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Title

EXPERIMENTS ON THE FREEZING OF WHOLE FISH AND FILLET BY MEANS OF DIRECT AND INDIRECT IMMERSION

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Experiments on the Freezing of Whole Fish and Fillet by Means of Direct and Indirect Immersion.

By D.B. Finn.

In the preceding part of this paper two questions have been answered. Firstly it has been shown why frozen fish is inferior to the fresh product. Secondly it has been shown that these defects may be overcome by freezing the fish very rapidly in brine. This part of the paper will deal with the attempts which have been made at the Atlantic Experimental Station for Fisheries to develop a brine freezer which will be suited to the needs of the industry. The investigations that are here reported are far from finished, and this paper must be regarded as the history of an evolution rather than a complete and final answer to a definite question.

If a machine is to employ the fast freezing principle and at the same time is to be commercially applicable, it must have the following characteristics.

(1) It must be efficient. The amount of work taken out of the machine must equal as nearly as possible, the work put into the machine.

(2) It must be of low initial cost, therefore simplicity must be the keynote of its design.

(3) Its upkeep must be low, therefore it must be rugged.

(4) Its operating cost must be low, therefore it must be automatic and its product handled with a minimum of labour.

(5) It should be applicable to the needs of both the large and the small handlers of fish.

Keeping these essentials in mind as something to be achieved, we may now consider just what is involved in a refrigerator and just what we have to work with.

There are three essential parts to a refrigerator:

Firstly a source of cold which is the means of lowering the temperature. Such a source of cold may be an expanding gas such as ammonia or carbon dioxide, or it may be the commonly used salt (sodium chloride) and ice. This source of cold takes up heat from its surroundings, thereby lowering the temperature. In order to do this most effectively, it must be circulated, otherwise it would soon be nearly as warm as its surroundings, and its cooling power be lowered.

Secondly a cooling medium which takes up heat from the material to be cooled and gives it up to the source of cold. In the old type of refrigerator known as the "sharp freezer", air is the cooling medium and the cold ammonia in the coils is the source of cold. The air takes up heat from the fish and gives it to the cold coils. Air is a very poor cooling medium for the following reasons:

(A) It is a poor conductor of heat.
(B) It has a low specific heat.
(C) It has a low specific gravity.
Note: With regard to specific heat and specific gravity, it must be explained that some substances hold more heat than do others, and the greater the specific heat and the greater their specific gravity, the greater will be the amount of heat that they will hold.
(D) Fish lose weight (Shrinkage) when frozen in air.

In the new system, sodium chloride brine is used as a cooling medium. Sodium chloride (common salt) brine is a much better cooling medium than air, because:

(A) It is a relatively good conductor of heat.
(B) It has a high specific heat.
(C) It has a high specific gravity.
Note: This means that it can take up a very great deal more heat than can air, volume for volume.
(D) Fish do not lose weight while being frozen in brine.

Thus whereas air, even when very cold will freeze fish slowly, brine will freeze them rapidly. It is common practice to leave fish in the "sharp freezer" for twenty hours, while in brine they can be frozen solid in one hour.

The third component in a refrigerator is the material to be frozen. In this case the material is fish. This can be frozen in two ways, one by direct immersion in which the brine comes directly into contact with the fish, the other by indirect immersion in which the fish is separated from direct contact with the brine by a thin metal container. Whole or gutted fish can be frozen by either method. Filleted fish is best frozen by the latter method on account of its fragility and its tendency to absorb the salt of the brine. This tendency is more marked in the cut surfaces of the fish than in the unbroken surface where the skin is intact.

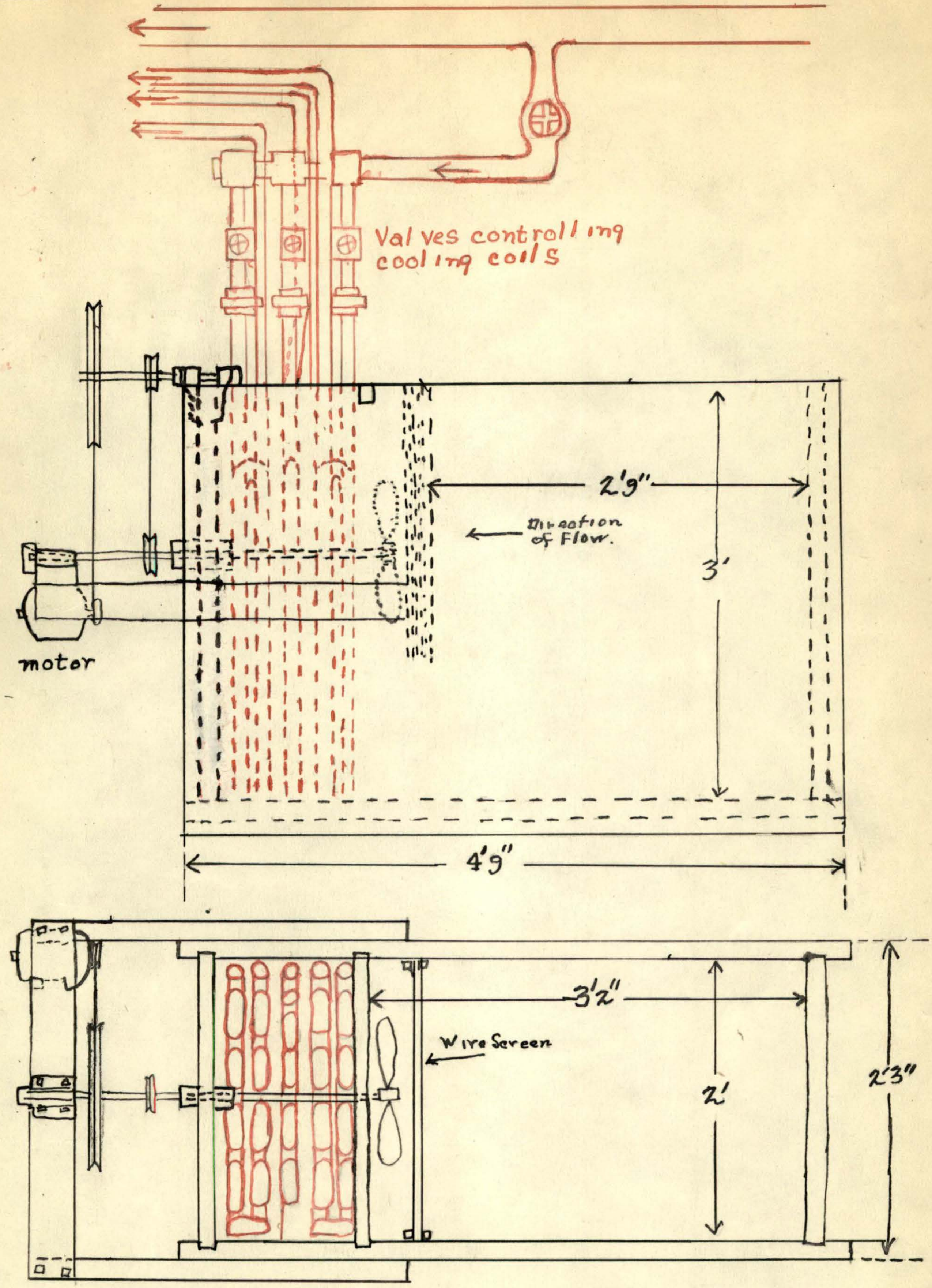
Whichever of these two methods is used, the arrangement of the fish in brine is of great importance. Our first consideration must be that of efficient freezing. It will be readily seen that the more the warm fish come into contact with the cold brine, the more rapid will be the freezing, and the freezing will be the fastest when the fish are arranged so that the brine comes into contact with all their body surface. In the case of fillets which must be placed in pans, the shallower the pan, the less the freezing time will be, for the greater the thickness of fish, the longer it will take to freeze them through.

Circulation of the brine past the fish is another very important factor. Everyone knows that a cold wind feels colder than still air at the same temperature This is because in still air a thin film of air sticks to the body, and soon becomes warm, thus forming an insulating coat which protects the body against further cooling. When a current of air is blown against the hands and face, this thin film is removed and the body loses more heat, and consequently we feel colder. The same holds true for fish in brine, the more the brine circulates, the more heat it will take up from the fish, and the more heat it will give up to the source of cold. The fish then must be arranged so that they offer as little resistance to this circulation as is compatible with efficient freezing.

One of the most important features, from the point of view of the industrial man is the ability of the machine to handle large quantities of fish with the minimum of trouble.

The mechanism which holds or carries the fish through the brine must be simple in its operation requiring no special skill on the part of the operator. Further the fish must be straight and flat when it leaves the machine in order that it may be easily packed or stored.

If a machine could be developed which embodied all these characteristics, and at the same time was capable of continuous operation with just as little, or less handling than the ordinary "sharp freezer" methods involve, the question of comparative cost of the two methods would be solved, and at the same time we would have a frozen product which was equal, if not superior to the fresh unfrozen product. Indeed the term "Frozen Fish" would disappear from the vocabulary of the retailer and consumer.



Scale 1" = 1 foot.

Development of Apparatus.

The apparatus consists of a wooden tank made of 1½ inch clear pine, the inside dimensions being 2 feet by 3 feet by 4 feet 6 inches. The inside was coated with a layer of parawax which was "ironed" into the wood. At one end a ¾ inch watertight propeller shaft bearing (L) was placed one foot from the bottom of the tank. Directly above this at the top of the tank was a ¾ inch double bracket bearing (J) and (K) to take the shaft (H) of a speed reducing pulley (C).

A set of coils consisting of 3 units - Unit A containing 20 lineal feet - Unit B containing 40 lineal feet, and Unit C containing 40 lineal feet of 1 inch iron pipe. Thus it was possible to use 20, 40, 60, 80 or 100 lineal feet of pipe at a time.

These coils were placed at the end of the tank so that the propeller shaft extended through them as is illustrated Figure (1) To the end of this shaft a single bladed 18 inch wooden propeller was attached. A 1/8 H.P., 110 V., 60 cycle 1725 R.P.M. motor furnished the power to pulleys which were arranged so that the propeller revolved at 115 R.P.M.

A screen (O) two feet square made of one-half inch mesh galvanized wire netting was constructed so as to fit in front of the propeller.

After this apparatus was assembled, tests were made of the circulation.

Circulation Tests.

The tank was filled with water and the propeller revolved so as to bring the liquid towards and up through the coils as is shown in Figure (2)

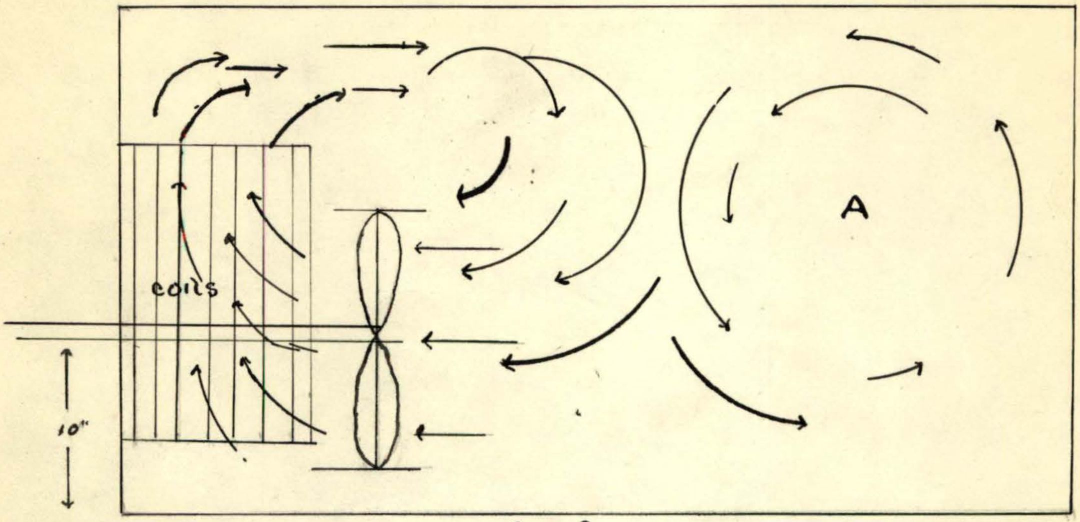


Fig 2.

It was found that with this arrangement the circulation was very incomplete, large eddies occurring, as shown in (A) Figure (2) cut off the circulation from the end of the tank which was most remote from the propeller.

The direction of revolution was then changed so that the liquid was pulled down through and away from the coils Figure (3).

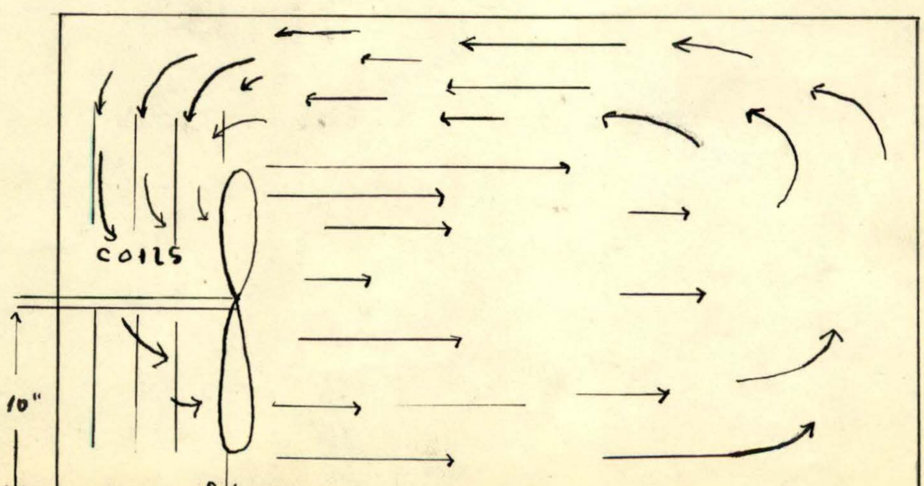


Fig 3

This resulted in a much better circulation, giving a relatively large body of liquid at the bottom of the tank moving away from the coils with a smaller rapidly moving body of liquid moving towards the coils at the top of the tank.

It was thought that this topmost layer of quickly moving liquid might be undesirable in case of indirect immersion. In order to overcome this, the propeller was moved up so that it was 20 inches from the bottom and its direction of revolution reversed, which resulted in the same type of circulation except that the slowly moving liquid was now at the top, and the swift stream of liquid at the bottom Figure (4).

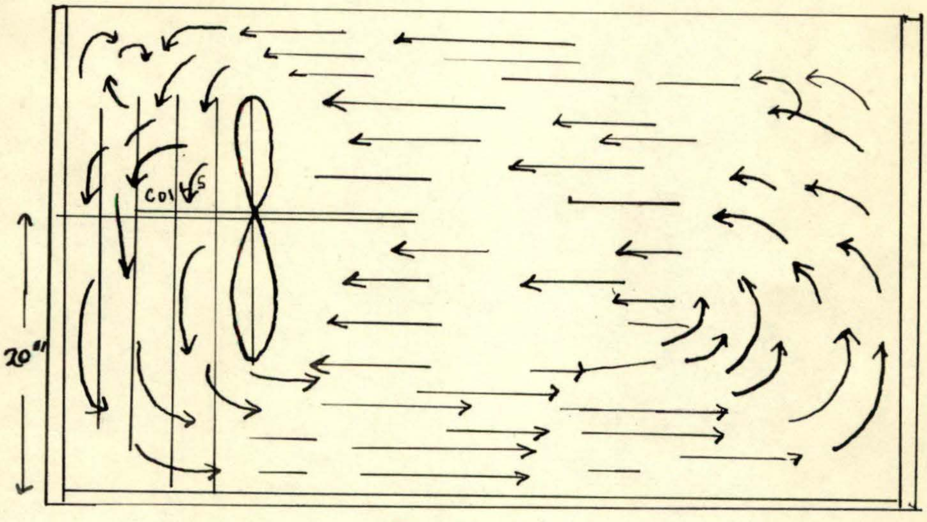


Fig 4.

This particular movement of liquid seemed most desirable since it was non turbulent and steady. Further the variations in density of the liquid due to cooling, aided rather than impeded this circulation, since as the liquid cools it tends to sink down through the coils.

It was then sought to increase the efficiency of this circulation by adding another set of blades to the propeller, thus making it four bladed. After this was done, it was found that the surface of the liquid above the propeller was becoming broken, and that there were small eddies directly above the coils. In order to overcome this the coils were lowered and a six inch collar made of galvanized iron was placed round the propeller (R) Figure (1)

Attention was now turned to the containers for the fish.

There were four types. Two for indirect immersion, where the fish were separated from actual contact with the brine by a thin layer of metal, and two for direct immersion in which the brine was allowed to come into direct contact with the brine.

The first container designed was a fish envelope for freezing cod. Headless market cod vary from 15 to 18 inches in length, from 3 to 4½ inches laterally and from 5 to 8 inches dorso-ventrally. Accordingly a can was constructed with an oval mouth 4½ inches wide and 9 inches long. From this mouth the can tapered down in a wedge shaped fashion for 26 inches to a 7 inch base Figure (5)

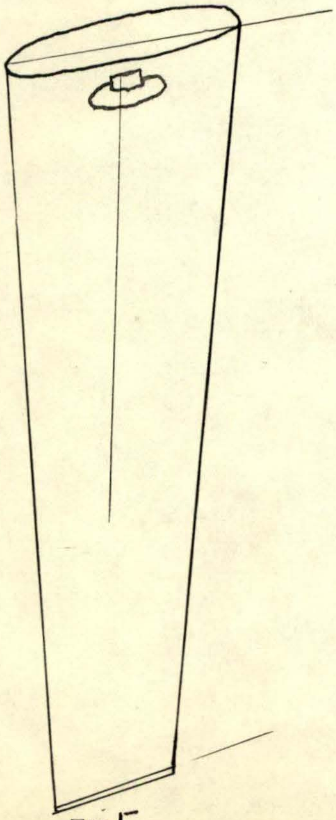


Fig. 5.

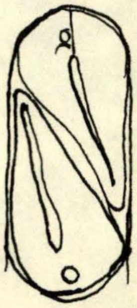


Fig. 6.

Fish could be placed in this container in the manner illustrated Figure (6). In this manner two fish could be frozen in one can, and the thickest part of the contained fish would be no thicker than a single fish. When frozen the fish appeared in a wedge shaped block, two such ones making a rectangular block which lends itself to convenient packing Figure (7).

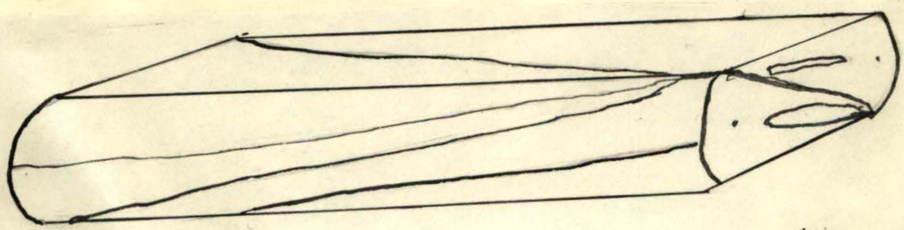


Fig. 7.

The second type of holder designed for indirect immersion was a pan for freezing fillets. The first designed was of No.16 gauge galvanized iron 14 inches by 9 inches by 1½ inches, with a lid which slid into groves which were made by doubling back the rim Figure (8)

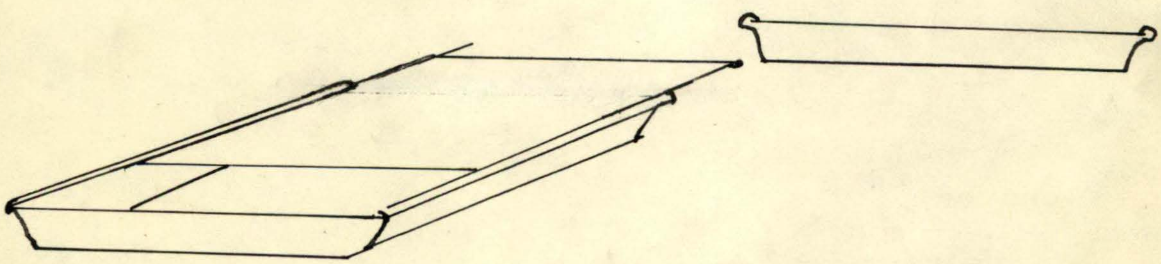
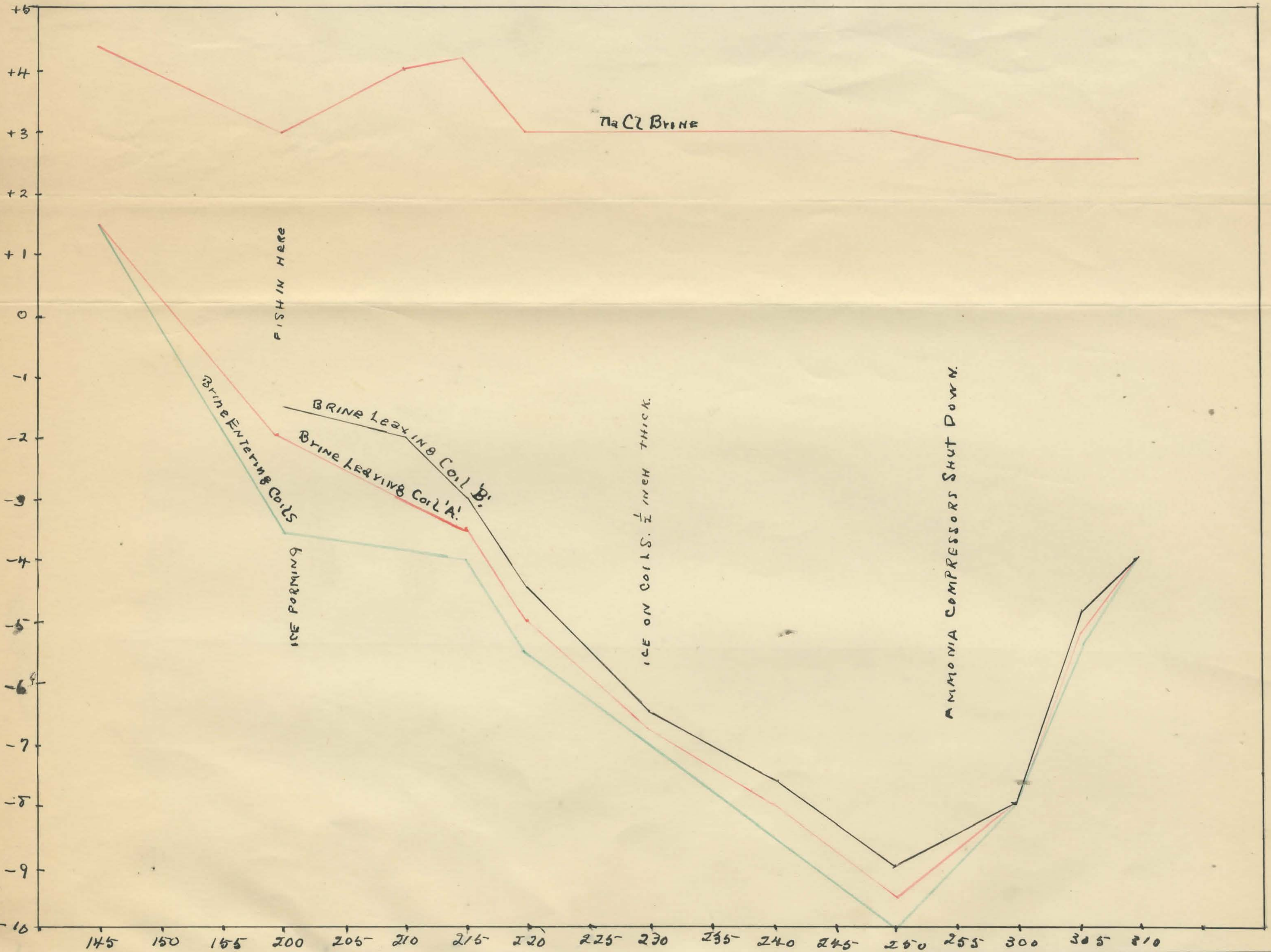


Fig. 8.

GRAPH I. Expt. I



It was found that this pan was hard to open and close and that it proved unsatisfactory.

The second pan was of the same size and material but was of the construction shown in Figure (9)

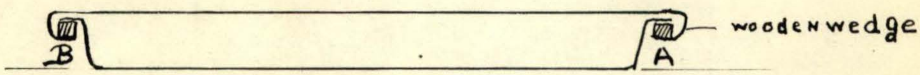


FIG 9

The lid (C) having a large double right angle turn so that it fitted loosely over the rim of the pan, where it was secured by means of wooden wedges (A) and (B) Figure (9). It proved quite easy to open and close this pan both before and after freezing.

The third pan to be designed was still more simple. It was made of No. 16 gauge sheet iron and heavily galvanized after completion. The inside dimensions were 16 inches by 9 inches by $1\frac{1}{2}$ inches. The closing mechanism Figure (10)

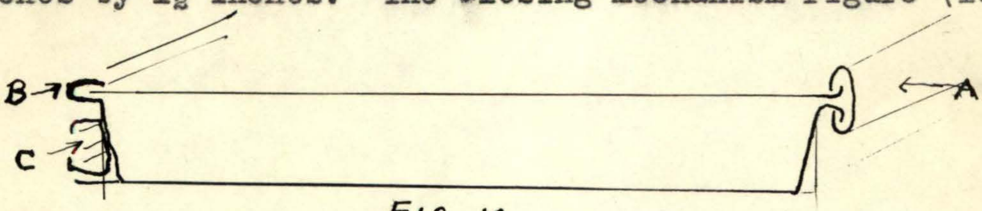


FIG. 10.

consisted of a tube (A) which slid over the upturned edge of the lid and the downward edge of the pan. This was situated along one side of the pan. On the other side of the pan was a double turn of the Rim (B) in which the other flat edge of the lid engaged itself.

On the ends of the lid there were turned down flanges Figure(11)

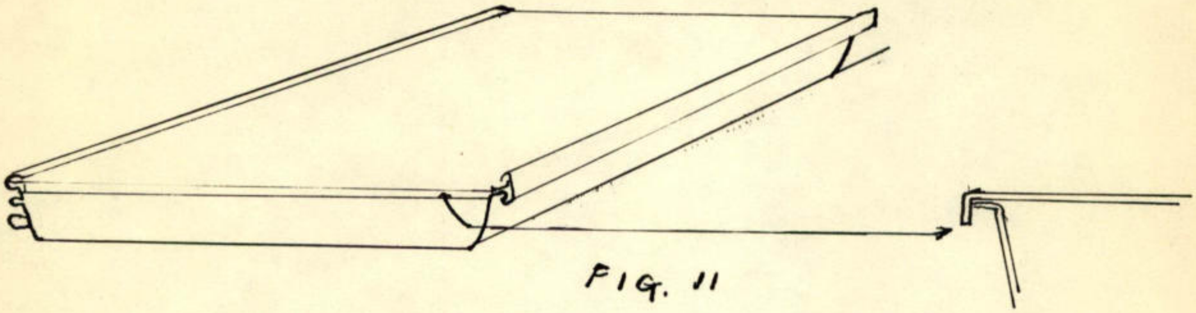
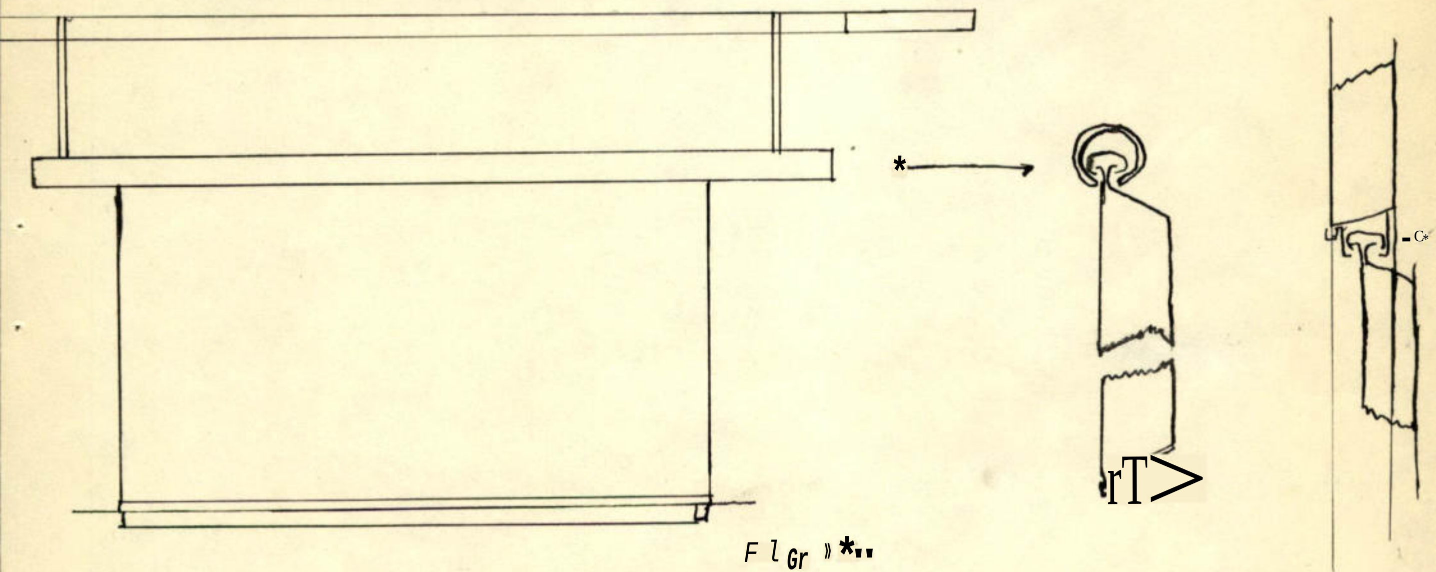


FIG. 11

which fitted snugly over the ends of the pan rim. This pan was very easily filled and closed and was found to be practically watertight, when filled with fish.

The mechanism for suspending the cans in the brine is illustrated in Figure (IE)



F l Gr » *..

It will be seen that the tube C. Figure (IE) which is fastened on to the pan serves as a means of fastening one can to another, Thus a series of cans can be suspended from the same hanger.

The third container is a rectangular basket made of 1 inch angle iron and chicken netting.

This basket is made so that five trays can be easily placed within it. The trays are made of 1 inch galvanized strap iron and ½ inch mesh galvanized wire netting. Each tray has four five inch legs, so that when the trays are placed in the basket, they form 5 compartments, figure (14).

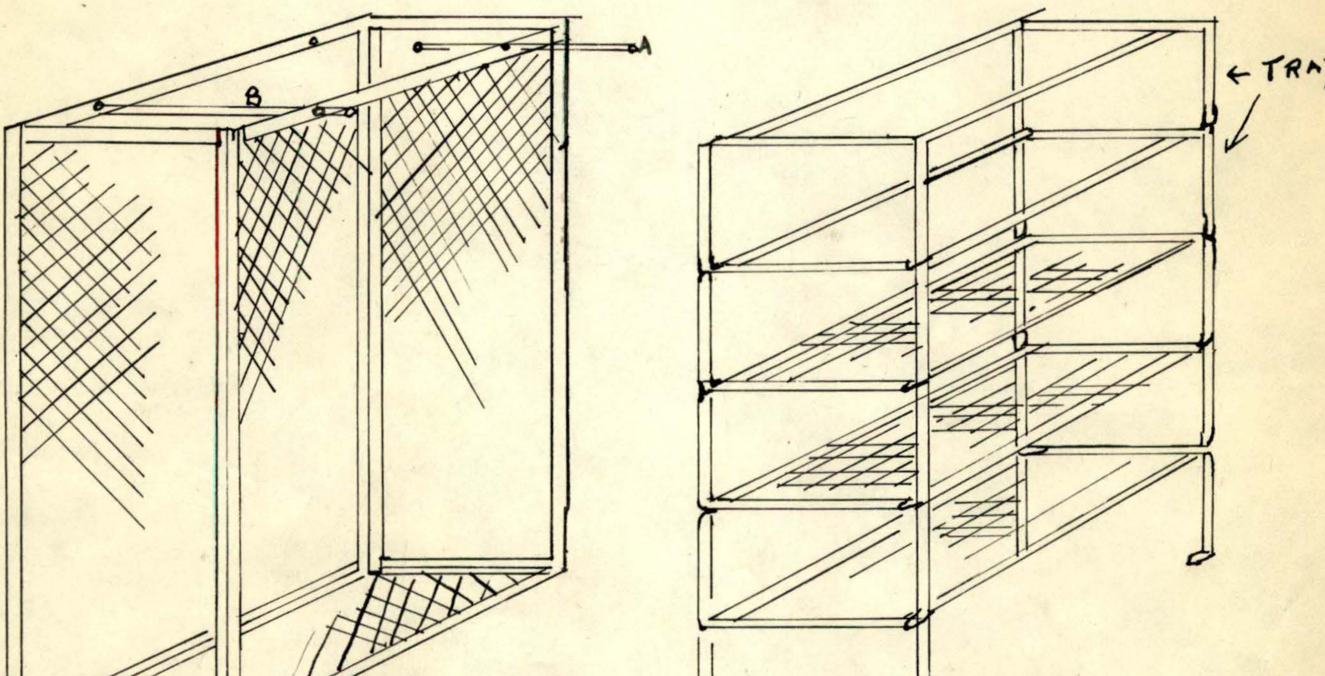


Fig. 14.

In filling this basket, first a layer of fish is put into it, then a tray, then another layer of fish, then another tray, and so on until the last tray is placed in position, where it is fastened by two rods A and B - Figure (14). When filled and placed in the brine, the fish float to the top of each compartment, thus making five layers of fish, each separated from each other by about two or three inches, and each layer being one fish thick.

Fish frozen in this manner were not contorted, and could be easily packed.

The fourth appliance, one for direct immersion, consisted of a galvanized iron rod, on which were placed a number of hooks. Figure (15). Fish were fastened to this by placing the hooks through the soft parts of the snout.

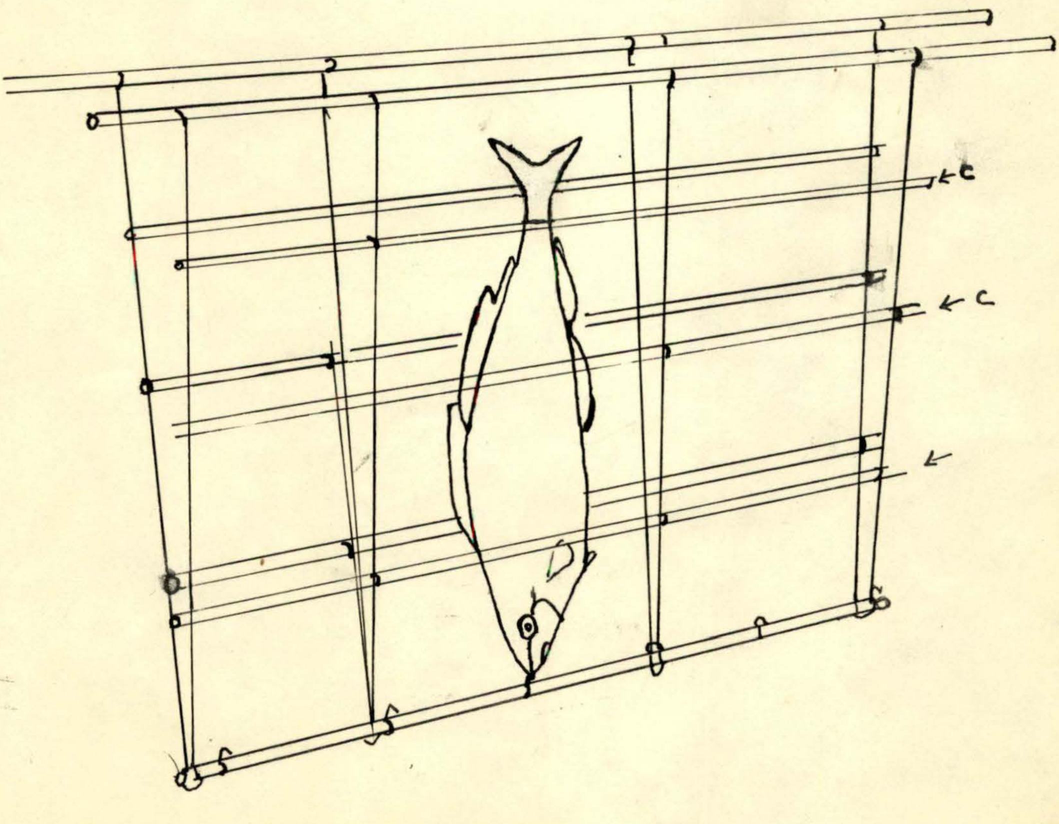


Fig. 15.

Fish having been fastened to the rod, it was placed in a hanger which consisted of several pieces of stout cord to which were fastened wooden slats (C).

When this was placed in the brine, the fish which tend to float were weighted down by the rod, and thus assumed an upright position, and were prevented from being moved by the circulating currents, by means of the slats on the hanger.

Of these four devices, the most used were the basket and the fillet pans. Both were found easy to operate, and it was thought that both would be applicable to processes on a large scale.

It was noted that the holding tubes (C) Figure (12) which were riveted to the pans, had a tendency to break away with rough handling. This could be overcome by more rigid construction from heavier metal. It was further noted that unless the pans were tightly packed, brine would leak in at a few places. Where this happened there was evidence of salt penetration in the fillets - the impregnated surface showing up as a spot which was slightly darker than the rest of the fish.

Tests of the efficiency of the Freezer.

Through the kindness of the North Atlantic Fisheries, we were permitted to install this refrigerator in their plant at Halifax, and thus were able to use calcium chloride brine at a temperature of about -6° F. as a cooling agent for circulation through the coils.

The tank was filled with saturated sodium chloride brine, which was circulated in the manner already described.

Experiment No. 1.

The pans were packed with newly filleted haddock closed and weighed.

Table I

	Col. I Tare lbs. oz.	Col. II Gross lbs. oz.	Col. III Net lbs. oz.
Pan A	8 - 14.5	17 - 11	8 - 12½
" B	8 - 14	17 - 12	8 - 14
" C	8 - 12	17 - 05	8 - 09
" D	8 - 13	17 - 00	8 - 03
" E	9 - 01	17 - 03	8 - 02
" F	8 - 15	17 - 2	8 - 03
" G	8 - 11	16 - 9	7 - 14
" H	9 - 05	17 - 12	8 - 07
	71 - 05.5	138 - 6	67 - 00½

At 11 a. m., the calcium chloride brine was at +11° F. due to heavy storage work in the plant.

At 3.30 p.m. the calcium chloride registered +3°F. It was then decided to defer the experiment until next morning. Examination of the filled pans next morning showed that some of the juices were leaking away from the pans, due to having remained unfrozen over night. The calcium chloride brine was still at a fairly high temperature at 9.50 a.m. At 1.15 p. m., the temperature started to drop and coils A. B and C were turned on full, thus using the 100 lineal feet of pipe, Unit A containing 20 feet, B. 40 feet and C. 40 feet.

TABLE II

		Calcium Chloride Brine				
Time	Temp °F. Brine entering coils	Temp. °F. Brine leaving coils.			Sodium Chloride Brine	Remarks
		Coil A 20 feet	Coil B 40 feet	Coil C 40 ft.		
1.45 p.m.	+1.5	+1.5	---	---	4.4°	
2.00	-3.5	-2.0	-1.5	---	3.0	Fish in here
2.10	-3.8	-3.0	-2.0	---	4.0	
2.15	-4.0	-3.5	-3.0	---	4.2	
2.20	-5.5	-5.0	-4.5	---	3.0	
2.30	-7.0	-6.8	-6.5	---	3.0	
2.40	-8.5	-8.0	-7.6	---	3.0	
2.50	-10.0	-9.5	-9.0	---	3.0	
3.00	-8.0	-8.	-8.0	---	2.5	
3.5	-5.5	-5.3	-5.0	---	2.5	
3.10	-4.0	-4.0	-4.0	---	2.5	

The temperature of the brine leaving Coil "C" was very difficult to take because of the position of its outlet. Since this coil contained the same number of lineal feet as coil "B" and since the temperature of the entering brine was the same, it was assumed that the temperature would be the same as the brine leaving coil "B".

At 2 p.m. at a temperature of +3° F, ice started to form in the tank, and on the coils. This was evidently due to lack of sufficient sodium chloride in solution. At 2.09 the temperature was still + 3° F, and ice was still forming. 67 lbs. of fish contained in the pans at a temperature of 45° F were now placed in the tank. This relieved the ice trouble a little, the temperature of the sodium chloride brine rising 1°. Coils A. B and C were still running full and remained so during all the experiment. At 2.40 p.m. the $Ca\ Cl_2$ brine was getting to a low temperature and the ice of about ½ inch thickness had formed on the coils. This interfered slightly with the circulation. At 2.50 p.m. the circulation was being seriously interfered with and means were taken to raise the temperature of the incoming Ca Cl2 brine from -10 to -8°. It was evident that the ice interfered with the heat transfer since $Ca\ Cl_2$ brine entering the coils at -8 left the coils at -8 and -7.6 respectively, the temperature of the Na Cl brine being constant at +2.5.

This can also be seen by referring to Graph (1), where it will be noted that although there is a steady decrease of temperature in the $Ca\ Cl_2$ brine which is flowing through the coils, there is no corresponding decrease in the temperature of the sodium chloride brine. The heat given up by the freezing fish, and the heat liberated by the formation of ice in the tank partially accounts for this. The extent to which these two factors entered into the problem could not be determined at the time, since there was no way of determining the variations in density of the brine, (this being a way of finding out the rate of ice formation) nor was it possible to determine the exact rate at which heat was being given up by the freezing fish.

At 2.55 p.m. ammonia compressors were shut down. The $Ca\ Cl_2$ brine rapidly rising in temperature until 3.10 p.m. when the machine was shut down. The fish were removed. The temperature at the middle of a block of frozen fish as shown by a mercury thermometer was +20° F.

Experiment No. 1.

W_B = Weight of Na Cl brine = 1914 lbs.

S_B = Specific Gravity " = 1.17

C_B = Specific Heat " = 0.771

(t_1-t_2) Total drop in temperature $(4.4°-2.5°)$ = 1.9°

Q_B = Heat given up by brine = $W_B S_b (t_1-t_2)$
= 1914 x 1.17 x 0.771 = 2803 B.T.U

W_F = Weight of Fish = 67.3 lbs.

C_F = Specific Heat of Fish = 0.86

t_1 = Initial temp. of Fish = 45°F.

t_2 = Final temp. of Fish = 20°F.

Q_F = Heat given up by fish cooling from
45° to 32° = $W_F C_F (t_1-32)$
= 67.3 x 0.86 x (45-32) = 752 B.T.U.

* Latent heat given up by fish =
$W_F L$ = 67.3 x 124 = 8345 B.T.U.

* Heat given up by cooling fish from
32° to 20° = $W_F (t_1-t_2) C_{FF}$ =
67.3 x 12 x 0.43 = = 348 B.T.U.

Weight of pans = 71.3 lbs.
Specific heat of iron = 0.1
Total drop in temp. = 25°
Heat given up by pans in cooling =
71.3 x 0.1 x 25 = 178 B.T.U.

Work done by Machine 12,426 B.T.U.

*Latent heat of fish calculated as 124 BTU per lb. from S.H. which was found to be .86 above 32°F.

C_{FF} *S.H. of frozen fish taken as 0.43 calculated from S.H. of fish above 32°F.

The Calcium Chloride brine was leaving the 20 foot coil at the rate of 1/8 gallon per second, and the forty foot coils at 1/10 gallon per second. The temperature of the entering and leaving brine are shown in Table II.

Since considerable heat was liberated from the sodium chloride, due to the formation of pure ice crystals, which amount of heat was not measured, no very accurate calculation of heat transfer can be made.

An approximate is reached as by the following, which does not take into consideration any heat losses through insulation, etc.

Work done - 12,426 B. T. U.
Total length of pipe 100 feet - 1" pipe.
A = Total area of outside surface - 34.45 square feet.

Δt_1 = Mean temp. of $Ca\ Cl_2$ entering pipes =

$$\frac{-10° + (-3°)}{2} = -7.5°$$

Δt_2 = Mean temp. by $Ca\ Cl_2$ leaving pipes =

$$\frac{-9.5° + (-1.5°)}{2} = -5.5°$$

Δt_3 = Mean temp. of $Ca\ Cl_2$ in pipes =

$$\frac{\Delta t1 + \Delta t2}{2} = \frac{-7.5° + (-5.5°)}{2} = -6.5°$$

Δt_4 = Mean temp. of Na Cl Brine

$$= \frac{2.5 + 4.2}{2} = +3.3°$$

Δt = Mean temp. difference between coils and Na Cl Brine.

$$= \Delta t_4 - \Delta t_3 = +3.3° - (-6.5°) = +9.8°$$

K = B.T.U. per hour per square foot per degree, difference in temperature.

$$= \frac{B.T.U. \times 60}{A \times T \times \Delta t} = \frac{12426 \times 60}{34.45 \times 70 \times 9.8} = 31.5 \text{ B.T.U.}$$

Where T. is time of run in minutes.

This value for K indicates that the machine had low efficiency during this experiment. It is not possible to say what value of K should be possible with this machine because in order to do this, the rate of flow of Na Cl brine past the coil must be determined, which could not be done.

Experiment No. 2.

The pans, 16 in number, were filled with freshly filleted cod at 2 p.m., and placed in the refrigerator at 3.42 p.m. with units A.B and C of the coils all running.

The initial temperature of the fish was 34°F, the final temperature of the fish was +17.5° F.

At the end of the experiment, the frozen fish was examined and it was found that small quantities of brine had entered the pans near the edges where the fish was not tightly packed. These places showed up as spots, slightly darker than the rest of the fish. The brine had penetrated a thin layer of the muscle which was not solidly frozen on this account.

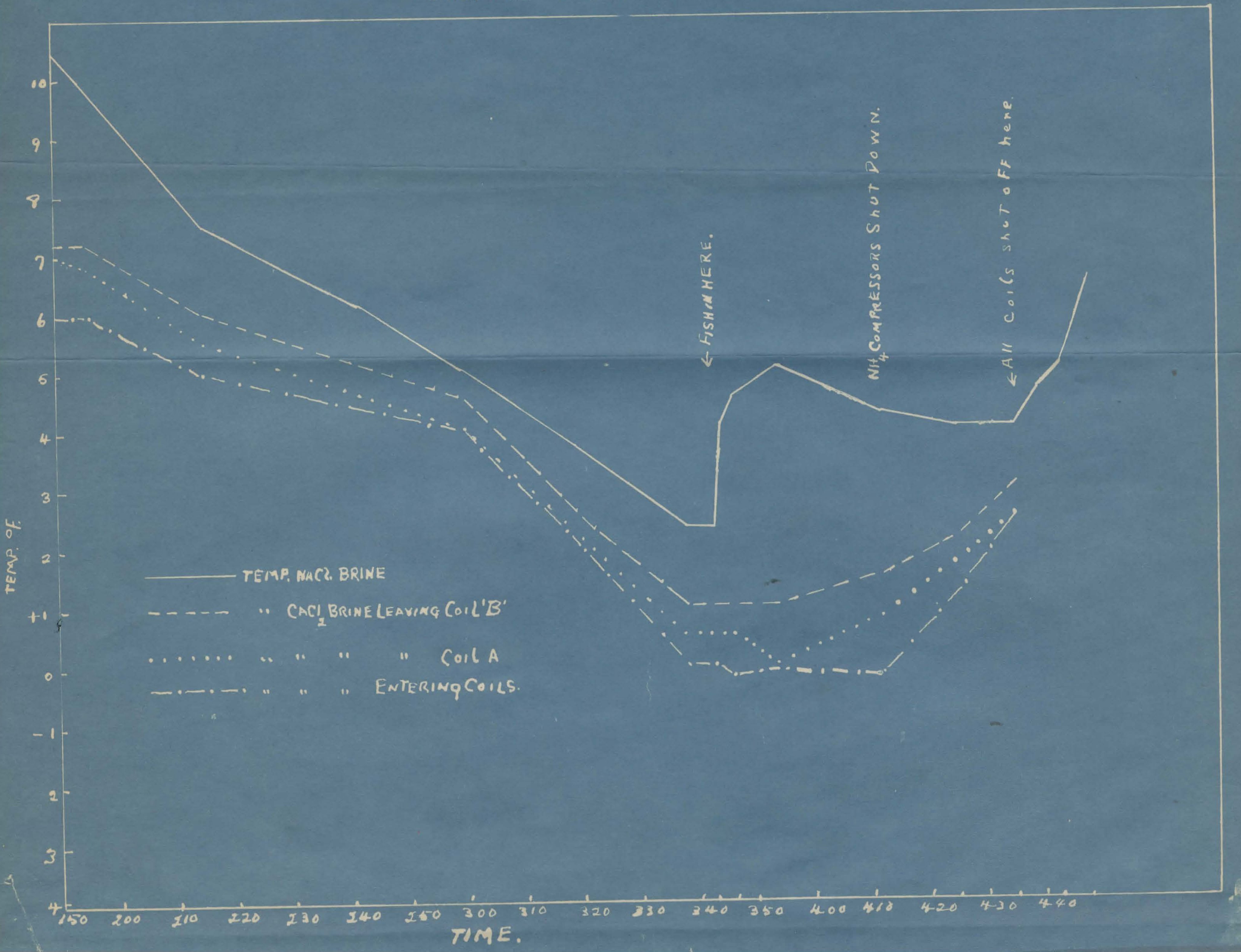
TABLE III
WEIGHT OF PANS, ETC.

Pan	Weight of Pan	Gross	Net Lbs. Oz.
A	8.10	17.14	9.04
B	9.00	17.04	8.04
C	8.15	18.00	9.01
D	9.00	17.05	8.05
E	9.02	17.02	8.00
F	9.03	17.08	8.05
G	9.05	17.03	7.14
H	9.01	17.02	8.01
I	8.14	17.09	8.11
J	9.03	17.12	8.09
K	9.01	17.00	7.15
L	9.01	17.01	8.00
M	9.00	17.03	7.13
N	9.06	17.15	8.09
O	9.03	18.04	9.01
P	9.09	18.2	8.09
			134.05
			= 134.31 lbs.cod

TABLE IV

Time P.M.	Calcium Chloride Brine: Brine entering Coils °F	Brine leaving °F: Coil A 20'	Coil B 40'	Coil C 40'	Sodium Chloride brine before going past Coils °F	Sodium Chloride Brine after going past Coils °F.	Remarks
1.50	+6	+7.0	+7.2			+10.5	Room temp +8°F
1.55	+6	+6.8	+7.2			+10.0	Coil A 1/8Gal. per sec.
2.15	+5	+5.5	+6.0			+7.5	Coil B 1/10 " "
3.00	+4	+4.0	+4.5			+5.0	
3.20	+2	+2.1	+2.5			+3.6	
3.38	0	+0.5	+1.0			+2.3	Fish in 3.42
3.43	0	+0.5	+1.0			+2.3 R	
3.44					+4.0	+4.0	
3.46	-0.2	+0.5	+1.0		+4.5	+4.5	Room temp 12.0°F
3.54	-0.1	0.	+1.0		+5.0	+5.0	
4.12	-0.2	+0.8	+1.5		+4.2	+4.2	Room temp 7.5°F
4.25	+1.2	+1.7	+2.1		+4.0	+4.0	
4.35	+2.5	+2.5	+3.0		+4.0	+4.0	
4.39						+4.6	All coils shut off at 4.35
4.43						+5.0	
4.48						+6.4	
							Fish taken out 4.50

GRAPH II EXPT. #2.



Experiment No. 2.

W_b = Weight of Na Cl Brine = 1914 lbs.

S_b = Specific Gravity " = 1.17

C_b = Specific Heat " = 0.771

$t_1 - t_2$ Total drop in temp " (2.3 - (+4.0)) = -1.7

Q_b = Quantity of heat given up by Brine =
$W_b\ C_b\ (t_1 - t_2)$ = 1914 x 0.771 x -1.7 = -2509 B.T.U.

W_f = Weight of fish = 134.31 lbs.

C_f = Specific Heat of fish above 32° = 0.86

t_1 = Initial temp. of fish = +34°

t_2 = Final temp. of middle of frozen block of fish = 17.5°

t_m Since the temperature of the outside of the block of frozen fish is the same as the temperature of the brine, or nearly so, i.e. +5°, the mean temperature of the fish will be

$$\frac{+5 + 17.5}{2} = 11.2°$$

Q_f Heat given up by fish.
$= W_f\ (\ (t_1 - 32)\ C_f + (32 - t_m)\ C_{ff} + L)$

(Where C_{ff} = S.H. Frozen fish = 0.43
L = latent heat of fish = 124)
= 134.31 ((34-32) 0.86+(32-11) 0.43 +124) = 18097 B.T.U.

Heat given up by brine = -2509 B.T.U.

15588 B.T.U.

Heat taken up by iron pans.
= Weight given x S.H. Iron x temp. drop
= 145.55 x 0.1 x.30 437

Work done by Machine = 16025 B.T.U.

In Experiment No. 2, no ice appeared in the coils or in the tank, and thus the circulation was not impeded.

It will be noted by referring to Table IV. that the temperature of the brine was taken before and after having passed by the coils. No difference could be observed with the thermometers which we have at our disposal.

An approximation of the value of K may be made in two ways. Firstly by relating the total work done as calculated, to the surface area of the coils, and relating this to the time and temperature difference. Secondly, by taking the difference in work done between coil A which is 20 feet long and coil B which is 40 feet long, and relating this to the difference in surface area between the two coils.

First Method. Calculations based on temperatures from 3.43 p.m. to 4.35 p.m.

Work done = 16,025 B.T.U.

Total length of pipe 100 feet.

A. Total area of outside surface of pipe - 34.45 square feet.

Δt_1 Mean temperature of $CaCl_2$ entering pipes = .13°

Δt_2 Mean temperature of brine leaving coils

Coil A - +.64°
Coil B - +1.33°
Mean - +.98°

Δt_3 Mean temperature of brine in coils =

$$\frac{\Delta t_1 + \Delta t_2}{2} = \frac{0.13 + 0.98}{2} = +.55°$$

Δt_4 Mean temperature of Na Cl Brine = +4.6°

Δt = Mean temperature, difference between coils and Na Cl brine.

$= \Delta t_4 - \Delta t_3 = 4.6 - 0.55 = 4.1°$

K B.T.U. per hour per square foot per degree difference in temperature.

$$= \frac{B.T.U. \times 60}{A \times T \times \Delta t} = \frac{16025 \times 60}{34.45 \times 53 \times 4.1}$$

= 128 B.T.U. per square foot per hour per degree

Where T is time of run in minutes.

With regard to the second method of determining K, it is necessary to know the effect of velocity of brine in the pipes on variations of K. Data on this point could not be obtained and since the velocities of brine in the two coils were different, it was thought inadvisable to make calculations which would be of questionable value.

Third Method. It will be noted that all coils were shut off at 4.35 p.m. but that the fish were not taken out of the tank until 4.50 p.m., and that temperature readings of the Na Cl brine were continued until 4.48 p.m.

During this time the temperature of the Na Cl brine had risen from 4.0° at which temperature it had been constant for 10 minutes, to 6.4°. Since the weight of the Na Cl brine undergoing this rise in temperature was 1914 lbs, and since its specific heat was 0.771, the amount of heat given up by the fish was

$$1914 \times 2.4 \times .771 = 3542 \text{ B.T.U. in 13 mins.}$$
$$= 2724 \text{ B.T.U. in 10 mins.}$$

Assuming that this had been the rate of heat loss by the fish for the previous 10 minutes, we can then calculate the K factor for that period.

Δt_1 = Mean temp. of $Ca\ Cl_2$ brine entering coils between 4.25 and 4.35 p.m. = 1.85°

Δt_2 = Mean temp. of brine leaving coil A = 2.06°

Δt_3 = Mean temp. " " " " B = 2.55°

Δt_4 = Mean temp. " " in the coils

$$= \frac{\Delta t_1 + \frac{\Delta t_2 + \Delta t_3}{2}}{2} = \frac{1.85 + 2.30}{2} = 2.07°$$

Δt_5 = Mean temp. of Na Cl brine during that period = 4.0°

Δt = Mean temp. difference between coils and Na Cl brine $= \Delta t_5 - \Delta t_4 = 1.93°$

Heat transfer was 2724 B.T.U. in 10 minutes.

Square feet of coil surface = 34.45

Heat transfer per square foot = 809 B.T.U.

$K = \frac{809 \times 60}{1.93 \times 10}$ = 252 B.T.U. per hour, per square foot per degree difference in temperature. This value is almost twice as great as the one which was derived by the first method, which took the whole run into account.

Experiment No. 3.

This experiment was made using 113.38 lbs of fish and with only coil C running i.e. with 40 feet of coil. Here again, the engineer of the plant was forced to shut down the ammonia compressors at 4 p.m. which resulted in a rise in temperature of the Ca Cl brine. No ice appeared in the tank which reached a temperature of -0.2° F.

WEIGHT OF PANS, ETC.

Pan	Pan Weight	Gross	Net. lbs, oz.
A	8.14	17.12	8.14
B	9.02	17.14	8.12
C	9.02	17.08	8.06
D	9.06	16.14	7.08
E	9.03	16.06	7.03
F	9.02	17.06	8.04
G	9.05	16.11	7.06
H	9.05	17.06	8.01
I	9.01	17.00	7.15
J	8.15	17.08	8.09
K	9.02	17.14	8.12
L	8.15	16.06	7.07
M	9.06	17.08	8.02
N	9.00	17.03	8.03
			113.06
			= 113.38 lbs.

TABLE V

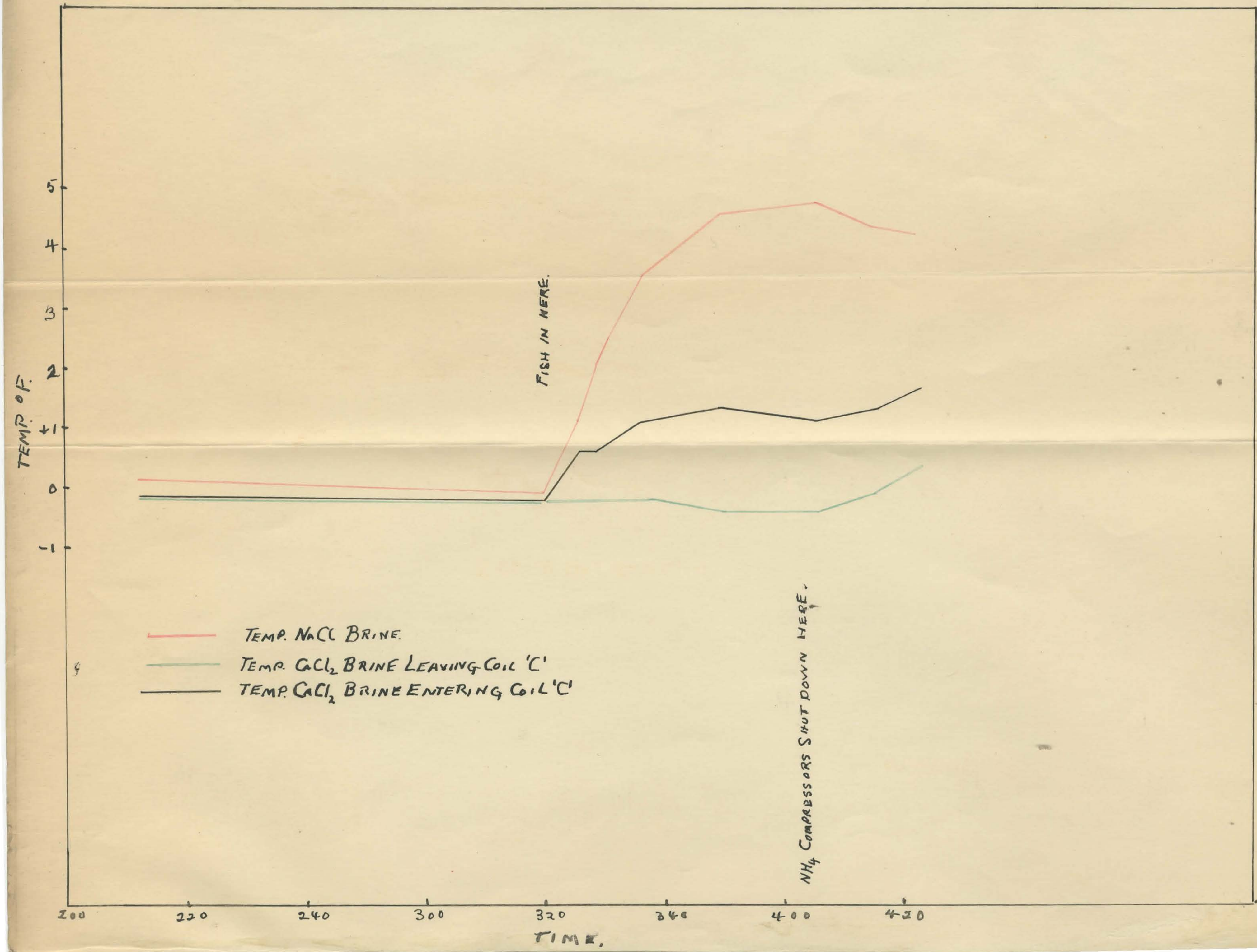
Time	Na Cl₂ Brine		Na Cl Brine.		
	Brine entering °F	Brine leaving °F	Before passing over coils °F	After passing over coils °F	Remarks
2.12	-0.2	-0.2	+0.1	+0.1	Initial temp. of fish
3.20	-0.3	-0.3	-0.2	-0.2	= 33°
3.25	-0.3	+0.5	+1.	+1.0	Fish in at 3.20 p.m
3.28	-0.3	+0.5	+2.0	+2.0	Coil"C" 1 Gal 6"
3.30			+2.5	+2.5	
3.36	-0.3	+1.0	+3.5	+3.5	Room temp. + 5
3.49	-0.5	+1.2	+4.5	+4.5	NH_4 shut off at 4 p.m.
4.5	-0.5	+1.0	+4.7	+4.7	
4.15	-0.2	+1.2	+4.3	+4.3	
4.22	+0.2	+1.5	+4.2	+4.2	

Experiment No. 3.

W_b Weight of Na Cl Brine = 1914 lbs.
C_b Specific Heat of Na Cl Brine = 0.771
t_1-t_2 Drop in temp. of Brine
= (-0.2 - (+4.2)) = - 4.4°
Q_b Quantity of heat given up by Brine
= $W_b\ C_b\ (t_1-t_2)$
= 1914 x 0.771 x-4.4° = 6493 B.T.U.
W_f = Weight of fish = 113.38 lbs.
C_f = Specific heat of fish = 0.86
t_1 = Initial temp. of fish = 33°
t_2 = Final temp. of fish middle of block = 21.2
t_m = Final mean temp. of fish
$= \frac{21.2 + 4.2}{2} =$ 12.7° F
Qf = Quantity of heat given up by fish
$= W_f\ (\ (t_1-32)\ C_f + (32-t_m)\ C_{ff} + L)$

Where C_{ff} is specific heat of frozen fish = 0.43
L = Latent heat of fish = 124.
= 113.38 ((33-32) 0.86 + (32-12.7°) 0.43 124) = 14994 B.T.U.
Work done by Machine 14,994 - 6493 = 8501 B.T.U.

GRAPH III. EXPT. III.



The following approximation of the value of K is based upon the temperatures of the tank and coil from 3.20 p.m. to 4.20 p.m.

Work done = 8501 B.T.U.
Total length of pipe = 40 feet.
A = Total area " " 13.8 square feet.

Δt_1 = Mean temp. of $Ca\,Cl_2$ brine entering coil = -0.33

Δt_2 = Mean " " " " leaving " = +0.87

Δt_3 = Mean " " " " in coil =

$$= \frac{t_1 + t_2}{2} = +0.27$$

Δt_4 = Average temp. of $Na\,Cl$ brine = +3.6

Δt = Mean temp. difference between brine and coils = $\Delta t_4 - \Delta t_3$ = 3.6 - 0.27 = 3.33

K = B.T.U. per hour per square foot per degree difference in temperature.

$$= \frac{B.T.U. \times 60}{A \times T \times \Delta t} \quad \frac{8501 \times 60}{13.8 \times 60 \times 3.33} = 185 \text{ B.T.U.}$$

It is difficult to summarize these results. Time at my disposal permitted only three somewhat inadequate tests, which were carried out under rather adverse circumstances. Further, with the machine as it was at the time of the tests, it was impossible to estimate the amount of flow of brine past the coils, a knowledge of this being absolutely necessary if it is desired to relate the conductivity factor K to unit of flow inside and outside of the coils, and it is necessary to know this relation if any predictions as to performance of other machines based on this design are to be made.

In my opinion, Experiment No. III, is the most reliable, since there was least variation in temperature in the entering $Ca\,Cl_2$ brine, and since only one unit of coil was used, thus simplifying the calculations. If my calculations are correct, this experiment showed a value of 185 B.T.U. for K.

Suppose that mean temperature difference of 5° were maintained between the brine and the coils during operation, this would mean that $\frac{12,000}{K5} \times 2.9 =$ 38 lineal feet of pipe per refrigeration ton (= 288,000 B.T.U. per 24 hours) would be required.

If now it is desired to freeze at the rate of one refrigeration ton per hour, we should require 38 x 24 = 612 lineal feet of pipe. To this 20% should be added for a working margin. This brings it up to 734 feet.

It will be seen by referring to Graph III. that in the first 30 minutes after the fish were placed in the tank, the temperature of the Na Cl brine had risen 4.7° F, and since there were 1914 lbs of brine, the fish must have given up 8995 B.T.U. But the total heat given up by the fish (see Page 26) was 14994 B.T.U., so that the fish gave up approximately 60% of their heat in the first ½ of the run, leaving the remaining 40 % for the second half, the difference being 20%. This 40% may be considered to be the normal load. We must then provide for this extra load of 20% in the first half of the run if we are to maintain the brine temperature as nearly constant as is possible i.e. within 1°. We can do this by allowing a sufficient volume of brine. If we wish to freeze at the rate of 1 refrigeration ton per hour, the calculation is as follows:

$$\frac{20}{100} \times 288,000 = 57600 \text{ B.T.U.}$$

The weight of brine where specific heat is 0.771 which could take this up by a temperature rise of 1° would be

$$\frac{57600}{0.771} = 74708 \text{ lbs.}$$

at 12 lbs per gal = 6225 gals. or 1000 cubic feet per refrigeration ton of work per hour. Thus for ½ refrigeration ton per hour, the allowance for a rise of 1° would be 500 cubic feet and so on.

If further work is done in this connection, I would suggest:- That the tank be equipped with a definite return duct for the Na Cl brine, as it returns to the coils, such as a false floor. By doing this, a knowledge of the rate of flow could be obtained as well as assuring a positive circulation.

That the inlet valves of the coils be adjusted so as to produce exactly the same rate of flow in each of the units. This would simplify calculations.

That as far as possible, the temperature of the incoming $Ca\ Cl_2$ brine be kept constant, which would also simplify calculations.

With regard to my calculations of the mean temperature of $Ca\ Cl_2$ brine entering and leaving the pipes, this cannot be arrived at by simply adding all the temperatures together and dividing by the total number of readings, or by taking the arithmetical mean of the highest and lowest reading because the brine is flowing, and all we can record is the temperature of a small portion of the flow. It can be seen that time of flow enters into the problem.

On searching the literature which I have available, I was unable to find any calculations or equations which deal with this particular type of problem, consequently I developed one which works in cases where there are two or more definite periods at which the temperature is fairly constant.

$$\Delta t = \frac{\theta_2}{\theta_1 + \theta_2} (T_2 - T_1) + T_1$$

Where Δt = Mean temperature
θ_1 = Time of first period of flow
θ_2 = Time of second period of flow
T = Average temperature of first period of flow
T_2 = Average temperature of second period of flow

An illustration of this :-

Suppose the rate of flow was 1 lb of liquid per minute. The first period is, say, 20 minutes with the brine at 10°. The second period is 30 minutes with the brine at 5°

then:

$$\Delta t = \frac{30}{50} (5-10) + 10$$

$$= \frac{30}{50} (-5) + 10 = +7°$$

This can be proven in this manner.

Suppose the liquid had a specific heat of S, and that the brine was flowing into a tank - Then for the first period, it would deliver 20 lbs at 10° into the tank

$$= 20 \times 10 \times S.\ B.T.U. = 200S\ B.T.U.$$

For the second period it would have delivered 30 lbs at 5°

$$= 30 \times 5 \times S.\ B.T.U. = 150S\ B.T.U.$$

The total heat content of the liquid in the tank would be

$$150S + 200S = S(150 + 200)$$

and the temperature would be

$$S \frac{(150 + 200)}{Weight \times S} = \frac{150 + 200}{50} = 7°$$

If now we had taken the arithmetical mean of this we should have obtained

$$\frac{10 + 5}{2} = 7.5°$$

Another example:

First period = 30 minutes at 1°
Second " = 10 minutes at 20°

$$\Delta t = \frac{10}{40} (20-1) + 1 = 5.75°$$

The arithmetical mean = $\frac{1° + 20}{2}$ = 10.5°

The equation is rather cumbersome and could no doubt be put very nicely into calculus so as to make it a little more general in its application.