THE PRESERVATION OF FISH BY FREEZING

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The Preservation of Fish by Freezing

By Donald D. McKay

Efficient preservation of fish in transport is of prime importance to the fish industry; owing to the distances separating the points on the sea coast where fish are obtained, from the centres of population where large markets for fish are situated. Fresh fish and to a lesser extent smoked fish can be marketed at places two and more days journey from the coast only if they are transported and stored in a frozen condition. If frozen fish is to meet the demand for fresh fish in the inland markets the frozen products on thawing must be as nearly as possible like fresh fish both in flavour and texture. The Biological Board of Canada is endeavouring to find how this may be done as economically as possible. This report deals with certain phases of the problem, which the writer investigated during the summer of 1926.

Treatment of Fish Preliminary to Freezing

"Frozen Fish" has acquired a bad reputation from the fact that in the past a great deal of fish was frozen and sold as such, after it was/decomposed that it could not be kept any longer. This proceedure is quite wrong. Only fish which is absolutely fresh should be frozen, particularly if on defrosting it is to be sold as fresh fish.

When the fish are caught by trawlers or by schooners on the banks they are gutted and packed in ice until they can be landed. Dr. Dreyer and Mr. Dauphinee of this station who are working on the decomposition of fish muscle advise that a gutted fish on ice can only be considered fresh for a period of four days. For this reason fish destined for the freezer should be frozen before four days have elapsed from the time they are caught. The National Fish Company, here in Halifax, fillet their fish soon after landing, place the fillets in envelopes, pack them in boxes and freeze them immediately. The procedure of filleting is to be recommended because the expense of freezing heads, skins, and bones is done away with. Fillets, both fresh and smoked were used almost entirely in this work.

Methods of Freezing

In practice there are two distinct methods available, namely freezing in cold air and freezing in a salt solution of such a concentration that the temperature of the solution can be lowered to that desired. In a comparative examination of different freezing methods one of the most important points to consider is the rapidity of the freezing process. A second point of great importance is the question of interaction between the freezing medium and the frozen material.

Dr. F. Slater Jackson (1) in Canada, Droogleever Fortuyn (2) in Holland, and Reuter (3) in Germany have shown by Histological studies on frozen fish muscle that the freezing of fish must be as rapid as possible to ensure little or no change in the tissue on defrosting. The question of deformation of the fibres is dealt with in a note on some work done by Mr. C. B. Weld assisted by the writer (4).

The rate of cooling and freezing of a solid body such as fish depends upon:-

(1) The thermal properties of the body cooled; the rate of cooling will be more rapid, the greater the thermal conductivity, the lower the specific heat of the body, and the greater the extent of the surface of the body exposed to the cooling medium. The first two factors are nearly constant in fish but the third can be varied, so that the fish must be in a form exposing as large a surface to the cooling medium as possible.

(2) The thermal properties of the cooling medium; the rate of cooling will be more rapid, the lower the temperature, the greater the thermal conductivity, the greater the specific heat, and the greater the rate of circulation of the cooling medium.

Air Freezing

Air freezing is in use on this continent with varying success. For certain kinds of fish it seems satisfactory, however the low thermal conductivity, the low specific heat, and the low specific gravity of air contribute to make it an inefficient cooling medium. For this reason brine freezing is the method dealt with in these investigations.

Brine Freezing

According to the Special Report No. (5), "At the same temperature brine removes heat from a body fifteen times more rapidly than air, surface area and temperature differences being the same. Both the brine concentration and circulation have their influences on the rate of cooling, but the effect of the latter diminishes rapidly with increasing speed. This is important in practice and needs special consideration". This influence of the rate of flow has been the subject of several experiments which unfortunately could not be completed. The kind of brine used was sodium chloride in all cases; but the use of Calcium chloride brine should be considered.

Methods of Cooling the Brine

The brine that surrounds the fish and absorbs heat from them must in its turn give up this heat to some other body which is maintained at a lower temperature than the brine itself. In most commercial operations this is done by using the heat expansion of compressed ammonia to cool calcium chloride brine, a saturated solution of which can be cooled to about -56° F before the solution freezes. It is not necessary to use a saturated solution as this would be expensive to keep up, usually the calcium brine solution has a freezing point of between -25° to -30°F. The expanding ammonia can not be used in coils in the freezing tank with the sodium chloride brine, because it produces too low a temperature in the coils this temperature is hard to control; under these conditions there would be a tendency for ice to form on the cooling coils. It is much better to cool the sodium brine in the freezing tank with calcium brine in the cooling coils, which in turn is cooled by the expansion of ammonia. This is the method used in our experimental freezer at the North Atlantic Fisheries plant. The cooling coils of our freezer are connected to the calcium chloride return line from the sharp freezers and cold storage rooms of the North Atlantic plant. Thus we have a supply of calcium brine which has a temperature of from -5° to +5°F, depending on the work that the sharp freezers and cold storage rooms are doing. Figures 1 and 11 show the compressors and a view of the valves controlling the cooling coils of our freezer.

The plan and elevation of this freezing tank is shown in the diagram Figure 111. It was constructed under the direction of Mr. Finn during January and February last.

It was found that the cooling coils through which the calcium brine is circulated were more than sufficient for the volume of sodium brine to be cooled. In experiments where 25 to 50 lbs. of fish were frozen one double coil was sufficient to cool the sodium brine if the calcium brine was at a temperature of -3° or -4°F. The sodium brine could be held at 0°F. which froze the fish contained in pans in a little less than one hour. The pans and other containers for the fish are illustrated in Figures 1V and V and V1.

Experiments with the Brine Freezer at the North Atlantic Fisheries

Freezing

Experiment 31 August 6

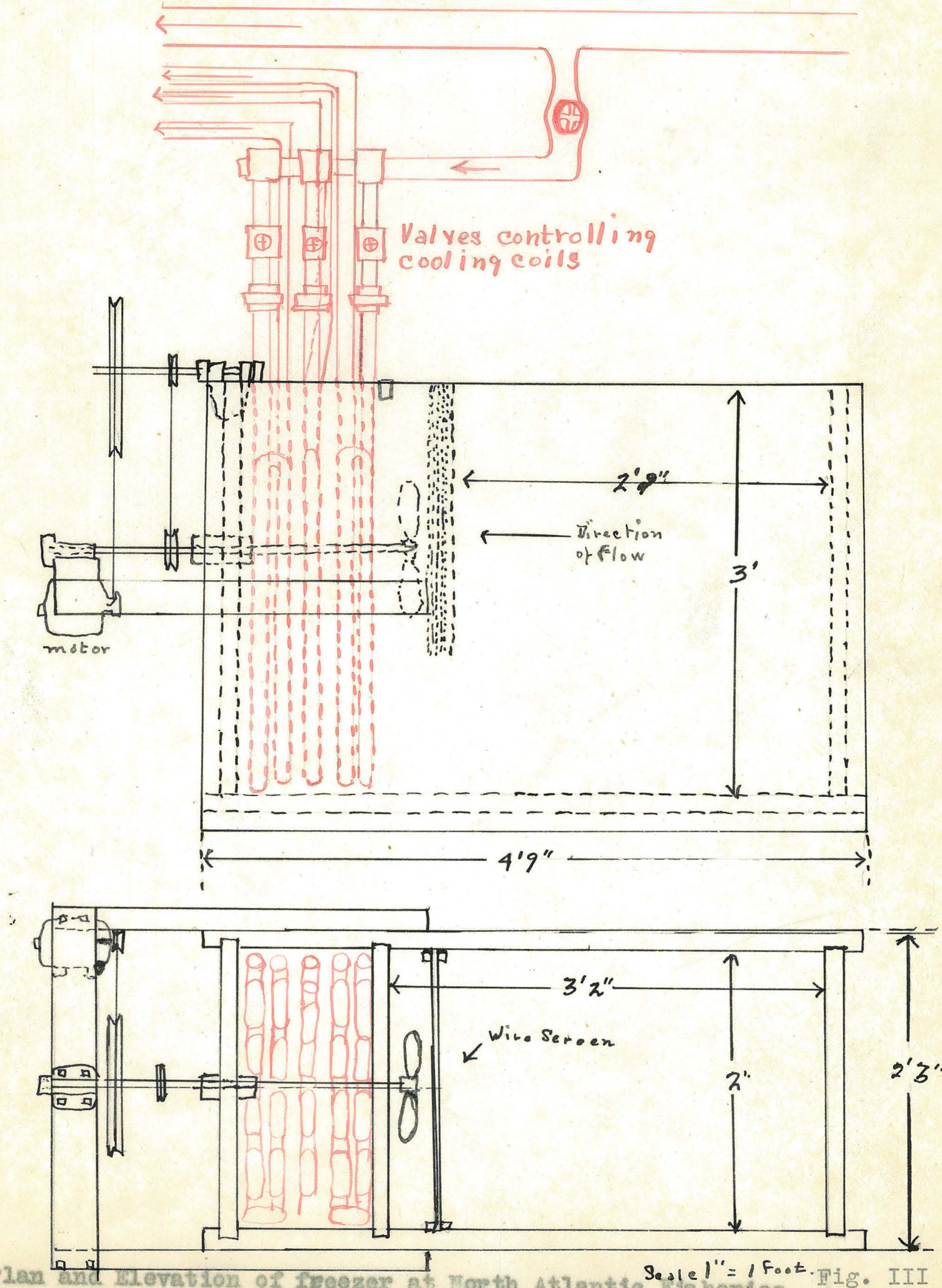
Four Haddies which had received the following treatment were frozen.

No.	Salting % saturation of Brine	Temp. of Brine	Drying Time in hours	Smoking Time in smoker	Freezing S Time in freezer
1L(control)	55	45°F.	10	8 hrs.	30 min.
2L	90	50°	10	8 "	40 "
1R	55	45°	outside in air for 6 hr	8 "	30 "
2R	55	45°	Not dried	8 "	40 "

The fish were obtained from the National Fish Company. The salting and drying occupied one day. The fish remained at room temperature over night, they were smoked; then after standing at room temperature for another 24 hours they were frozen directly in brine. The fish were removed from the freezing tank and left in the freezing room for 24 hours, after this period it was observed that although they had been quite stiff when taken from the freezing tank, they were now pliable, especially number 2L which had been heavily salted.

Data on the freezing:

Temperature of brine in freezing tank during experiment= 0°F.
Temperature of freezing room during the experiment = +3°F.



Plan and Elevation of freezer at North Atlantic Fisheries. Scale 1" = 1 Foot. Fig. III

Fish No.	Surface after Freezing	Putrefaction after thawing	Pellicle as measured by Mr. Weld
1L	good	present	very thick
2L	dull	absent	very thick
1R	good	--------	very thick
2R	good	---------	very thick

The haddies remained in the freezing room for a period of one week, they were brought up to the station cooked and eaten, that is numbers 1L and 2L. The thawing was done in cold water. In the case of number1L putrefaction had started under the back bone at a distance of about 5 inches from the tail. There was a decided taste to the flesh in this region. Both fish tasted more salty than a normal haddie.

<u>Experiment F2 and S2 August 7</u>

Four pans were filled as follows with fish obtained from the National Fish Company.

Expt. No.	Pan No.	Weight in lbs.	Material
F2a	I	6½	Fresh fillets
F2b	II	6¼	Fresh fillets in envelopes
S2a	III	4¼	Kippered herring
S2b	IV	4½	Smoked fillets.

With the brine in the tank in circulation, but no flow of calcium chloride brine in the cooling coils the four pans were placed in the tank, and kept there for one hour, the temperature of the brine was noted every 15 minutes.

Room temperature 5°F.

Time	Brine temperature
Start 3.15 P.M.	1.0°F.
3.30	1.5°
3.45	2.0°
4.00	2.5°
Stop 4.15	3.0°

The pans were opened and their contants examined.

Pan I The fresh fillets were frozen completely.
" II The fresh fillets in envelopes were frozen completely.
" III The Kippers were pliable and there was oil on the surface.
" IV The smoked fillets were frozen completely.

The freezing was done on Saturday afternoon, on Monday afternoon the pans I, II, and IV were brought to the station and allowed to thaw in air. All the material had a good appearance and smell after defrosting. The smoked fillets and fresh fillets were eaten on Tuesday, and Wednesday 24 and 48 hours after defrosting and pronounced indistinguishable from fresh unfrozen fish.

<u>Experiment 33 August 12</u>

Fourteen pounds of smoked fillets of the type known as "Little Gems" were obtained from the National Fish Company. These were packed in two pans, 7 pounds each, and placed in the freezing tank. In this experiment the calcium chloride brine was circulated in all three coils. The temperature of the calcium chloride brine was -2.5°F. The temperature of the freezing brine in the tank was -2°F.

Temperature of freezing room +2.0°F
Temperatures of the tank were taken every 15 minutes.

Time	Brine temperature
Start 3.30 P.M.	-2.0°F.
3.45	-2.0°
4.00	-2.0°
4.15	-1.5°
4.30	-2.3°

The frozen cakes were left in the pans in the freezing room over night. The following morning at 11 A.M. the cakes were removed from the pans dipped in cold water and left in the freezing room at a temperature of 5° for 4 hours. They were then wrapped in oiled paper and tagged S3A and S3B. S3A was dipped in water after wrapping to try if a glaze was possible on the paper, however the oil in the paper prevented the ice from forming. The cakes were placed in storage on August 15.

<u>Experiment F4 August 15</u>

Fifteen pounds of fresh fillets in "Sea Sealed" envelopes were obtained from the National Fish Company. The circulation was started in the cooling coils and when the temperature of the brine in the freezing tank had become constant the fillets were placed directly in the brine. The fillets were left in the brine until the thickest of them was frozen dolid, this occurred in 45 minutes.

Temperature of the freezing room = +5°F.
Brine temperature at start = -1°F.
" " " end = -1°F.

The fillets were left in a box in the freezing room. On August 16, 3 fillets were taken up to the station and defrosted in cold water. Part were fried in fat and part steamed.

When eaten the fish could not be distinguished from unfrozen fillets.

The remainder of the lot were divided into two parts both of which were washed, while one part was glazed and wrapped the other was wrapped with oiled paper without glazing. Both parcels were placed in storage.

Experiment F5 A and B and F6 A and B August 17

From the National Fish Company were obtained the following material which was placed in four pans, and all put in the freezing tank. Pans I and II contained 7 and 7½ lbs. respectively of fresh fillets. Pans III and IV contained 7 lbs. each of fresh fillets in envelopes. Temperature of the freezing room +2.5°F.

Time	Brine temperature in freezing tank	Calcium chloride brine temperature
Start 3.10P.M.	+1.5°F	+1.0°F
3.25	2.0°	1.0°
3.40	2.0°	1.0°
3.55	1.5°	1.0°
Stop 4.10	1.0°	1.0°

The room temperature at the end of the experiment was 2.0°F. The cakes were left in the pans over night, they were then removed and one cake of the fillets in envelopes was glazed and one cake of the wrapped fillets was glazed. These cakes were wrapped in oiled paper and tagged as follows: F5B the fillets, F6B the fillets in envelopes. The other two cakes were wrapped and tagged F5A and F6A. These cakes were placed in storage on August 18.

Experiment S7 August 18

Six large smoked fillets of cod were obtained from the National Fish Company weighing in all 10 lbs. Three of these were placed in envelopes. They were placed directly in the brine, which was at a temperature of 4°F throughout the experiment. The fillets were immersed in the brine for a period of 60 minutes. The temperatures were as follows during this period.

Time		Temperature of the brine
Start	3.20 P.M.	+4.0°F
	3.35	4.2°
	3.50	4.0°
	4.05	4.0°
	4.20	4.0°

The room temperature during this time was 4.5°F.
The fillets were not stiff when removed from the tank, yet it was impossible to pass a knife through them.

The fillets were washed and glazed. A sample was brought to the station, defrosted in air, cooked and eaten. There was a strong salty taste but it is doubtful if the salt taste was greater than would be found in the commercial fillets, in an unfrozen condition.

Experiment S8 August 19

Four Finnan Haddies which were brined, dried, and smoked at the station under the direction of Mr. Weld, were used in this experiment. The Haddies had been obtained from the National Fish Company. The haddies had been brined, dried, and smoked during a period of 24 hours, they were frozen about 4 hours later so that the exposure to room temperature that the haddies in experiment S1 were subjected to was eliminated. They were taken

down to the freezer after they came out of the smoker where they were kept at a temperature of about 4°F until frozen.
Temperature of the freezing room 4.5° F.
Temperature of the calcium chloride brine 4.0°F.
The temperatures of the brine in the tank during the experiment were as follows:

Time	Temperature of the brine
Start 2.40	+ 4.0° F
2.55	4.3°
3.10	4.0°
3.25	4.0°
3.40	4.0°

The haddies were removed from the brine, washed, and hung in the freezing room.

Experiment 39 September 2

The sub-committee on refrigeration of the Biological Board requested that a demonstration of the method of brine freezing that we were using be given. A report of this is given here as Experiment 39.

The fish were obtained from the National Fish Company, in the afternoon and kept in the chilling room at a temperature of about 35° F, until 8 P.M. when they were loaded into pans and placed in the freezing room.

Data on demonstration of Brine Freezing, at North Atlantic Fisheries on Thursday September 2, at 8 p.m.

Material frozen.

A - In cans.
Fresh fillets 2 cans of 8 lbs. each.
Fresh fillets in envelopes "Sea Sealed" 2 cans, 7½ lbs. each.
Fresh gutted cod, 2 of about ¾ lbs. each.

B - In brine directly. Placed in wire basket subdivided by horizontal shelves.
Fresh fillets 9 lbs.
Smoked fillets medium size 10 lbs.
Fresh fillets "Sea Sealed", 3 only, about 1½ lbs.
Fresh cod, gutted, 2 of about ¾ lbs each.

Record of Temperature.

Time	Temperature of freezing tank.	Temperature of Calcium brine.	Temperature of room.	Cooling coils in use.
8.10 P.M.	-1°F	-3°F	+3°F	one double
8.25	0°	-2°	+4°	one double and one single
8.40	+1.5°	-1°	+3°	two double and one single
8.55	0°	-3°	+2°	two double
9.10	-1°	-4°	+2°	one double

After 30 minutes a smoked fillet was removed from the top layer of the basket, and found to be thoroughly frozen. After 60 minutes the only piece of material left unfrozen was a spot of about ½ inch diameter at the centre of one of the cod frozen in the can.

The fillets frozen directly in brine were washed and left in the freezing room. A pan of fresh fillets and a pan of "Sea Sealed" were opened to show the committee, and a pan of each was kept in the storage for testing later.

One of the whole cod was sawed into steaks, brought up to the station defrosted in air, cooked and eaten. It could not be distinguished from fresh cod. Although this one had been frozen directly in brine and had not been washed after removal from the tank, there was not the least taste of salt to it.

Mr. Walter Boutilier of the National Fish Company had placed a lot of fish exactly similar to those frozen in brine, in the sharp freezer at the same time. We sent him the two pans which we had saved for further experiment and had these and the sharp frozen fish defrosted under the same conditions. Samples of brine frozen, air frozen, and fresh fillets were sent out to a number of people to cook and eat them and they were requested to grade them. The fillets were identified with coloured ribbon, so those testing did not know which fillet was which.

The results of this test were very diverse. A number of people placed the brine frozen fillet first and the fresh fillet last. Some who were more familiar with fish placed the fresh fish first and the air frozen last. There seemed to be a number of the fresh fillets which were older than either of the frozen lots. For this reason - the different ages of the lots - these results are not of much value. If this experiment were repeated the frozen fish should be stored for longer than one week, because storage is part of the freezing process as applied to fish. Also all samples for test should be of the same age, since the age of the fish before freezing and the age of the fresh fish before eating is of fundamental importance.

Experiment S10 September 14

Mr. Walter Boutilier told me that it was not feasible to freeze, store and later to smoke cod fillets or split haddocks. He showed me some of the fillets that were frozen during the demonstration experiment S8. Brine frozen and air frozen fillets had been defrosted and put through the smoking process at the same time. The air frozen fillet were not good, but were better than the brine frozen. In both cases the flesh tended to flake and break up. The smoked surface was not hard enough to hold the fillets together. They had the appearance of cooked fish.

In order to study this result, as it seemed to be an abnormal condition of the smoked surface, the following experiment was carried out with the assistance of Mr. Weld who was working on the surface formed in smoking.

Four fresh split haddocks from the National Fish Company were frozen at 5° F in one hour. They were washed, and stored for two days in the freezing room. They were then brought up to the Station, defrosted in air, brined in brines of different concentrations ranging from 98% to 45% saturated, dried in the drier and smoked.

Sections of the smoked surface showed a zone ½ to 1 mm. under the surface where the fibres seemed to be macerated. The haddies were flabby, the surface was average but not very hard. The day these fish were dried was a wet day so that the drying was not so thorough as might have been This result encouraged us to try a further experiment.

Experiment S11 September 18

Six split haddocks were obtained from the National Fish Company. They were frozen directly in brine at 5° F, as the engineer at the freezer could not get the brine below this temperature. For this reason they were in the freezing tank for 1½ hours. They were removed from the tank and left in the freezing room without washing for 5 days. They were then brought up to the station along with an air frozen fillet and a fillet frozen in brine at the same time as the haddocks.

Sections were cut from this material which showed in the case of the haddocks before and after smoking the same condition that was observed in experiment S10. Details of the microscopic work is given in the report of the writer and Mr. Wold. (4).

Summary of Freezing Experiments

Experiment No.	Material Frozen	Temp. of brine tank in °F Start	Stop	Temp. of room °F	Time of immersion in minutes.	Treatment of material after freezing.	Remarks
S1	4 Finnan haddies	0	0	7	30&40	Left in freezing room one week	Frozen directly in brine.
F2(a) (b)	8½ lb.f.f. 6½ "f.f. in envelopes	1.0	3.0	10	60	Left in pans in freezing room 48 hours.	Perfectly good eaten 36 hours after defrosting.
S2(a) (b)	4½lb. Kippered herring 7½lb. smoked fillets	1.0	3.0	10	60	Same as F2	Same as F2
S3A & B	2x7 lbs. smoked f.	-2.0	-2.3	5	60	Left in pans overnight, glazed, wrapped. S3A glazed on paper.	Took good glaze frozen quite solid.
F4	15 lbs. f.f. in envelope	-1.0	-1.0	5	45	Half washed, wrapped, placed in storage. Half washed, glazed, wrapped. Then stored.	
F5A & B F6A & B	2x7½lb.f.f. 2x7 "f.f. in envelopes	-1.5	-1.0	1.5 to 2.0	60	F5A wrapped. F5B glazed and wrapped. F6A wrapped. F6B glazed, wrapped.	
S7	10 lbs. Smk. fillets. ½ in envelopes	4.0	4.0	4.5	60	Washed, glazed, wrapped.	Frozen directly in brine.
S8	4 haddies from Weld 1R, 3R, 3L, 1L2R.	4.0	4.0	4.5	60	Washed, hung in freezing room.	

f.f. - fresh fillets

Cooling by Salt and Ice

Another method of cooling the brine for freezing is by the absorption of heat by melting ice. When ice melts 80 calories of heat per gram of ice are absorbed. If salt is mixed with the ice the mixture attains a temperature of about -5°F due to the rapid absorption of heat. This phenomenon may be adapted to the cooling of brine in two ways. Either by immersing the ice in the cooling brine, or by passing the cooling brine through a copper coil which is surrounded by a salt and ice mixture. In the first case where the salt and ice are in contact with the cooling medium two things will take place. The ice melts increasing the volume of brine to be handled, and the brine is dilutedbby the addition of this water from the melting ice. This dilution tends to slow the rate at which the ice will absorb heat from the brine.

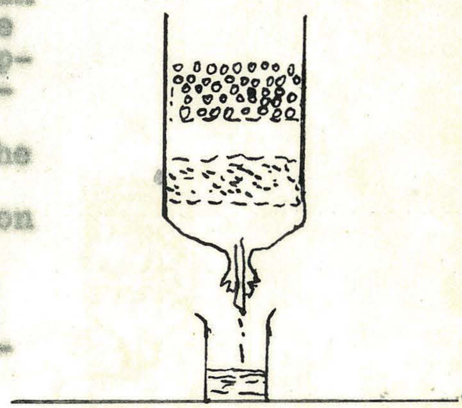
The following experiments were performed to study the cooling effect of different circulation systems.

Preliminary Experiments on Salt and Ice Freezing.

Experiment I July 8

The apparatus illustrated below was set up, consisting of a winchester with the bottom removed, the layers of salt and ice were supported on wire trays which fitted snugly against the sides of the bottle.

I Placed about 1½ lbs. salt in the lower compartment, and about the same weight of crushed ice in the upper. Two litres of brine 79.5% saturated were poured into the top of the apparatus, the temperature of the brine entering the apparatus and leaving was noted. The concentration of the brine after the passage was measured with the salinometer. The increase of volume of the brine was measured and the weight of ice melted calculated from this.



II The bottle was then cleaned out and the positions of the ice and salt reversed. The ice now being in the lower compartment and the salt in the upper. The amounts of ice and salt in the second experiment were the same as in the first. The results of the experiment are recorded below.

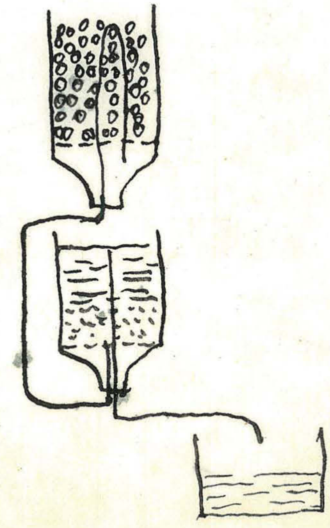
Expt.	Vol. of brine cooled	%saturation of the brine	Temp. of brine Start	Stop	Room Temp	Wt. of ice fused	elapsed time
I a	2000 cc.	79.5	22°C	10°C	25°C	1000g.	5 min.
b	2000 cc.	85.0	10°C	5°C	25°C	500g.	5 "
c	2000 cc.	98.0	6°C	4°C	25°C	200g.	5 "
d	2000 cc.	98.0	5°C	1.5°C	25°C	400g.	5 "
IIa	2000 cc.	78.0	22°C	12°C	26°C	500g.	5 "
b	2000 cc.	82.0	12°C	5°C	26°C	300g.	5 "
c	2000 cc.	85.0	5°C	2°C	26°C	150g.	5 "
d	2000 cc.	87.0	2.5°C	-2°C	27°C	200g.	5 "

<u>Experiment 2 July 23, 1925</u>

As it seemed worth while to study the cooling effect of salt and ice in separate containers the following apparatus was constructed. The ice was placed in the upper container which had a constant level device on the outflow, the liquid from which was withdrawn from the bottom. The salt was placed in the lower vessel, the out flow of which was from the top.

The brine was poured in at A and the temperature of the brine at the outlet observed during the experiment. Temperature of the brine at the top of the ice tank..........23°F
Temp. at bottom of ice tank..30.2°F.
Temp. through salt tank.....30.2°F.
Temp. at outlet..............30.2°F.

A



Expt.	Volume of brine cooled	% Saturation of brine.	Temp. of brine Start	Temp. of brine Stop	Room Temp.	Wt. of ice fused	Elapsed time
2 a	0.8 gal.	98	62°F	40°F	70°F	2 lbs	12 min.
b	088 "	98	34	31	70	0.5 "	6 "
c	0.8 "	95	35	30	70	0.5 "	10 "

Experiment 3 July 27 1926

In order to study the temperatures obtainable with brines of different concentration and ice the following experiment was conducted. The apparatus consisted of a metal can with an open top, surrounded by a layer of sawdust about 3" thick, the whole contained in a wood-pail the walls of which were ⅝" thick. A stirrer was placed in the centre of the can, the stirrer was driven by an electric motor at a rate sufficient to keep the ice and brine thoroughly mixed and in motion.

About 3 litres of brine 95% saturated and at a temperature of 13°C, were placed in the container, and about 3 lbs. of ice added. The stirring was begun and the temperature noted on a thermometer immersed in the brine, every 5 minutes.

I 95% brine

Time in mins.	0	5	10	15	20	25	30	35
Temperature°C.	10	-10	-12.5	-13.0	-13.0	-13.0	-13.0	-13.0
Time	40	45	50	55	60	Brine 65% saturated after 60 minutes.		
Temperature°C	-12.8	-12.0	-12.0	12.0	12.0			

II 50% brine

Time in mins.	0	5	10	15	20	25	30
Temperature°C	10	-4.5	-6.0	-6.5	-6.5	-6.5	-6.5

II 50% Brine (continued)

Time	35	40	45	50	55	60
Temperature °C	-6.5	-6.5	-6.0	-5.5	-5.5	-5.0

Brine at end 25% saturated

Expt.	Vol. of brine	%sat'n	Temp. of brine start	Temp. of brine stop	Room temp.	Weight of ice fused	Elapsed time.
I	3000cc.	95	15°C	-13°C	26°C	2.5lbs.	12 minutes.
II	3000cc.	80	10°	-6.5°	26°	1.5 "	12 "

Experiment 4 July 23 1926

This experiment was devised to determine how the concentration of sodium chloride brine is raised by flowing over salt contained in trays.

The trays were 3 in number, 20 inches long by 8 inches wide and 1½ inches deep. An even layer of salt about ½ inch thick was placed on the bottom of each tray. The trays were mounted on a stand and arranged so that the top tray delivers liquid to the next and so on. The slope of the trays was 1 in 20. There was a depth of liquid in the trays during the experiment of about ⅜ inch.

Water at a temperature of 67°F was poured into the top tray, allowed to run through and collected at the outlet of the bottom one. The rate of flow was 100 cc per minute. The liquid as it ran out at the bottom was caught and the % saturation of the salt determined with a salinometer.

About 0.8 gallon of water was used.

The first 100 cc. through was 40% saturated.
0.4 gal. " " 45% "
all liquid " " 50% "

The 50% brine was immediately poured through again.

The first 100 cc through was 60% saturated.
0.4 gal. " " 75% "
all liquid " " 80% "
The small amount of brine left in the trays was poured out, it was 85% saturated.

The passage of water through the trays as was done, twice, shows that to raise water to 80% saturated brine requires 120 inches or 10 feet of tray 8 inches wide, with a rate of flow of 100 cc per minute.

Experiment 5 July 25 1926

Fitted up a copper coil, supplied by Mr. Eagar, in a box containing an intimate mixture of salt and ice. The coil was ⅜ inch copper tube having a 1/16 inch wall, and was 72 inches long. The brine, 96% saturated, and at a temperature of 15° C was run through by gravity at a rate of 5 inches per second in a ¼ inch tube on the outlet, this amounts to 8.8 cubic inches per minute (144.2 cubic centimeters per minute). The brine was cooled to a temperature of 1° C.

Brine at 5°C was run through at 1 inch per second in the same tube or 2.9 cubic inches per minute (47.5 cubic centimeters per minute). The temperature attained in this case was -7°C.

This experiment shows that this is a possible method of cooling the brine. It would be better to use a copper tube of smaller diameter, forming a number of spirals attached to a header.

The advantage of this system is in the fact that the brine does not come in contact with the ice and salt. Ice and calcium chloride could be used which would give a much lower temperature than ice and sodium chloride.

Summary of Preliminary Experiments on Salt and Ice Freezing.

The results of the foregoing experiments are tabulated below on a comparative basis, namely the ratio of the heat removed from the brine to the heat that must have been absorbed to melt the ice used up. This ratio multiplied by 100 gives a percentage efficiency of the cooling. As some experiments lasted longer than others this percent efficiency was divided by the time in minutes these figures are given in the last column.

The data from which the weights of the brine and the heat quantities were calculated is given here before the comparative table:-
A saturated solution of Sodium Chloride at 10° C has 26.4 grams NaCL in 100 grams of solution, Specific Gravity=1.20433 (Gerlach) (6).

A solution 98% saturated	= 25.87% by weight	= 1.195	specific gravity.
" 95% "	= 25.08% " "	= 1.192	" "
" 87% "	= 22.97% " "	= 1.175	" "
" 85% "	= 22.44% " "	= 1.171	" "
" 82% "	= 21.65% " "	= 1.164	" "
" 80% "	= 21.12% " "	= 1.160	" "
" 50% "	= 13.20% " "	= 1.097	" "

The specific heat of sodium chloride brine at 0°C taken as 0.750

Expt. No.	Weight of brine	Δt	Heat removed from brine	Heat absorbed by ice.	Efficiency cooling %	Efficiency time
I Ia	2320 g.	12C	20880 cal.	80000 cal.	26.1	5.2
b	2342	5	8783	40000	21.9	4.4
c	2390	2	3585	16000	22.4	4.5
d	2390	3.5	6274	32000	19.6	3.9
IIa	2320 g.	10C	17400 cal.	40000 cal.	43.5	8.7
b	2326	7	12212	24000	50.8	10.1
c	2342	3	5270	12000	43.8	8.7
d	2350	4.5	7931	16000	49.5	9.9
2 a	9.560 lb	22F	137.74BTU.	288 BTU	54.78	4.56
b	9.536	3	21.44	72	29.78	4.96
c	9.536	5	35.76	72	49.67	4.96
3 1	3585 g.	28.00	75285 cal	90718 cal.	83.0	6.9
II	3291	16.5	40726	54450	74.8	6.2

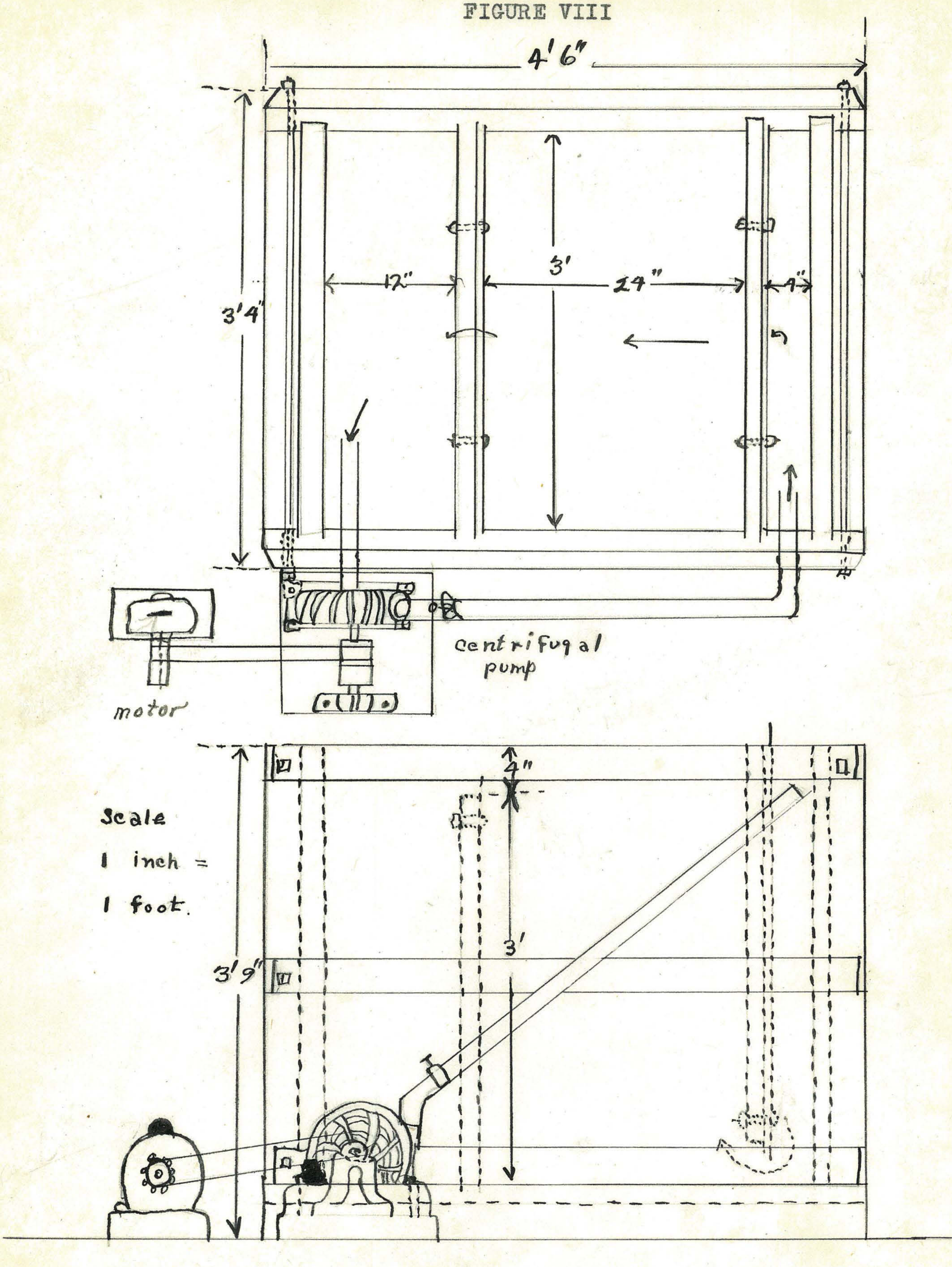
Although this data is not by any means conclusive yet it shows that a freezer using salt and ice is possible, but the efficiency is not likely to be greater than 60%. The above results show that if the salt and ice are separate it is better to have the circulation run from the ice to the freezing tank rather than from the salt tank to the freezing tank.

It was decided to construct a freezer with a freezing tank of about 100 gallons capacity. The cooling and replenishing of the brine with salt to be done with a series of trays filled with salt and ice alternately, and built into the side of the freezing tank.

About this time the writer talked to a Mr. Hubley of St. Johns, Newfoundland, who told of using a salt and ice freezer which was quite satisfactory. In this freezer there was a box in which the salt and ice were placed in layers, the brine was sprayed from pipes running around the top edge of the box, so that the inflow of brine to the box was distributed over the entire surface of the ice and salt. Mr. Hubley further told me that this freezer was not successful until they found that the brine must not fill the salt and ice box - so that the salt sunk to the bottom and the ice floated on the surface thus preventing an intimate mixing of the salt and ice.

It was decided to try this method as well as the tray method of cooling. The freezer was constructed as shown in the following diagram, figure VIII.

FIGURE VIII



Plan and elevation of Salt and Ice freezer constructed at the Station.

Rate of Flow in Brine Freezers

A factor of great importance in the design of brine freezers is the rate of flow of the brine past the material being frozen. An attempt was made to obtain some data on this problem (which is reported here) although I was unable to do more than start the work before I had to leave Halifax.

The cans described in experiment 13 of the section on Thawing of this report were mounted at equal distances from the sides and from each other in a glavanized iron box with open ends, which could be placed in the flow at the surface of our brine freezer. The box was provided with screens at one end to control the flow through it. The cans were insulated at each end with cork and on the bottom with wood, so only the sides offered a passage for the heat from the fish in the can.

Time-temperature curves of the material in the cans were made with different rates of flow past the cans. This data was as follows:

I Flow 120 feet per minute, (no screens) Air temperature 5°F
Sept. 28

Time in Minutes	Temp. of Brine	Temp. of Can No.1	Temp. of Can No.2	Temp. of Can No.3
0	3° F	50°F	60°F	50°F
15	3	40	40	40
30	3	30	30	32
45	3	29	29	30
60	2	18	19	20
75	3	4	6	5

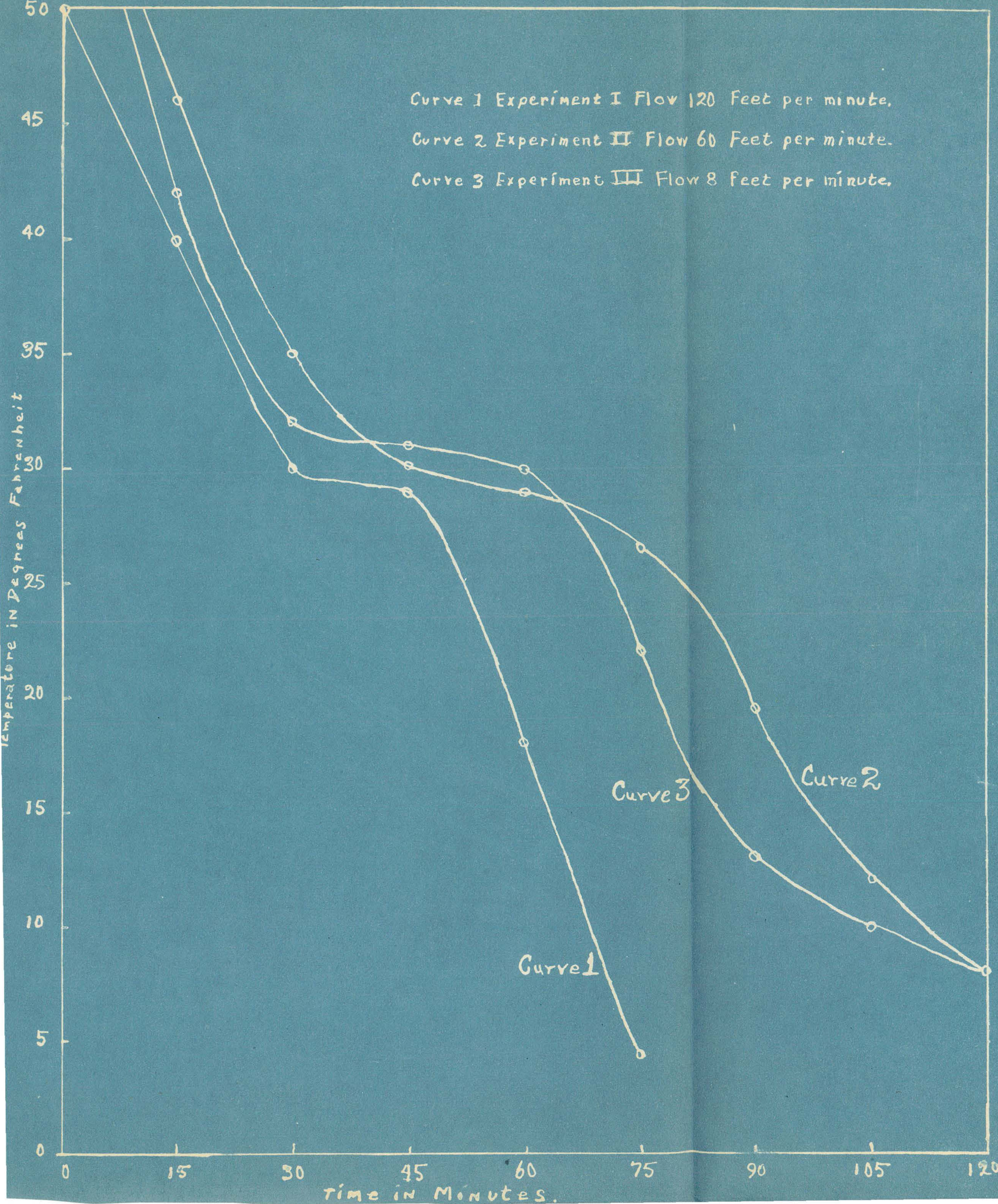
II Flow 60 feet per minute, (two coarse screens) Air Temp. 5°F.
Sept. 29

Time in Minutes	Temp. of Brine	Temp. of Can No. 1	Temp. of Can No.2	Temp. of Can No.3
0	5°F	60 °F	60 °F	60°F
15	5	46.0	46.0	46.0
30	5	35.0	35.0	36.0
45	5	30.2	30.0	31.0
60	5	29.0	28.8	30.0
75	5	26.5	27.0	28.0
90	5	19.5	20.0	20.2
105	5	12.0	12.2	12.2
120	5	8.0	8.5	8.5

III Flow 3 feet per minute (one fine screen) Air temperature 5°F.
Sept. 30

Time in minutes	Temp. of Brine	Temp. of Can No.1	Temp. of Can No.2	Temp. of Can No.3
0	5°F	60°F	60°F	60°F
15	5	42	42	42
30	5	32.0	31.0	31.0
45	5	31.0	30.0	30.0
60	4.8	30.0	28.8	29.0
75	4.8	22.0	25.8	24.0
90	4.8	13.0	13.0	14.0
105	4.8	10.0	10.0	10.5
120	4.8	8.0	8.0	8.5

Rate of Flow Experiments.



Discussion of Results of Rate of Flow Experiments

Curves were drawn (Page 30) of the temperatures of the fish in can No.1 only. It is hard to explain why curve 3 lies between curve 1 and 2. It is true that the freezing period is longer but cooling seems quicker. However these rate of flow experiments are not sufficiently complete to draw any final conclusions from them.

Theffreezing times (taken over the flat part of the curve) are:

for 120 ft. per second - about 18 minutes.
" 60 " " " - " 25 "
" 8 " " " - " 35 ""

These results seem reasonable as far as they go; but apparently none of them are on the horizontal part of a curve expressing the relation between the rate of flow and the freezing time.

If a curve showing the rate of cooling against the brine velocity were drawn, the slope of this curve would be a function of the thermal conductivity of the material being frozen; or expressed algebraically

$$\frac{\partial -\frac{d\theta}{dt}}{\partial v} = f(H)$$

where θ = change of temperature in time t; v = velocity of the brine; and H = the thermal conductivity of fish muscle.

It would seem that if this expression could be applied to a given freezer it would enable an economical rate of flow to be calculated. However the foregoing experiments do not supply sufficiently reliable data for a calculation of this nature.

Storage of Frozen Fish

When fish have been frozen they are stored until required in cold chambers. If the fish have been frozen rapidly in brine it is difficult to detect any difference between the frozen and fresh fish when thawed, cooked and eaten a few days after freezing. But during prolonged storage of even a rapidly frozen fish changes in the material take place which must be considered. Probably the most marked change is the loss of water by evaporation. With this loss of water there is a loss of aromatic substances to which the fish owes its specific taste.

Moisture determinations were made on pieces of cod fillets frozen by Mr. Finn during February 1928. These cakes of fillets had been wrapped in oiled paper and stored in the freezing room at the North Atlantic Fisheries. The temperature of the room varied from 0° to 10° F. Samples were taken from different parts of the cake, they were weighed, thawed in air and dried at 110° C to constant weight.

	% Water
1 - End surface	67.90
2 - Centre of top surface	72.71
3 - Centre of cake 4" from end	79.08
4 - Centre of cake half way between ends	79.80
5 - Fresh cod	81.87

The top surface of the cake (Sample 2) had been protected by the cake piled on top of it; but the end surface was exposed to the air of the storage room, its only protection being the 2 layers of oiled paper over it.

As far as I could learn these cakes had not been glazed before placing in storage. Some of this material, and a fresh fillet, was steamed and eaten. The frozen fish had a very flat taste compared with the fresh, and was more fibrous in texture.

All changes taking place in frozen material can be lessened by maintaining a low temperature. Plank and Ehrenbaum(3) suggest a temperature of -7°C (19.4°F) however the cold storage temperatures at the North Atlantic Fisheries are much lower than this.

The relative humidity of the air in the storage chamber should be considered. Plank and Ehrenbaum (5) recommended a relative humidity of 80 to 90. Also it would be advisable to avoid movement of the air. However these last two points are difficult to control and as no experimentation has been attempted in this work they are merely mentioned in passing.

Although the fish frozen by the writer during this work were not in storage long enough to carry out any experiments on, yet they were in most cases done in two lots one of which was simply wrapped in oiled paper, the other glazed and wrapped. In the case of fish frozen directly in brine it is necessary to wash them thoroughly before glazing. The salt in the surface even though the penetration is slight, prevents a satisfactory glaze from forming. With salt fish like Kippers and smoked fillets the glaze is almost impossible. An attempt was made in the case of a cake of smoked fillets to glaze on the wrapping paper.

The flexibility of the paper caused a great deal of breakage in this glaze. Stiles (7) page 145 mentions other forms of glaze such as a mixture of waxes to produce a water tight, air tight covering for the fish during storage. This is certainly a point which could be investigated. Possibly an elastic glaze which could be applied before freezing would be the solution of the problem of protecting the fish from the brine during freezing.

Not only in glazing and wrapping to be recommended but close packing of the wrapped cakes or boxes in the storage room.

Thawing

All frozen material must be thawed before use. This process is the reverse of freezing, and the factors influencing the rate of thawing are the same as those influencing the rate of freezing. If the fish is frozen slowly enough for large ice crystals to form it is unlikely that the normal structure of the tissue will be regained by rapid thawing, But when a fish is frozen rapidly the effect of thawing is minimised.

Three methods of thawing are worthy of consideration:
1. Thawing in crushed ice.
2. Thawing in air at room temperature.
3. Thawing in water at about 10°C.

The first of these is the slowest and the last the most rapid. When water is used as the thawing medium the fish may be immersed directly in the water, some of the continental workers favour this process the advantage of the prodecure lies in the fact that the moisture lost during storage is made up; but at the same time the water dissolves a certain amount of soluable material which is lost. For this reason it is better to protect the fish from the water during its immersion.

Thawing Experiments

Experiment VI August 3, 1926.

A cake of cod fillets frozen by Mr. Finn and placed in storage on February 3, 1926, was brought up to the station and cut into two pieces about 16"x 4"x 1½". A hole was bored in the block along the longitudinal axis, to take the bulb of the recording thermometer. One block was placed in crushed ice and one in a pan of water at a temperature of 60°F. The readings of the recording thermometer were checked by a mercury thermometer in a hole bored at right angles to the recording thermometer bulb. The room temperature was 70°F. The temperatures recorded are as follows:

I Block in ice.

Time in Hours	0	1	2	3	4	5	6	7	8	9	10
Temp. in ° F.	23	25	26	28	30	31	31	32	32	32	32
Time	11	12	13	14	15	*16	17	18	19	20	
Temperature	32	33	33	34	35	37	40	46	54	66	

*Ice all melted in box by this time.

II Block in water

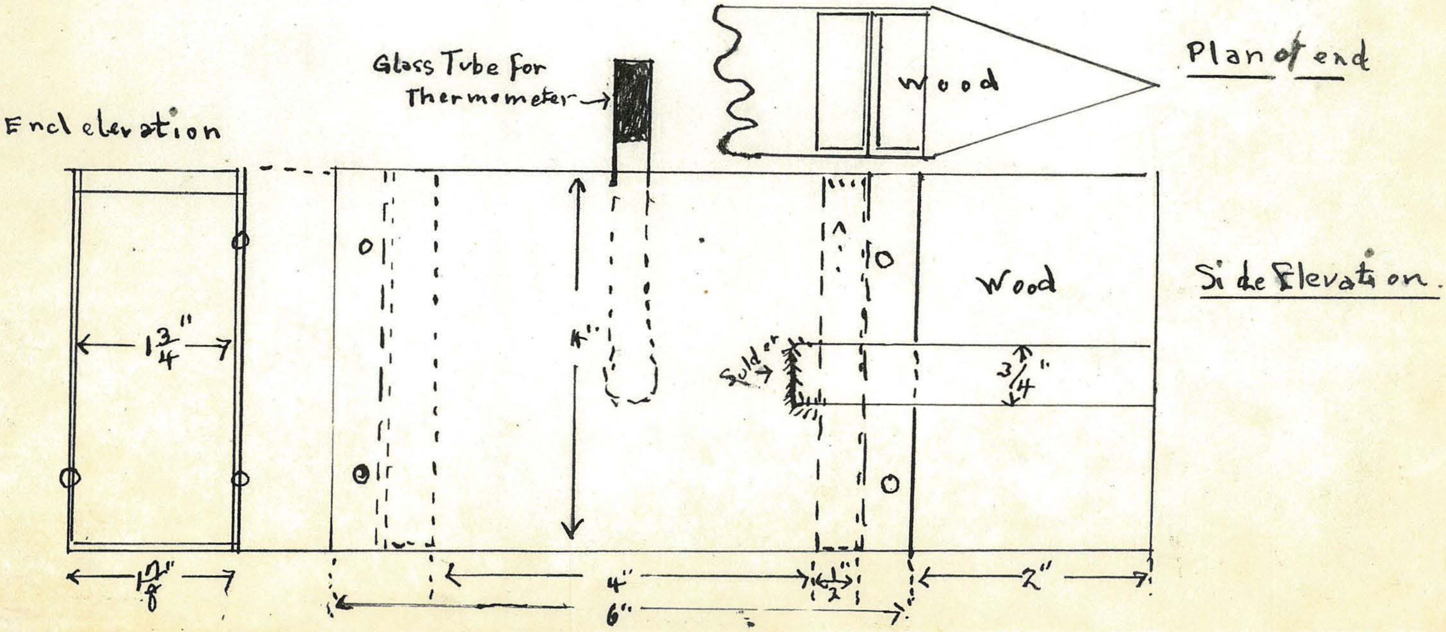
Time in hours	0	1	2	3	4	5	6	7	8	9	10	11
Temperature in degrees F.	25	30	32	32	34	40	46	52	56	58	59	59

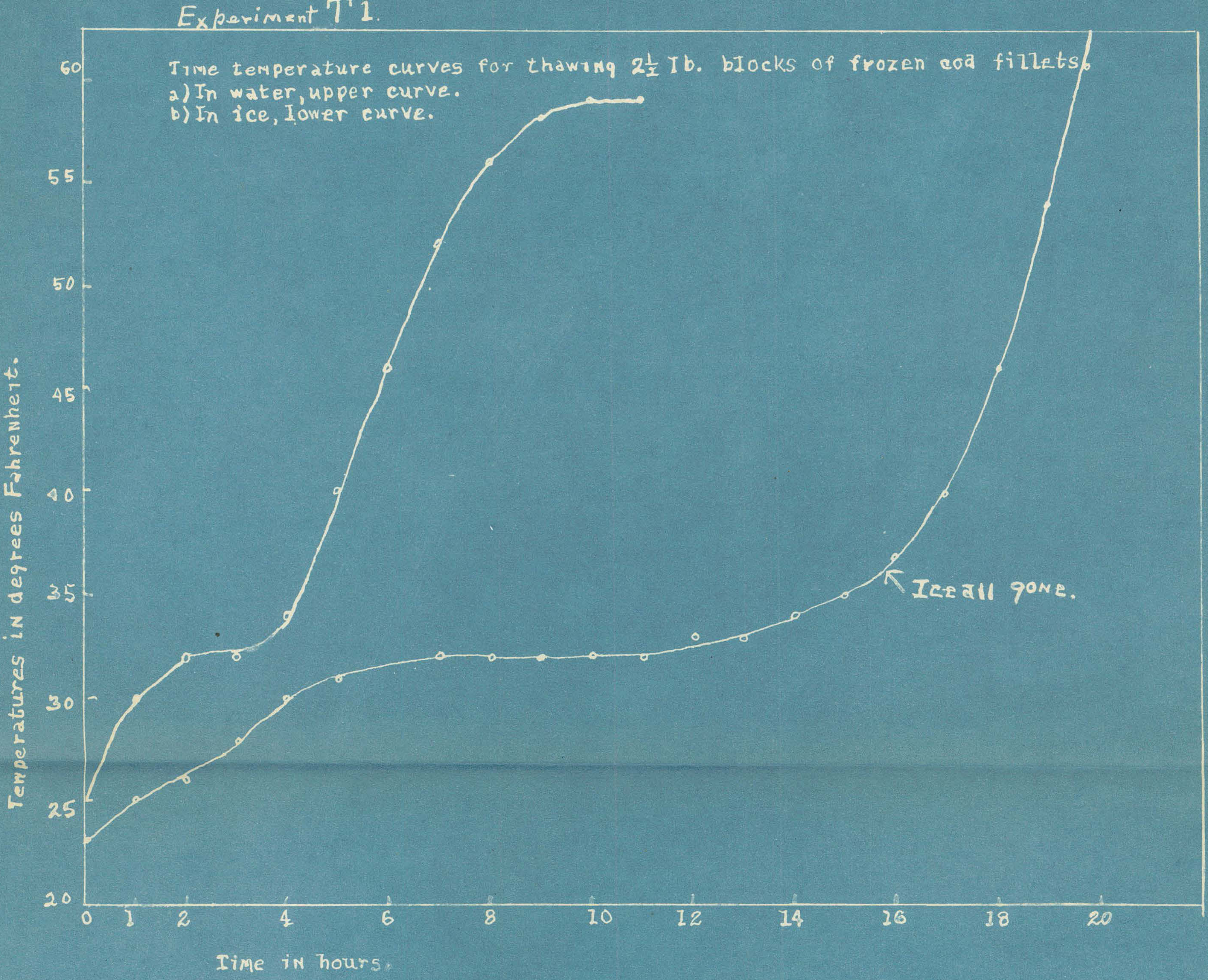
Experiment 12 August 9, 1926

A cake of frozen fillets of cod, frozen by Mr. Finn on January 27, 1926, weighing 8½ lbs., wrapped in oiled paper, the paper was not removed and the cake placed in the "cold room" at the station where the temperature was about 40 to 50°F. About 5 lbs. of fresh fillets from the National Fish Company were wrapped and placed beside the frozen cake. In 15 hours the frozen cake was completely soft so it could be bent in any direction. In 3½ days time from defrosting both fresh and frozen fish had a strong stale smell, between the 5th and 6th days the frozen fish had begun to liquify, and was unfit for use. The fresh fillets after the 5th day were not so soft and did not exude so much liquid.

Experiment 13

In experiment I curves were obtained for the rate of thawing of fish directly in ice and water. In practice this is not used as the water will leach out soluble material from the fish. It was decided to conduct thawing experiments in metal containers . These containers were made as shown.




Experiment T 1.
Time temperature curves for thawing 2½ lb. blocks of frozen cod fillets.
a) In water, upper curve.
b) In ice, lower curve.
Ice all gone.
Temperatures in degrees Fahrenheit.
Time in hours.
60
55
50
45
40
35
30
25
20
0
1
2
4
6
8
10
12
14
16
18
20

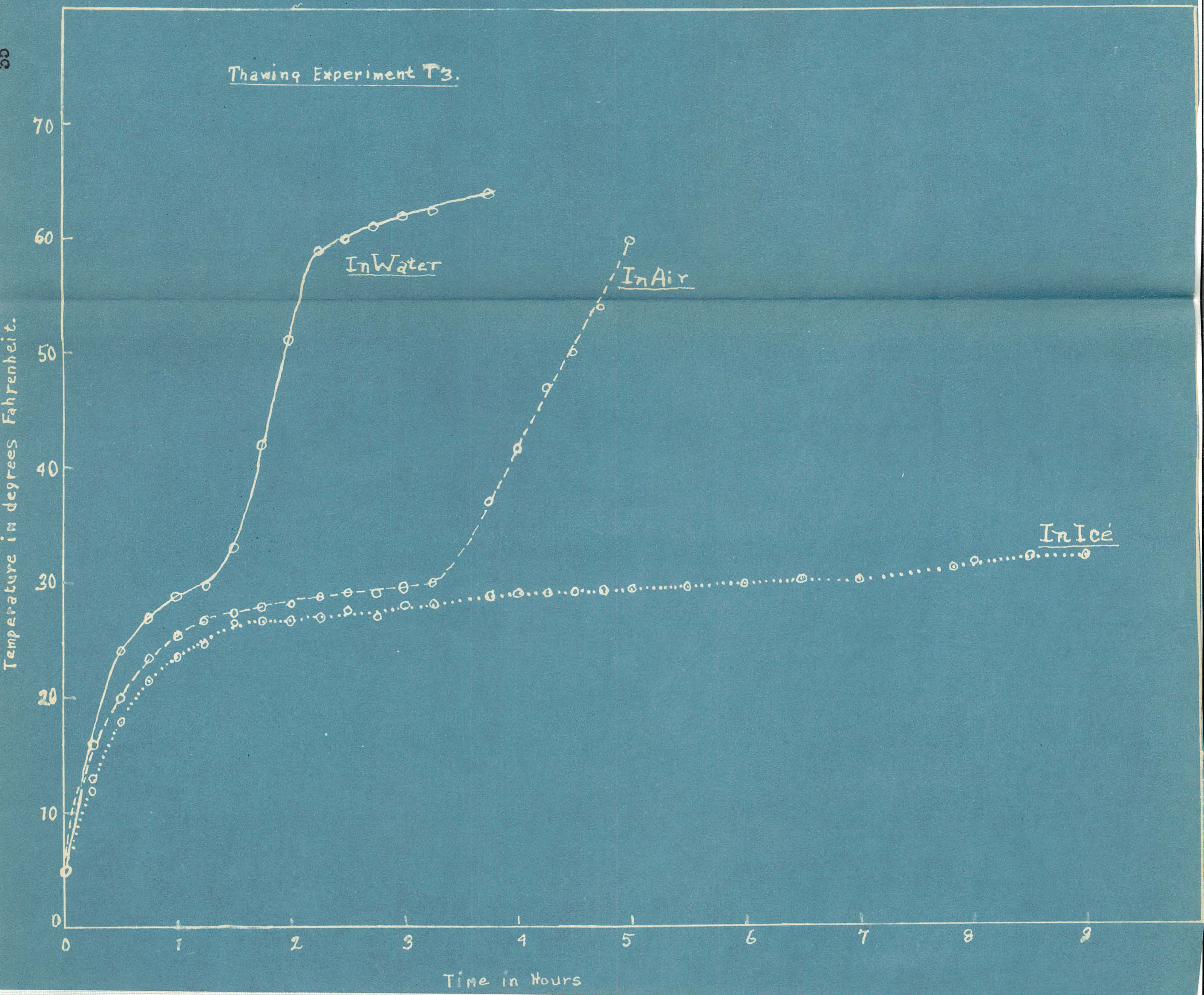
Owing to the pressure arising in the material during freezing which would press the walls of the thermometer bulb and even break it, a thermometer could not be placed directly in the fish.

To take the temperatures a glass tube which had a diameter large enough to permit the thermometer to be placed inside it was sealed at the bottom and shoved down through the fish in the can until the bulb was about the centre as shown. To ensure sufficient contact, mercury was placed in the tube which formed a layer between the thermometer bulb and the protecting tube. Fresh fillets were cut in pieces to fit the cans and packed in layers about 3 layers to a can. The freezing of these cans of fish was done at the North Atlantic Fisheries on our brine freezer. Temperatures were noted every 15 minutes.

Time	Temp. of brine tank	Temp. fish Can No. 1	Temp. fish can No. 2	Temp. fish can 3	Temp. $CaCl_2$ brine	Temp. air
2.50 P.M.	3° F	47°F	49°F	47°F	2.5°F	3°F
3.00	3	41	40	41	2.5	3
3.15	2.5	32	32	32	2.0	3
3.30	2.0	29	29	30	1.5	3
3.45	2.0	22	19	20	1.0	3
4.00	1.5	8	6	7	1.0	2.5

Cans removed from the tank at 4.00 P.M.

The cans were left overnight at the freezer and brought up to the station in a pail of crushed ice. One can was placed in the ice, one in a pail of water, and one allowed to stand on the bench. The air temperature and water temperature were observed frequently. The temperature of the frozen fish was recorded every 15 minutes.


Thawing Experiment T3.
In Water
In Air
In Ice
Temperature in degrees Fahrenheit.
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
Time in Hours

Room temperature 64.0°F throughout.
Thawing in thawing water temperature 65°start - 63°F at end.

Time in hours	Ice	Air	Water	Time in hours	Thawing in Ice
0	5.0	5.0	5.0	6.50	30.0
0.25	12.0	15.0	16.0	[illegible]	[illegible]
0.50	18.0	20.0	24.0	7.00	30.0
0.75	21.5	23.5	27.0	7.50	31.0
1.00	23.5	25.3	28.8		
1.25	24.3	26.8	29.9	8.00	31.5
1.50	26.5	27.2	33.0	8.50	32.0
1.75	26.8	28.0	42.0	9.00	32.0
2.00	26.8	28.3	51.0		
2.25	27.0	28.8	59.0		
2.50	27.5	29.0	60.0		
2.75	27.0	29.1	61.0		
3.00	28.0	29.6	62.0		
3.25	28.0	30.0	62.5		
3.75	28.8	37.0	64.0		
4.00	29.0	41.5	----		
4.25	29.1	47.0	----		
4.50	2912	50.0	----		
4.75	29.3	54.0	----		
5.00	29.4	60.0	----		
5.50	29.5	----	----		
6.00	29.9	----	----		

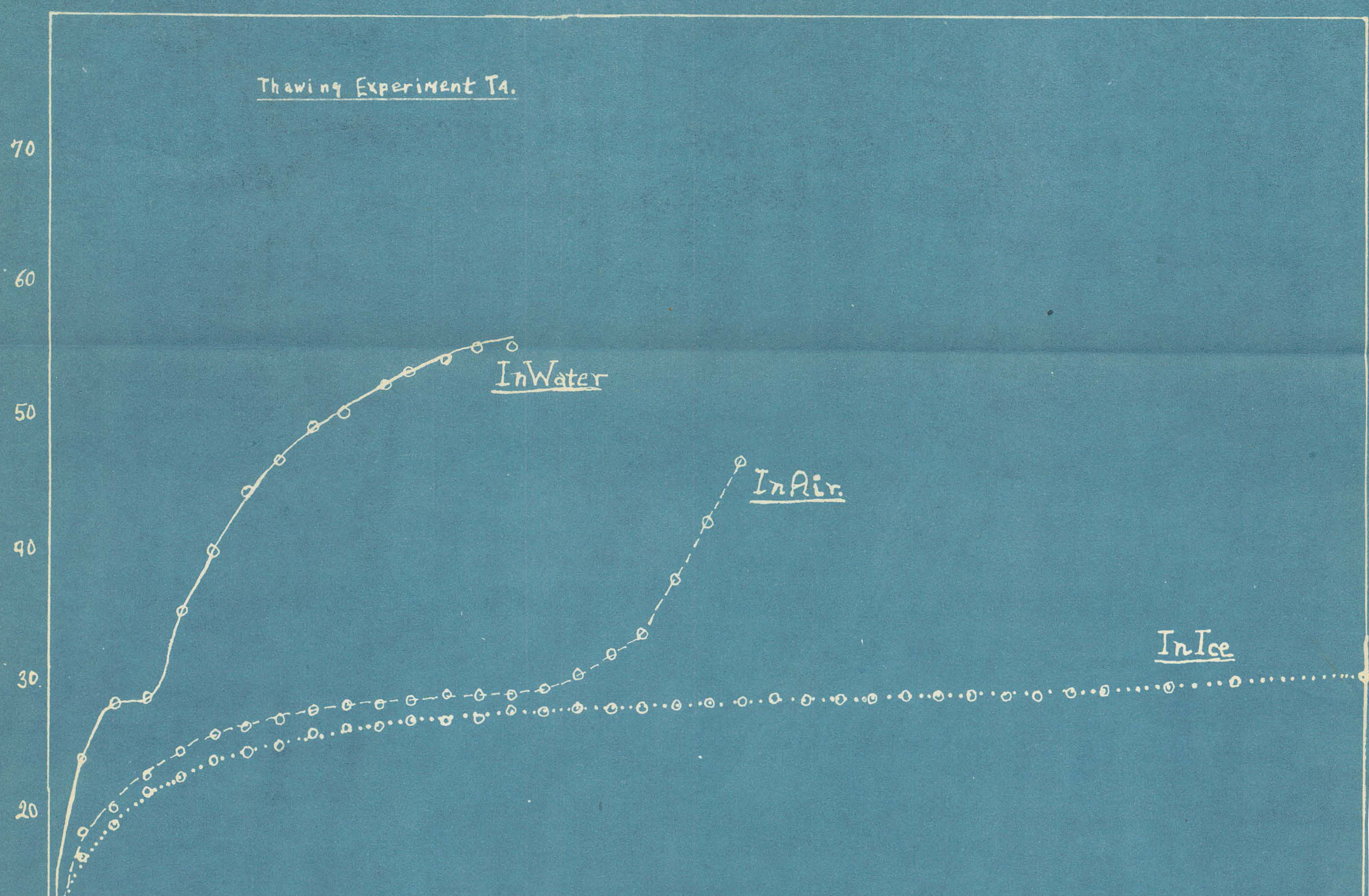
In each case 13 ounces of fish were thawed

Experiment T4 September 14

This experiment was performed in the same way as Experiment T3 only the thawing in ice was begun before the thawing in water and air so that the three lots of fish were finished together. The times and temperatures recorded were as follows.

Time in hours	Thawing in ice	Thawing in air	Thawing in water	Time in hours	Thawing in ice.
0.00	10.0	5.0	5.0	5.50	28.8
0.25	16.5	18.5	24.0	5.75	28.8
0.50	19.0	20.2	28.2	6.00	28.9
0.75	21.5	22.8	28.6	6.25	28.9
1.00	22.6	24.5	35.0	6.50	29.0
1.25	23.9	25.9	39.5	6.75	29.0
1.50	24.5	26.6	44.2	7.00	29.0
1.75	25.0	27.0	46.5	7.25	29.0
2.00	26.0	27.8	49.0	7.50	29.0
2.25	26.4	27.8	50.0	7.75	29.2
2.50	26.6	28.2	52.0	8.00	29.4
2.75	27.0	28.6	53.0	8.50	29.8
3.00	27.0	29.0	54.0	9.00	30.0
3.25	27.2	29.0	55.0	10.00	30.5
3.50	27.8	29.0	55.0	11.00	32.0
3.75	27.9	29.5	----	-----	----
4.00	28.0	30.4	----	In each case 15 ounces of fish were used.	
4.25	28.0	31.9	----	Air temperature 60°F.	
4.50	28.0	33.5	----	Temperature of thawing water Start 60°F end 55°F.	
4.75	28.2	37.6	----		
5.00	28.4	42.0	----		
5.25	28.5	46.5	----		

When all the material was thawed the fish was taken from the cans and placed on the bench with some pieces of the same fillet which had been kept on ice while the freezing and thawing was being done. There was no noticeable change in the fish for 36 hours. At this time the frozen fish smelt stale, in 42 hours both frozen and fresh had a stale smell. In 54 hours all were unpleasant to smell. There was no appreciable


Thawing Experiment T4.
In Water
In Air.
In Ice
Temperature in Degrees Fahrenheit.
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Time in Hours.

difference between the air water and ice thawed fillets. The frozen fish dried on the surface in this time more than the fresh, the frozen felt softer after standing, than the fresh. However, the differences were very slight. These results are in accordance with the findings of Plank and Ehrenbaum (3) who made a number of comparative tests of the three thawing methods with haddock, mackerel, eel, cod and plaice; the fish being cooked and eaten afterwards. They came to the conslusion that the velocity of thawing influences neither the taste nor the keeping properties of the fish.

SUMMARY

Owing to the diversity of the questions dealt with in this investigation it is impossible to conclude this report with a concise summary of the findings. The greater part of the practical side of freezing fish must be worked out for various local conditions. It is impossbile to stress too much the need for strictly fresh fish for the freezing process. The adaption of the brine as a freezing medium on a large industrial scale is simply a problem for the engineer. It would be well to have exact data on the existing methods of brine freezing that are in commercial operation, for example the OTTESEN process.

I understand that Mr D. B. Finn determined the specific heat of cod, and it would be useful for purposes of calculation to know the thermal conductivity of both fresh and frozen cod and haddock muscle.

Although the German workers (3) have studied the question of storage very thoroughly for the temperatures in use on the continent, yet it would be well to know whether the lower temperatures used in our Canadian cold storage plants preserve the fish more efficiently.

I wish to take this opportunity to thank the following people for their kind assistance during the course of this work:

Dr. A. G. Huntsman, the director of the station.
Mr. R. F. Eagar who assisted me with the engineering and constructional work.
The Superintendent and the two engineers at the North Atlantic Fisheries, where most of the freezing and storage was done.

Mr. C. B. Weld who made microscopic sections of some of the frozen material, and who with Mr. H. Tanner helped me with the photographs.

And finally the members of the staff of the station who ate "frozen fish" at frequent intervals and discussed its quality with me.

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