride than occurs in fish. Haddock contains about 1.45 per cent mineral salts in quite different proportions from those of sea water. The living fish is able to resist and regulate the osmotic penetration of the excess salts in sea water, but when dead it is not able to do so. Therefore there will be an interchange between the piece of fish and sea water when fish are bathed or chilled in it.

EATON AND CAMERON'S METHOD

A method [88] similar to Larsen's was designed by Eaton and Cameron, but differing from it principally in the use of ordinary salt brine 80 per cent saturated and flowing at a temperature of 12° to 15° F., wherein the fish are reduced to a surface temperature of 27° to 29° F. in 30 minutes without freezing. The principles underlying the effect of temperature and concentration of brine on the rate of penetration (see p. 578) indicate that under these conditions the fish would absorb much salt. A temperature of 12° may be reached satisfactorily in brine only 54 per cent saturated, and such a brine certainly would not penetrate as rapidly as the much stronger brine specified by these inventors. However, the inventors' first claim covers any temperature and concentration that will cool fish from 38° to 27° or 29° F. in 30 minutes.

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[87] U. S. Patent 1322312, Nov. 18, 1919. For a recent account of plans and claims for this method see "Politiken" (Copenhagen), Aug. 12, 1925.
[88] A. C. Eaton and W. R. Cameron, U. S. Patent 1404352, Jan. 24, 1922.

Eaton and Cameron's method of applying this invention is to float the fish in flowing brine in an elongated tank. A tank of this kind, used for the "Chilpack" product put up by the Deep Sea Fisheries, Inc., at Rockland, Me., is about 30 feet long, 5 feet wide, and 3 feet deep. Perforated wooden panels, attached to a moving chain, serve to carry the fish, fillets, or steaks under the brine and through to the emergence end, very much after the manner of Goër de Hervé (see p. 588). Pipes situated along the side walls of the tank keep the brine at from 20° to 25° during the freezing.

REFRIGERATION ON MENHADEN STEAMERS

Menhaden or bunkers (*Brevoortia tyrannus*), the fish that have been caught many years in large quantities along the Atlantic coast for the manufacture of fertilizer, fish meal, and oil, have been held in the holds of vessels without ice or other refrigeration. The steamers engaged in this fishery carry purse-seine boats that operate the seines. When the seines surround the fish and are pursed below, forming a bowl, the fish are scooped out, brought aboard the steamer, and dumped in the hold. Here it has been the custom to leave them, without ice or other preservative, until the vessel has accumulated a catch, when it proceeds to the factory. In the several days that sometimes elapse before the fish reach the factory much decomposition occurs, the odor becomes offensive in the neighborhood of the factory, and some nitrogenous material is made soluble by decomposition and is lost in the water pressed from the fish in manufacture. Recently a method of applying refrigeration to preserve the menhaden in the holds of the vessels was introduced by the Marine Products, Inc., of Reedville, Va. John A. Palmer, of that firm, in a private communication to the author, described the process as follows:

On the steamer *Gloucester* we take sea water into two closed round tanks, 4 feet in diameter and 8 feet long, each having 2,200 feet of cooling coil. Ammonia is supplied to the coils through a manifold of five pipes, the outlets being similar. The fish hold is supplied with a false bottom, from under which sea water is pumped by a centrifugal pump through the tanks and to ¼-inch spray nozzles, which deliver the cooled sea water uniformly over the fish. The water percolates among the fish to the false bottom, where it is again picked up by the pump and put through the same cycle. After about six hours the water is slimy and is pumped overboard and replaced by fresh sea water. We use a double strainer next to the pump to remove scales, dirt, etc. The size of the compressor is 7½ by 7½ inch Frick two-cylinder. This has taken care of 250 tons of fish and prevented decomposition. The average temperature of the sprayed water is 42° F.

The steamer *Louise* has cooling coils under the false bottom, and the water is pumped from there directly back to the sprays, but we have not had good results from this installation. We believe it to be because of the smaller compressor. The C. M. Robinson Co. of Baltimore installed the *Gloucester* outfit.

ICING FISH

Ice, the now almost universally used preservative for fish, has been used for many years. The first record of its use in the United States is that of a halibut smack out of Gloucester, Mass., in 1838, natural ice, of course, being used. It was slow of adoption, and at first the ice was not allowed to come in direct contact with the fish, but was used only to keep the hold cool. When it was found to do no harm the fish were packed in crushed ice. By 1845 ice was in general use on these boats. Because of a prejudice against its use, iced packages were not shipped inland until 1858, when iced packages were shipped to New York as an experiment, whereupon adoption of the method rapidly followed.

The first use of ice on English North Sea fishing vessels was in about 1868; and with the establishment of a steam-trawling fleet in the eighties the taking of large quantities of ice aboard became the general practice, enabling the vessels to stay at sea as long as two weeks. Ice is now used in the holds of trawlers and in smaller boats for keeping the catch until it can be landed, in boxes and barrels of fish for shipment, in the bunkers of refrigerator cars, in piles to cover fish on the floors of fish houses, and in windows and show cases of retail fish stores.[89]

PROPERTIES OF ICE

The properties of ice that make it peculiarly suitable for preserving fish are numerous. As a vehicle for refrigeration it costs nothing or very little. The price of ice is largely the price of the refrigeration it contains. If any other substance is used to carry refrigeration, the vehicle itself may be expensive aside from the refrigeration it contains. Water, the melted product of ice, usually is harmless. Water ice contains more refrigeration per pound than can be put in most other common substances (even liquid air contains less, or only 122.4 B. t. u. per pound, as compared with 144 B. t. u. in water ice), though solid carbon-dioxide "ice" absorbs 249 B. t. u. in warming to 10° F. below zero. The temperature of ice is constant at the convenient temperature of 32° F., and this temperature can not be raised until all the ice is melted. Ice is convenient to handle, split, crush, and apply.

While the temperature of ice can not be raised above 32° F. without melting it, the temperature can be lowered below 32°, contrary to a prevalent impression, just as can the temperature of any other solid. A cubic foot of ice weighs 56.7 pounds, and the specific heat of ice is about 0.5; that is, 0.5 B. t. u. of heat is required to raise the temperature of ice 1° F. without melting it.

Natural ice is essentially the same as artificial ice. It may or may not be as pure, depending on its source.[90] It is generally cheaper where it is available, the cost being around $2.50 per ton, as compared with $4.50 to $6.50 per ton for manufactured ice. Manufactured ice may be made from ordinary water; but it is more generally made from either distilled water or is blown with a small stream of air during freezing to keep it in motion. When it is frozen in this way the impurities are driven to the center and removed, leaving a clean ice of satisfactory purity. Glacier ice is sometimes used in Alaska and other northern countries, but is not considered satisfactory for fish, being very hard and tending to impart a yellowish color to the fish.

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[89] For a description of the methods of icing and transporting fish in England see "The handling and transport of fish," by Edgar Griffiths and Crawford Heron. Department of Scientific and Industrial Research, Food Investigation Board, Special Report No. 5, 25 pp. London, 1925.

[90] H. S. Cummins (Journal, American Medical Association, Vol. LXVII, p. 751, Chicago, 1916) states that the slow crystallization of natural ice tends to purify it—an advantage over artificial ice.

EFFECT OF ICE ON FISH

Ice has no sterilizing effect on fish. If impure, it may have the opposite effect. It kills few, if any, bacteria, but by its cold only retards their growth. Neither does it arrest autolysis, but only retards it. The water produced by melting ice coming in contact with fish dissolves some of the soluble substances and causes some swelling and blanching of the tissues. It may also crush or bruise the fish, promoting autolysis instead of arresting it, and the water may cause a bleaching of the colors in the skin of fish.

To overcome the dissolving and bleaching effect of ice, sea-water ice has been tried for fish, but the use of this ice does not seem to have been adopted in practice. (See Larsen's method of chilling, p. 621.)

CHEMICAL PRESERVATIVES IN ICE

Attempts have been made also to fortify the preserving effect of ice by the addition of chemical preservatives. Sodium hypochlorite was tried and excited much interest in the industry a few years ago.[91] A solution containing sodium hypochlorite was sold under a trade name to be put in the water to be frozen. However, on investigations made by the British Food Investigation Board,[92] sodium hypochlorite failed to give promising results. In concentrations low enough not to taste or not to be injurious to health it failed to have any noticeable preserving effect. The same was found to be true of formaldehyde. They also investigated homoflavine and crystal violet, two dyes that are relatively harmless to man but exceedingly toxic to bacteria. In the presence of 0.1 per cent of ordinary salt these dyes will freeze uniformly in ice, but in permissible concentrations they failed to have any useful preserving effect.

The methods of using ice for fish are too well known to require lengthy description, but certain details are worthy of notice. Ice taken aboard trawlers and other fishing boats is usually crushed. Ice companies deliver the ice at the wharf, crush it, and chute it into the holds. Some fish freezers manufacture ice as a side line and crush it for the fishing boats. At some places elaborate arrangements are provided for this purpose, as at the Commonwealth Fish Pier in Boston. Aboard the boats the crushed ice is contained in barrels, boxes, bins, or loose in the holds. The customary method of packing is to alternate layers of ice and fish and cover the heap with a generous amount of ice. This practice is followed in the banks trawler fisheries of the East and the salmon, halibut, and cod fisheries of the west coast, and for snapper and other fisheries of the Gulf of Mexico.

DRESSING FISH FOR ICING

Large fish nearly always are gutted before being iced. This applies to cod, haddock, hake, pollock, halibut, and salmon. The heads are left on as a protection of the flesh, but in the case of hali-

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[91] For particulars see Gibbs, Proceedings of the Fourth International Congress of Refrigeration, London, 1924, Vol. II, sec. III, pp. 1222–1244.

[92] Great Britain, Report of the Food Investigation Board for 1923, pp. 8–10. London.

but the heads are removed when the vessel lands. Smaller and medium-sized fish, such as croakers, spot, butterfish, shad, small weakfish, mackerel, mullet, and flounders usually are round. Gutting removes the focus from which infection may spread—the intestine—but exposes the belly cavity to the effect of water and infection of a different kind. In large fish, such as salmon and halibut, it is customary to fill the belly cavity with the crushed ice. For obvious reasons this hastens the thorough chilling of the whole fish.

ICING PACKAGES FOR TRANSPORTATION

For this purpose boxes or barrels are used. Where boxes are used a layer of ice is put on the bottom, then a layer of fish, then ice, and so on. There is no standard size of box, but shippers have their own shapes and sizes, usually designed to contain 100, 150, or 200 pounds net, of fish. One size of box, rated at 150 pounds, is 33 by 19 by 15 inches deep, inside dimensions, and is used in the Gulf of Mexico snapper fishery. A Great Lakes box measures 26 by 17 by 12 inches deep. On these boxes a board on each side is about 8 inches longer than the box proper, extending 4 inches on each end, to form handles and to prevent the boxes from being stood on end. A halibut box used on the west coast, rated at 200 pounds net, is 51½ by 25 by 16½ inches deep, inside measurements. This box has no end extensions for handles, but some of them have rope handles. Another box, used in California, is 34½ by 18 by 9¾ inches deep. This is rated at 150 pounds net.

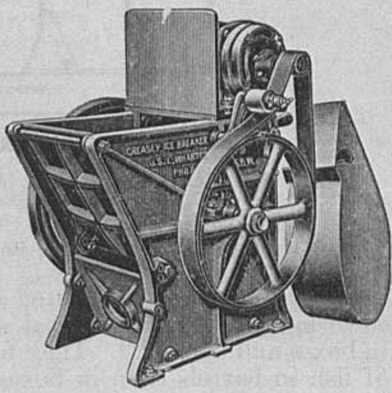

FIG. 48.—Ice breaker. Courtesy, Cochrane Corporation.

The common practice is to crush the ice used for fish. The smaller sizes of lumps are preferred—from ½ to 1 inch. Sailer[93] summarizes the answer given by 40 fish dealers to a questionnaire on the use of ice for packing fish. There is shown a general preference for boxes rather than barrels. The ice and fish layers are alternated, with a heavy layer of ice at the top. The amount of ice required for 100 pounds of fish varies from 50 to 100 pounds, according to the weather and the opinions of the packers. Ice that has been used once for packing fish rarely is used again for that purpose. There is also a strong concurrence of opinion among fish packers that fish should be thoroughly precooled in ice and repacked for shipment.

Every plant that uses much ice has a mechanical ice breaker. This is a revolving drum provided with steel spikes, inclosed in an iron casing, with a hopper for feeding in the cakes of ice. Such a machine (see figs. 48 and 49) will crush a ton of ice in three minutes.

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[93] W. Sailer, "Broken Ice for packing shipments of fish." Paper read before the annual convention of the United States Fisheries Association, at Atlantic City, N. J., Sept. 2 to 5, 1925. Published by the Cochrane Corporation, Creasy Ice Breakers Department, publication No. 1360. Philadelphia, 1925.

Barrels usually are iced in the same way as boxes. Sometimes a "cone" of ice is used; that is, a long columnar chunk in the center of the barrel, surrounded by the fish. This method is especially suitable for eels. Sometimes a barrel is packed with fish and a large chunk of ice put on them at the top, but this is undoubtedly poor practice. For a head it is general practice to cover the barrel with a piece of burlap, which is held on by a hoop, which is nailed.

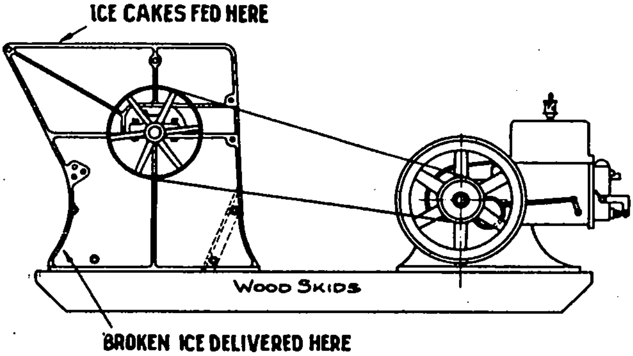

FIG. 49.—Arrangement of ice breaker driven by gasoline engine. Courtesy, Cochrane Corporation.

COMPARISON OF BOXES AND BARRELS AS CONTAINERS FOR ICED FISH

L. H. Almy, of the United States Bureau of Chemistry, and his coworkers have made several studies of shipments of fish on ice in in boxes and barrels.[94] They found a considerably greater shrinkage of fish in barrels than in boxes, as shown by Table 26, representing conditions in a carload of fish en route from Jacksonville, Fla., to New York.

TABLE 26.—*Shrinkage of fish in transit by freight, Jacksonville to New York*

Container	Layer of fish examined	Net weight of fish, pounds		Change in weight			
				Pounds		Percentage	
		Before shipment	After shipment	By layers	Total in package	By layers	Total in package
Box	Top	40	38	−2		−5.0	−1.3
	Bottom	40	41	+1	−1	+2.5	
Do	Top	38	33	−5		+13.2	−1.3
	Bottom	43	47	+4	−1	+10.5	
Barrel	Top	80	74	−6		−7.5	−6.6
	Bottom	130	122	−8	−14	−10.0	
Do	Top	108	106	−2		−1.9	−5.7
	Bottom	101	91	−10	−12	−9.9	

While these figures are not borne out by all their experiments, it is indicated clearly that shrinkage is greater in barrels than in

[94] L. H. Almy, H. R. Hill, and E. Field, "The shrinkage of fish in boxes and barrels." Fishing Gazette (New York). Vol. XXXIX, September, 1922, pp. 29–30. L. H. Almy and H. R. Hill, "Transportation of fish in boxes and barrels." Fishing Gazette, April, 1923. L. H. Almy, E. Field, and H. R. Hill, "A study of the preservation of fish in ice." The American Food Journal, Vol. XVIII, January, 1923, 36–38.

boxes, probably because of the greater pressure on the fish at the bottom of the barrels. The temperature conditions also are favorable to boxes in express shipments, as shown in Table 27, a shipment of fish in boxes and barrels from West Palm Beach to Jacksonville, Fla., in which temperature readings were made at intervals through the day. From 7 a. m. to 6.30 p. m. the temperature at the top of the barrel rose from 31.5° to 49.1°, while in the box the corresponding rise was from 33.1° to 41.1°.

TABLE 27.—*Temperature in transit by express, West Palm Beach to Jacksonville*

Readings for temperature of—	Apr. 22, 1922			
	7 a. m.	10.45 a. m.	2.30 p. m.	6.30 p. m.
	°F.	°F.	°F.	°F.
Fish in top layer in box	33.1	33.5	34.3	41.1
Fish in top layer in barrel	31.5	35.0	40.8	49.1

Experiments made by Almy and his coworkers on fish packed in boxes and held in ice in a cold room, where more exact work was possible, indicated that for the first few days there was a gain in weight in fish kept in ice, perhaps because of absorption of water, the greater gain being in the upper layer. By the tenth day the gain had stopped and a loss had begun, and after this the loss continued. Gutted fish generally kept better than round fish, but the gutted fish, on the average, showed more loss of mineral matter than the round fish. These writers recommend boxes in preference to barrels.

SHIPMENTS OF CARLOAD LOTS OF FISH ON ICE

These workers found that packages (boxes and barrels) placed in refrigerator cars and covered with crushed ice on and between the packages kept in excellent condition from Jacksonville to New York. Slat racks on the floor of the car permitted cold air to circulate under the packages. Another car of iced boxes and barrels was shipped, but the bunkers were packed with ice and salt and no ice was put on and around the packages in the car. The temperature conditions en route are shown in Table 28.

TABLE 28

Average readings for temperature of—	March—					Average for trip
	27	28	29	30	31	
	°F.	°F.	°F.	°F.	°F.	°F.
Atmosphere	70.3	54.7	66.8	58.3	59.0	61.8
Fish in barrels	32.0	31.7	32.0	32.3	32.0	32.0
Fish in boxes	32.5	31.8	31.8	32.2	32.2	32.1
Air in car	32.3	34.8	37.0	32.7	33.9	34.1

SÖLLING'S METHOD OF ICING FISH

A refinement in the method of icing fish was devised by Sölling[95] to avoid, as far as possible, the known causes of spoiling in iced fish; namely, the access of bacteria to the fish through the air and melting ice and the leaching action of the water from the melting ice. He also found, what Tressler[96] later determined by more precise scientific analysis to be a fact, that the blood of fish is more prone to spoil than is the muscle tissue, and that if blood is early and carefully removed the fish will be more perfectly preserved.

Sölling's method is as follows: The fish must be gutted and bled and the gills removed as soon as possible after the fish are caught. The sound must be split lengthwise to insure removal of the blood underneath, and the fish should be split behind the vent so that all accumulations of blood may be removed. The fish are then washed and scrubbed inside and out with a stiff brush and clean sea water or in a solution of 4 or 5 per cent salt in fresh water until all blood is removed. The fish is then laid aside to drain, care being taken that no water is left in the belly cavity.

Each fish is then carefully wrapped in vegetable parchment paper—a paper that does not disintegrate in water. The paper is cut square, and each dimension is at least one and one-half times the length of the fish. The wrapped fish are then packed in crushed ice. The fish are chilled by the ice but are protected from the water and air and consequently from bacterial infection.

Sölling packed experimentally 147 soles, turbot, brill, plaice, lemon sole, and witches (*a*) gutted, wrapped, and iced; (*b*) not gutted, but wrapped and iced; (*c*) gutted, not wrapped, but iced; (*d*) not gutted, not wrapped, but iced. Ten days later the fish (*a*) were still perfectly white and firm, with no odor, skin not discolored, and most of the fish had retained their stiffness (rigor mortis). The fish (*b*) were in most cases damaged inside. The fish (*c*) and (*d*) were soft, stale, and their skin was discolored. Fifteen days after being packed seven different kinds of the fish (*a*) were cooked and found to be perfectly fresh and of good flavor.

A lot of halibut, caught in Davis Strait and packed by Sölling's method, were shipped to Peterhead, thence by rail to Grimsby, where they fetched a comparatively high price three weeks after capture.

It is hardly to be doubted that such care in preparation will produce the results indicated, and there is little doubt that the care would be repaid. Improvements such as this must come in time as fish become dearer and the demand more fastidious; but whether or not this method can be applied on our fishing vessels as they are now constructed and operated is doubtful, indeed.

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[95] A. Sölling, "An Improved and Practical Method of Packing Fish for Transportation." Bulletin, U. S. Bureau of Fisheries, Vol. XXVII, 1907 (1908), pp. 295–301. Washington, 1910. See also, by the same author, "An improved and practical method of packing gutted fish for transportation keeping it fresh for a lengthened period." Premier Congrès International du Froid, Paris, 5–12 Octobre, 1908. Rapports et Communications, Sections I, II, et III, 2e Tome pp. 1072–1077. Paris. See also Second International Congress of Refrigeration, Vienna, 1910, pp. 375–378.

[96] D. K. Tressler, "Some Considerations Concerning the Salting of Fish." Appendix V, Report, U. S. Commissioner of Fisheries for 1919. Bureau of Fisheries Document No. 884, 55 pp. Washington, 1920.

ICING OTHER FISHERY PRODUCTS

Shucked oysters are shipped in large quantities in 1-gallon tin cans provided with friction lids. To guard against these lids coming out, two or three fourpenny nails are driven through the friction seal from the outside of each can. The cans are then imbedded in cracked ice in a wooden shipping box and shipped.[97]

FILLETS OF FISH

The practice of filleting fish at the point of production, freezing and shipping them, has already been described briefly under the head of freezing methods. The greater part of the business in fillets, how-

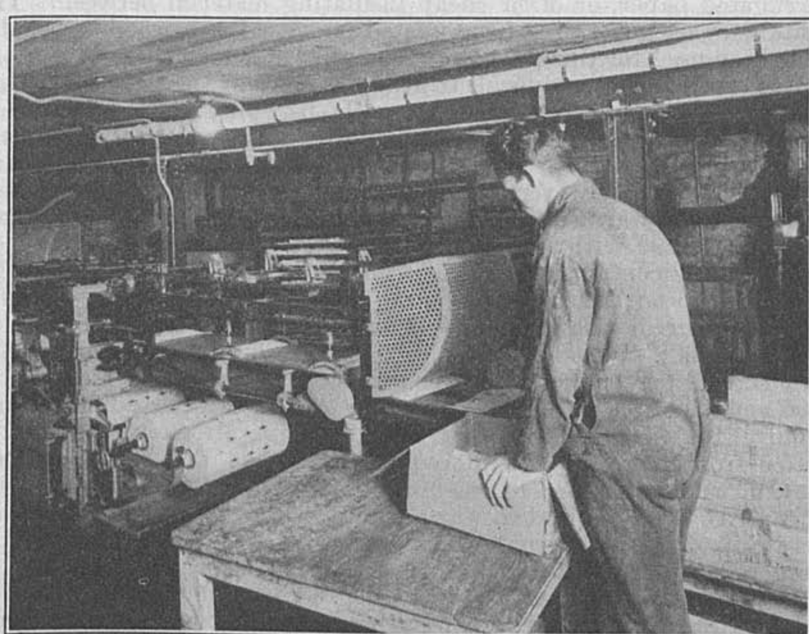

FIG. 50.—Wrapping machine for single frozen fillets. Courtesy, Atlantic Coast Fisheries Co.

ever, is in the chilled-in-ice rather than the frozen product, the greatest production being in Boston. The fillets, cut so as to have no bones, are wrapped in vegetable parchment paper and packed in rectangular or round cans. Sometimes the fillets are not wrapped but are packed in layers in the cans, sheets of vegetable parchment or other water-resistant paper separating the layers. The cans are covered with a lid, packed in cracked ice in a wooden box, and shipped. In some plants the fillets are given a preliminary chilling in a cold room before they are packed. This is an excellent practice, for if the fillets are a few degrees above the ice temperature they may

[97] As a guide to good practice in collecting, preparing, and shipping oysters see "Oysters," Ruling No. 9, Commissioner of Agriculture of Georgia, Atlanta; also "Rules and regulations for the sanitation of the oyster industry and to render its product readily marketable." North Carolina Fisheries Commission Board, Morehead City.

be many hours or even days in chilling completely because of the thickness of the can. A few degrees makes a great difference in the keeping of these fillets.

INSULATED PACKAGES FOR SHIPPING CHILLED FRESH FISH

Several inventors have designed insulated packages for shipping chilled fresh fish. The aim of all these inventions has been to chill fish to 32° F. or thereabouts and to insulate it in a package so that it will carry to destination in fresh condition. One of the earliest of these inventions used ice but provided sawdust to absorb the water from the melting ice. Later inventors, attempting to avoid the use of ice, made use of double-wall containers, with sawdust, eelgrass, corrugated paper, or other cheap insulating material between. The containers are generally of corrugated paper. Balsa-wood boxes also have been used for this purpose. The ideal at which these inventions aim is excellent but is difficult to attain because of the poor insulating quality of even the best insulators. If fish once chilled to 32° F. could be kept at this temperature, they would carry several days without spoiling, though even at this temperature deterioration occurs. Unfrozen water, however, requires a relatively small amount of heat in order to be warmed. Compare, for example, 10 pounds of frozen haddock at 28° with unfrozen haddock at 32°—only 4° difference. The haddock contains, say, 80 per cent water, and at 28° 62 per cent of this is frozen; that is, 4.96 pounds of ice in the 10 pounds. This is to be compared with 8 pounds of water at 32° in the unfrozen lot. To raise the 8 pounds of water in the unfrozen fish from 32° to 40° at 1 B. t. u. per pound would require $8 \times 8 = 64$ B. t. u. To melt the 4.96 pounds of ice in the frozen fish, at 144 B. t. u. per pound, would require $144 \times 4.96 = 714.24$ B. t. u. To raise all the 8 pounds of water from 28 to 40° would require $12 \times 8 = 96$ B. t. u. The total B. t. u. would thus be $714.24 + 96 = 810.24$ B. t. u., as compared with only 64 B. t. u. required to warm the unfrozen fish to the same temperature. If the external dimensions of the container are 1 foot cube, or 6 square feet, and the insulation is sufficient to pass 0.15 B. t. u. per square foot per hour, per degree difference in temperature between inside and outside (36° average for the frozen and 34° for the unfrozen), and the outside temperature is 70°, then 25 hours would be required to warm the frozen to 40°, and 2.1 hours would be required to warm the unfrozen to the same temperature. The time is not actually so short as this, nor the actual problem so simple, because the heat must penetrate the fish itself, but the difference will be relatively large. The prospects for an insulated package to keep fish fresh without ice in the fish or around it, therefore, do not seem bright.

TEMPORARY STORAGE OF FISH IN CHILL ROOMS

Most fish cold-storage plants have chill rooms where fish may be stored temporarily. The temperature of such rooms varies from 30° to 40° F., and a time limit is usually set to the storage of fish in this way. Barrels and boxes containing the fish are simply put in the rooms.

It is the consensus of opinion of those who are experienced in this kind of storage that fresh fish on ice maintain a better appearance if the temperature of the room is slightly above the melting point of ice, so that the fish are kept wet. If the room is too cold, the ice does not melt and the surface of the fish becomes dry. A temperature of 33° or 34° F. will allow the ice to melt very slowly. Such rooms are subject to the drip of condensed moisture from the walls and ceilings and sometimes the pipes; it is advisable, therefore, to place the fish or arrange drip pans so that the water does not drip on the stored goods.

Mild-cured salmon are held in some freezers at 30° to 32° F.; others hold them at slightly higher temperatures, ranging up to 38°.

The writer has chilled (that is, partly frozen) lake trout in brine, packed them in ice, and stored them at 28° F. for three weeks. They remained somewhat stiffened, but not hard, and were entirely good at the end of this time, though, as stated above, the skin was somewhat dry. On the other hand, haddock fillets frozen in 10-pound blocks were kept 6 weeks in a chamber in which the temperature was thermostatically regulated at 28°. At the end of that time the fillets were distinctly sour.

HOLDING LIVE FISH BY REFRIGERATION

It is known that many species of fish hibernate in winter; that is, they become inactive under the influence of low temperature, consume no food, and lie dormant for a long time. Carp have been known to be inclosed in solid ice and survive. (The freezing point of fish is lower than that of water, so that it is possible for fish to be inclosed in ice without themselves freezing.) Mir and Audige [98] devised a method of taking advantage of these facts by inducing hibernation artifically. The fish are held in tanks of aerated water, chilled to the freezing point. The fish become torpid. The water is then slowly frozen around them, care being taken not to lower the temperature below 32° F. The fish remain alive, dormant, and surrounded by solid ice, and if released by careful defrosting will still live. Oxygen must be present and available in small quantity, else the fish will suffocate, for they require a slight amount of oxygen to sustain life processes. This does not appear to be a practicable commercial procedure, though it might be useful in certain instances.

COLD-STORAGE LAWS

In the United States the power to regulate the holding of foods in storage remains with the States, several of which have enacted regulatory laws. No Federal cold-storage law has been enacted up to the time of this writing. Bills have been introduced in several sessions of Congress, providing for regulation, under the interstate commerce clause of the Constitution, of conditions under which cold-storage foods may enter interstate commerce. As frozen fish are so often shipped from State to State, such a law, if enacted, would have the practical effect of bringing all fish freezers and cold-storage ware-

[98] E. Mir and J. Audige, "Le transport des poissons congélés." Bulletin de la Société d'Aquiculture et de Pêche, tome 25, pp. 7–14. Paris, 1913.

houses under a Federal law, enforcible by Federal officers, and under the jurisdiction of Federal courts. These bills usually are worded so as to vest the enforcing power in the Secretary of Agriculture.

The provisions of the Federal Food and Drugs Act, administered by the Bureau of Chemistry, Department of Agriculture, apply to all foods imported, exported, entering interstate commerce, or manufactured, sold, or offered for sale in the District of Columbia or the Territories. The act does not mention cold storage specifically, but the selling of foods within the jurisdiction of the act after they have become contaminated or spoiled by cold storage is a violation.

A so-called " uniform cold storage law " has been enacted by many of the States. This law is, in its principal provisions, generally uniform, though modifications of a minor sort, and in some cases important modifications, have been made. The following States have enacted this law: California, Delaware (fish exempt), Indiana, Iowa, Louisiana, Maryland, Massachusetts, Minnesota, Nebraska, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Virginia, and Wisconsin. Kentucky, Michigan, South Dakota, and Utah have briefer and less restrictive laws. Florida has passed legislation providing for construction and operation of publicly-owned cold-storage plants. The uniform law, as enacted, places the enforcing power in the State department of agriculture, board of health, or food and drugs department, and usually gives the enforcing body discretionary power to make regulations under the law.

In most cases cold storage is defined as the holding of articles of food for 30 days or more in a cold-storage warehouse at a temperature of 45°—in some cases 40° F., or colder. A license to operate is usually required, a fee in most cases (but not all) being charged, ranging from $5 to $50 per annum. Records are required to be kept of receipts and withdrawals, and a report must be made monthly or quarterly to the enforcing body. In some cases the reports are compiled and are open to inspection. The enforcing body is given the power to inspect the premises of cold-storage plants, which, if found to be insanitary, may be closed or the license may be suspended or revoked. Goods are required to be marked with the date of receipt at the time when they are received for storage and with the date of withdrawal when withdrawn. In most cases the words "cold storage," or a similar mark, must appear on the package, and in a few cases the name and location of the warehouse where the goods were stored must also be shown.

In most of the States that have enacted the law a limit of 12 months (Delaware 6 months, Indiana 9 months, and Virginia 10 months) is placed on the period of storage, but the term may be extended in most cases on application to and inspection by the enforcing body. In some cases the term of extension is indefinite; in others it is 60 days, with a second extension of like length—a total of 120 days.

Most of the State cold-storage laws have clauses designed to enable the purchaser to ascertain whether or not foods have been cold stored. To this end they require that " cold storage," or similar device, appear on the goods, or that a placard to the same effect be displayed on the bulk of the goods when placed on sale. Some require invoices, advertising, etc., to state the cold-storage character of the foods.

Transfer of foods from one cold-storage warehouse to another is generally permitted if it is not done to evade the law regarding period of storage, markings, etc. It is prohibited to return foods to storage once they are withdrawn for sale.

In some of the States where no specific cold-storage law has been enacted the board of health or department of agriculture or food and drugs bureau has supervision over the sanitary and other conditions of cold storage.

National Oceanic and Atmospheric Administration

Report of the United States Commissioner of Fisheries

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