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Notes on an Extract from a Refrigerator Log Book.

By Mr. W. SINCLAIR (Member).

Read on Monday, October 16, 1911.

Chairman: Mr. JOHN LANG, R.N.R. (Mem. of Council).

Chairman: We have before us to-night a paper on "Notes on an Extract from a Refrigerator Log Book" from one of our members in Sydney, Mr. W. Sinclair. In his absence, I will ask our Hon. Secretary to read the paper on his behalf.

The following is a portion of the log of a marine refrigerating plant, consisting of an ammonia compound Linde compressor and a brine refrigerator working on about 9,300 cubic feet of hold space, the size of compressors being $\frac{6'' \ \& \ 10''}{10''}$

In order to lead up to the remarks in this short paper and to help in understanding the working of ammonia with brine refrigerating machinery, a few points will be briefly touched on.

The refrigerating medium, ammonia gas, in a saturated condition (that is saturated in the same manner as steam is understood to be) has constant properties, so that given the

Date.	Time.	Temp. Sea Water.	Condens. Press.	Refrig. Press.	Temp. Brine.	No. 1 Hold.	No. 2 Hold.	Revs.	Remarks.
Aug. 15	2 p.m.	62° Constantly.	150 Constantly.	58	60	60	60	120 Constantly.	Started machine 2 p.m.
	4 ,,			42	40	54	52		
	5 ,,			38	34	42	40		
	7 ,,			33	27	34	32		
	10 ,,			26	25	—	—		
	12 ,,			26	22	—	—		
16	2 a.m.			22	20	—	—		
	6 ,,			12	20	24	23		
	9 ,,			8	20	—	—		
	12 ,,			4	20	—	—		Stopped machine, overhauled valves, put in calcium chloride in refrigerator.
	3 p.m.			36	30	26	26		
	6 ,,			22	17	22	23		
	7 ,,			20	15	—	—		
	8 ,,			16	11	20	20		
	10 ,,			14	7	16	18		
	11 ,,			13	6	13	14		
17	1 a.m.			—	—	10	11		
	4 ,,			10	4	9	10		Started loading meat 8 a.m.
	8 ,,			10	4	8	8		

pressure the temperature is obtainable along with its latent heat of vaporization, relative volume, etc. When ammonia liquid vaporizes, the latent heat necessary for the production of the vapour must come from an outside source or the liquid will freeze itself and evaporation will cease, so that if the evaporating ammonia is surrounded by an uncongealable liquid, heat will be abstracted from this liquid, and if this evaporated gas is compressed and simultaneously cooled the gas will be condensed into liquid form and be again ready for evaporating. A refrigerating plant on the brine system, then, consists simply of an evaporator, a condenser, and a pump for drawing the evaporated gas from the evaporator and compressing it into the condenser ; the uncongealable liquid (brine) surrounding the evaporator pipes is pumped through pipes in the chambers, picks up heat and returns to the evaporator.

There are, as will be seen, three principal transfers of heat : (1) from the hold to the brine, (2) from the brine to the ammonia, and (3) from the ammonia to the condensing water, and unless there is between these various steps a difference of temperature level, heat will not flow from the one to the other ; for instance, if the hold temperature were 40° and the brine in the pipes in the hold also 40°, no flow of heat could take place from the hold to the brine ; the brine would require to be nearer 30° to do useful work.

Keeping these notes in view the log can now be examined. It is an ordinary everyday log, and we usually glance only at the final results, that is the hold temperatures, for to speak practically the other columns as they are here written are meaningless. Temperature of brine and temperature of gas in refrigerator coils should bear a known relation the one to the other, but here is temperature of brine and *pressure* of refrigerator standing side by side, and we cannot compare them. Temperature of hold and temperature of brine, however, can be compared, and, looking at these two, it would appear that the temperatures came down smartly, hung for some hours at 20° and after an upward movement fell steadily ; more than that we cannot state with any degree of certainty.

But suppose we turn up a table of properties of saturated ammonia and mark down against each refrigerator pressure its corresponding temperature, we then get with the average hold readings three columns of temperature, thus :—

Ammonia Temperature.	Brine Temperature.	Average Hold Temperature.
40	60	60
28	40	53
25	34	41
20	27	33
13	25	—
13	22	—
8	20	—
−5	20	23·5
−12	20	—
−19	20	—
23	30	26
8	17	22·5
6	15	—
1	11	20
−2	7	17
−4	6	13·5
—	—	10·5
−8	4	9·5
−8	4	8

This at once opens up a new view of the log, and in order to make the matter plain the various times and temperatures are shown in the form of a diagram.

On referring to these figures and the diagram it will be noticed that there is on an average 7° difference between the hold temperature and the brine temperature. Between the brine and the ammonia, however, the difference varies more widely. Nor must the log be brought under severe censure for this. As stated earlier in the paper, pressure and temperature are in constant relation and can be governed by the person running the refrigerating plant. One valve does it all, known as the regulating valve. It is the only valve that can be varied in a refrigerating plant during the working cycle, and it is the key to the whole system. Now if this valve be opened so that the evaporating *temperature* in the refrigerator coils is 12° to 15° lower than the temperature of the brine, then the machine is doing its best work, and as the temperature in the brine tank falls, so the engineer running the plant must handle the regulating valve to give the necessary result of difference in temperature level.

In the running of an ammonia compressor of this type there is a practical rule that most engineers work to, viz., that if the delivery pipe to the condenser is just warm enough to prevent the hand remaining on it, then (assuming all mechanical details are right) the plant is working as it should. The explanation of this rule is this: Suppose the regulating valve to be open far enough to pass more liquid ammonia into the evaporator than is actually needed to refrigerate the brine, then the ammonia gas is drawn into the compressor still possessing some of its property of absorbing heat, and during the compression process the curve will approximate to the isothermal line by reason of the heat of compression being taken up by this gas. All saturated gas machines are designed so as to take some advantage of this, and it has been found that when the gas comes back to the compressor at such a temperature, on being discharged at condenser pressure its heat is as stated above, then that plant is being worked as it was designed to be. If the delivery pipe is too cold the regulator is to be shut in, on the other hand if too hot it is to be opened out.

This plant was being handled along these lines, and on referring to the figures it will be noted that at 6 a.m. on the 16th

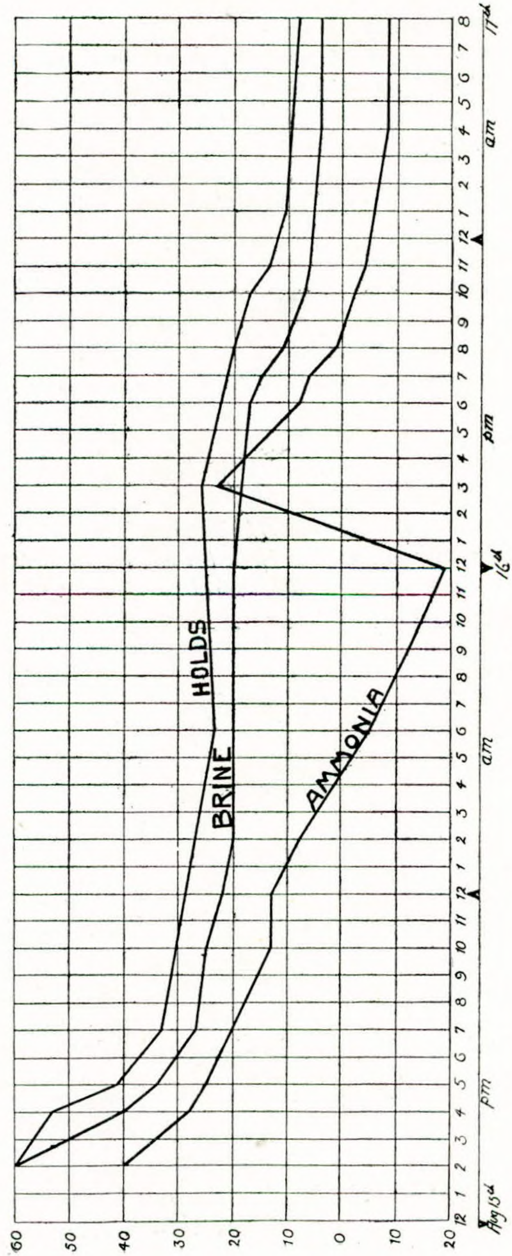
HOLDS
BRINE
AMMONIA
60
50
40
30
20
10
0
10
20
Aug 15th
16th
17th
am
pm

Fig. 1.

the brine temperature stood at 20° and the ammonia at 8°, six hours later the brine still stood at 20° but the ammonia had fallen to —19°, and still on the " hand feel " test the plant was working well and the regulating valve was being gradually closed down. Obviously then the ammonia gas was being drawn into the compressor without evaporating to the degree it should have done, for the brine was not availing itself of the ability of the ammonia gas to absorb heat during its evaporation, the brine could not therefore be coming in contact with the pipes in the evaporator where the ammonia was expanding, and as the evaporator was full of brine the inference was that the brine was freezing on the evaporator pipes, and so covering them with ice which would act as an insulator.

The brine was about 1,200 specific gravity and the freezing point of this brine is -12°, which as it was not intended to come any lower than about 3° would seem to be ample margin, but with slow circulation in the refrigerator and having in mind the necessary low ammonia temperatures to reach 3° brine temperature, 1,200 brine was not dense enough.

A start was accordingly made increasing the brine density. This caused the rapid rise in temperatures shown, which is most apparent in the ammonia figures. Then the increasing efficient working of the machine becomes apparent, as it will be noted that all three lines commence to fall in proper ratio until the working limit of the plant of 9,300 cub. ft. capacity is reached, shown by the gradual flattening out of the curves.

To explain this latter point about the working limit more fully, take the machinery as running at 3 p.m. on the 16th—

Ammonia gas suction temperature	23°
,, ,, ,, pressure.	36 lb.
Brine temperature	30°
Sea temperature	62°

Tables of saturated ammonia give us at this gauge reading—

Heat of vaporization . . .	541·28 B.T.U. per lb.
Volume of vapour in lbs. per cub. ft.	5·488 cub. ft. per lb.

As the liquid ammonia leaving the condenser will be about the temperature of the sea water, viz., 62°, and the brine is at 30°, 32° is taken cooling the liquid ammonia itself before any outside work is done.

541·28
32·00

509·28 = net refrigerating value of the liquid.

The low pressure compressor or gathering cylinder is 10 in. diameter × 10 in. stroke single acting at 120 r.p.m.

Volume swept by piston per hour in cub. ft. =

$$\frac{78\cdot54 \times 10 \times 120 \times 60}{1728}$$

and the B.T.U. per hour

$$\frac{78\cdot54 \times 10 \times 120 \times 60}{1728} \times \frac{509\cdot28}{5\cdot488}$$

As refrigerating machinery is rated in tons ice melted per 24 hours and a ton ice melted = 142 × 2240 = 318080 B.T.U., the machine would be theoretically rated as follows :—

$$\frac{78\cdot54 \times 10 \times 120 \times 60}{1728} \times \frac{509\cdot28}{5\cdot488} \quad \frac{24}{318080} = 23 \text{ tons.}$$

But take the final reading at 8 a.m. on 17th :—

The gauge reading is 10 lbs. suction gauge.

Brine temperature, 4°.

The heat of vaporization of the ammonia is 560·39 and volume 10·860, sea water at 62° = 62° − 4° = 58°.

560·39
58

502·39 net B.T.U. per lb.

Machine refrigerating capacity—

$$\frac{78\cdot54 \times 10 \times 120 \times 60}{1728} \times \frac{502\cdot39}{10\cdot860} \times \frac{24}{318080} = 11\cdot6 \text{ tons.}$$

At this point the B.T.U. extracted by the machine about equals the B.T.U. leaking through hold insulation, and to further reduce the suction temperature would mean that not sufficient weight of ammonia gas was being circulated in the evaporator coils, the working limit of the machinery on this capacity is therefore reached.

From the above notes it will be apparent that a log for a refrigerator should be carefully taken and as carefully analysed, and in many instances the source of any inefficiency in a machine can be discovered at a glance by setting out in a diagram form the different temperatures.

It must not, however, be expected that the curves should show absolutely symmetrical lines, and to find this on a plant unless it was an exceptionally well regulated plant would give rise to suspicion, for very few, if any, of even well run plants will make a first class showing on this method.

Were the machine to be one working on the direct expansion method, the intermediate step of heat transfer from the room to the brine would be omitted, and the heat picked up direct by the expanding ammonia, but in this latter case there would require to be at least the same difference in temperature in one stage as there was in the brine plant in two stages. Air is not so good a conductor of heat as brine, and unless there is this great difference in temperature level the heat will not flow.

CHAIRMAN : This paper deals with a subject of interest to a great number of engineers, and if there are any present who have had experience with the Linde machines, we shall be pleased if they will give us their views upon it.

Mr. WM. McLAREN : I cannot say that I have had much experience with the ammonia system ; I have been working more with the brine system and CO_2, and have two or three small machines working under my care just now. There seems to me to be something wanting in this log. He has given us a total of about forty-two hours' working to get the holds at the proper temperature. It seems to me rather a hard pull that after running for twelve hours it is only cooled down about a degree an hour. He then stops the machine, overhauls the valves and puts calcium chloride in the refrigerator. Perhaps there has been a greater defect in those valves, but I must say I cannot just follow up the log there. Then there is the question of the hydrometer, I am not quite clear about that. He gives the density as 1,200. It is a Twaddle hydrometer I am used to and we work at about 42. I notice it is a compound compressing plant, with cylinders $6'' \times 10''$ and $10''$ stroke, 150 on the condenser. The pressure seems to me to be rather high. I think, on an average, with water of about the temperature given we ran somewhere between 100 and 120. In the plant I am referring to we run to about 30 to 35 on the suction side. With regard to the putting in of the calcium, that, I should say, would be put in the tank for the test run before the machine was started for its full work.

Mr. JAS. ADAMSON (Hon. Secretary): The view you take is doubtless correct, so that instead of "put in," it would be more correct to have noted in the log book "added calcium chloride" to meet the full requirements of the case. However, there are other questions which arise in connexion with the machine and its work which, had the author been present, we might have had an explanation of. A description of the chambers, for instance, as well as the cubic capacity, would be of interest, also the passage-way between Nos. 1 and 2. The Twaddle hydrometer measure of 42 is about the specific gravity given.

Mr. WM. McLAREN: Yes. He refers to the fact that there was no perceptible difference in the brine temperature. On page 308 he says: "The brine could not therefore be coming in contact with the pipes in the evaporator." I think he is correct there in inferring that the brine was freezing; that instead of it being a non-freezing liquid, at that period there was nothing to prevent it forming ice if its density was not low enough. This is noted as between 2 a.m. on the 16th and 1 a.m. on the 17th. I should say about 3 p.m. on the 16th. I should have liked to ask the author what was the brine-pipe capacity in cooling free air, seeing that it took forty-one hours to bring the chambers down; what amount of brine capacity, that is, surface, he could cool with free air, and if this could be taken as a comparison. In chocolate cooling on this principle, it is not a low temperature; it is a temperature which should run somewhere about 40°. It was hard to get some basis to work on, say to cool 6,000 cubic ft. per minute to about 32°; that was to make allowance for the difference so that it should not exceed 40°. This was caused by the fact that you could not get back more than about two-thirds of the air owing to a certain amount escaping, principally by absorption into the material. In treating of a subject like refrigeration I have great sympathy with the author and think his paper is to be commended. It is short and crisp and I have pleasure in congratulating him. I notice he gives the hold space as 9,300 cubic ft., and states that his machine is capable of making 23 tons of ice per twenty-four hours. The machine doing the work I mentioned is equivalent to 4 tons for twenty-four hours and is a CO_2 machine. I have two plants of this kind doing this free air work.

CHAIRMAN: Is that CO_2 machine a compound ?

Mr. McLAREN: No, but it is double acting, and the ammonia machines I spoke of are double-acting also.

Mr. E. W. ROSS: I do not think I have much to say on this subject as I am not a practical refrigerating engineer. This paper is the record of a machine which, apparently, was not working satisfactorily, and it is a pity the author is not here to explain the difficulties. He has apparently taken nearly two days to bring down the temperature; on refrigerator practice generally, it is not usual to take so long as that, and the author might have explained why this was the case. This paper has not followed the lines I thought it would have taken. The author has confined his observations to the temperatures in the engine-room, and I understand there are many other temperatures recorded in an engineer's log, the temperatures of the hold, the temperatures for chilled meat, frozen meat, fruit, cheese and such like, and we would have been very pleased to have some information as to those temperatures.

CHAIRMAN: One thing which occurred to me in connexion with the paper is the very small hold space—9,300 cubic ft. That is a very small space which would have a capacity, roughly speaking, of about 200 tons, and in these days the temperature should have gone down much quicker than it did. The sea water has been at a good temperature, not too high—a difficulty encountered in the tropics—but the condenser seems to be abnormally high, that is 150. What is your experience, Mr. McLaren ?

Mr. McLAREN: About 100 to 130. I had one working very well to-day at 95.

CHAIRMAN: What was the temperature of the water ?

Mr. McLAREN: About 58°, I think.

Mr. ADAMSON : It will be much lower than that just now, is it not ?

Mr. McLAREN : I do not think so ; we can get it sometimes in the summer at about 45°. It is a long run ; this water is pumped up to the roof and falls back over louvres. In connexion with the ammonia system of refrigeration, I might mention there was a bad accident at a firm of provision merchants' stores in Smithfield a short time ago. They had a fire in the basement, where there was an ammonia plant, and whether or not it was due to the excessive heat that created a pressure sufficient to burst the pipe system I cannot say, but there were eight or ten men suffocated to such a degree that they had to be dragged out. There is a tendency towards prejudice against ammonia machines. I do not know how they get on so well on board ship. I remember once when on a vessel in the docks seeing men in helmets working ; they were simply repairing a leaky joint on an ammonia plant. I think it is rather an unsafe medium to adopt. We use the ammonia plant for the meat principally, and it was a conversion of one of them that we used for one of the coolers I spoke about. For our stores we have the CO_2 machines.

CHAIRMAN : What would those pipes be tested to ?

Mr. McLAREN : About 3,000 lb.

Mr. ADAMSON : The coils are usually tested to 3,000 lb. The great heat when the fire took place at Smithfield would cause a high pressure, probably burst the pipes or the joints. The fumes are overpowering, and the experience of being near an escape from even a bad joint one does not wish to repeat.

CHAIRMAN : Is the author quite right in making this observation : " Keeping these notes in view the log can now be examined. It is an ordinary everyday log, and we usually glance only at the final results, that is the hold temperatures, for, to speak practically, the other columns as they are here written are meaningless " ? I should think the other columns are very important also. If the holds are not going down, one looks at the other temperatures to be guided by them.

Mr. McLAREN : I should think that every item logged could be used for comparison with the others.

CHAIRMAN : They would come down in ratio.

Mr. McLAREN : Certainly, the final result would be the hold temperature. I have a monthly log, and each month, of course, stands by itself. Everything is taken down, even to the power that is going through the motor. They are run by motors ; each machine has a separate motor.

CHAIRMAN : What are the revolutions ?

Mr. McLAREN : The ammonia at about 120 ; two sets of CO_2 at 130, and two large sets at 94.

CHAIRMAN : What was the highest temperature of the water this summer ?

Mr. McLAREN : About 74° or 75°. That was water put on the roof in tanks.

CHAIRMAN : Are there any questions members would like the author to answer ? It is a paper which does not lend itself readily to discussion, and it is evident that there are not many here this evening familiar with the ammonia system.

Mr. A. ROBERTSON : There is only one point I would like to refer to. I am rather surprised that the author, if he was in charge of the plant, should not have discovered that the brine was of too light a specific gravity before having run half the time given. He then seems to have suddenly discovered it and increased the density. Then he might have told us what was the density he increased it to.

CHAIRMAN : He states : "The brine was about 1,200 specific gravity and the freezing-point of this brine is –12, which, as it was not intended to come any lower than 3°, would seem to be ample margin."

Mr. ROBERTSON : I think, also, the author might have taken a longer period. The short period he has taken cannot give us any indication of the efficiency of the machines, because during this short period one cannot tell by any means what amount of leakage of ammonia there is in the system, and that is an important factor in the running of any refrigerating system, whether by ammonia or carbonic-acid gas, the amount of leakage. Some ships will run a long voyage and use probably only five or six or perhaps a dozen bottles of CO_2, while others will use forty or fifty, and it is impossible to test the efficiency of the plant in that respect on such a short run as is given.

Mr. McLaren: I see it is given in this notebook that with 3 lb. of calcium to each gallon the figure should run safely down to -9. That would give you 42. The weight per gallon therefore would be about $13\frac{1}{2}$.

Mr. Adamson: That is pretty near what the author says. He gives 1,200 for $-12°$ and you quote it at 1,350 for $-9°$. That is only a difference of $3°$.

The meeting then closed with a vote of thanks to the Author and the Chairman.

MR. W. SINCLAIR'S REPLY.

I have to thank the various gentlemen for their criticism on the paper, and I think that I might reply to many of the points raised by a short statement as to how I came to write the notes. I find that as a rule papers on refrigerating machinery give full and accurate descriptions of the details of plants, but the actual running difficulties are seldom touched on, and it seemed to me that if I took as a text a job which had shown a difficulty and explained how that difficulty came about and how finally it was remedied, it might be of use to our Institute. The fact, pointed out by Mr. McLaren, that after running twelve hours the temperature came down only one degree an hour, was the difficulty.

With regard to brine density. Hydrometers are differently marked—some start with water at 1,000, and as I gave the density at 1,200, this meant 1·2 times heavier than water.

I do not think the Condenser Pressure is more than 5 lb. high for that temperature of cooling water, and in starting to cool down a vessel's holds, the plant being newly started may have contained a small quantity of air, which would account for this.

The cooling of free air by means of brine pipes is a complicated problem, and only practical data are of much use; for instance, were it only the air that was tested the calculation would simply be the weight of the air multiplied by its specific heat; but air contains moisture in varying percentages, and air has a specific heat of ·238 and water is unity. Then again the moisture from the air deposits on the cold pipe surface and reduces its efficiency. I am not quite clear, however, as to the proposition, if fresh free air is drawn into the cooler at the rate of 6,000 cubic ft. per minute to be cooled down from say 60° to 32°, I hardly think a 4-ton machine would do the work, by that I mean a machine = to 4 × 318,080 B.T.U. per twenty-four hours. Mr. McLaren is in error about the tonnage of the machine I instanced. I calculated out a theoretical capacity of 23 tons ice melted, not ice made, practically the machine is known, I believe, as a 10-ton machine, But if I assume that the CO_2 machine is equal to 4 tons ice made, which would be equal to 8 tons ice melted, and that the same air is used over and over again, being returned from the chocolate cooling room to the machine, then the two machines approximate in capacity, that is—

8 tons does about 6,000 cubic feet.
10 tons does about 9,000 cubic feet.

Replying to Mr. Robertson. The final density was 1,300.

Mr. F. J. Kean, B.Sc., writes as follows :—

I have been much interested by this paper, which bears evidence of distinct originality. The remarks made by the author regarding the cycle of operations during refrigeration have led me to refer to the method I have adopted here, at Leeds University, for making refrigerator tests. We have a small Linde ammonia plant with compressor, condenser, evaporator, brine tank and ice moulds. The greatest difficulty we experience is in arranging a test of a sufficiently short duration to comply with the regulation Student day of six hours ; and in the second place we always experience doubt of the accuracy of our heat balance on account of the impossibility of indicating the ammonia compressor and of obtaining a proper figure for the radiation loss into the brine tank from the air in the cold chamber. We have figures for the radiation loss, but the precise conditions under which they were made are not known, and to redetermine them would mean an all-night test and probably continuous observations for about forty-eight hours—a thing difficult to arrange at an Institution of this kind, although easily enough managed at sea in the ordinary course of the watches. Seeing that we do not run our compressor unless we are making a test, the plan I generally follow is this. Professor Goodman advises the running of the compressor on the previous day to lower the brine to something like the freezing-point temperature (32° F.) and this I always do in practice. During the night I find of course the brine rises again to about 40° F. or higher—depending on the weather. Then in the morning I get the Students to weigh the water into the moulds, and have everything ready for starting, including the circulating water supply turned on. When all is ready the signal is given to start the compressor (which is belt-driven) and observations commence from that moment. I take it that the brine tank is then in quite a "stable" condition as regards radiation and circulation at the start of the trial and that the final readings should not be taken until it is again in an equally stable condition. The brine agitator is started only at the commencement of the trial and is stopped again when the compressor is stopped. The compressor is run for about six hours continuously and then stopped, when it is ascertained by examination that the ice will all freeze up by the next morning. During the night an interchange of heat takes place between the brine, ammonia in the evaporator coils, and the ice in the moulds, with the result that (assuming things have been well arranged) the ice is all frozen solid to at least 32° F. and very often a good deal below that figure, and whatever the temperature of the ice, the ammonia and brine have the same temperature, showing the whole tank to be in a stable condition again. Then in working out the heat exchange our difficulty of radiation correction arises. Radiation has been going on into the brine tank not only during the day of the test, but also all night as well, thus affecting the heat exchange the whole time. We then endeavour to use our radiation correction to the best of our ability. I cannot say that I am ever pleased with the result, but I have explained the difficulties, and I hope to make another radiation test this year. I have determined the radiation loss into or out of the condenser, and this we know very accurately now. The author's remarks have caused me to think that I might get more satisfactory figures both from a theoretical point of view as well as from the practical consideration of the apparatus if I confined my observations to the actual running period of the test, I should not then have to concern myself at all by the "stable" or "unstable" condition of things existing in the brine tank. What I propose to do is to run the compressor until the brine is well below 32° F. and then on the day of the test to take the brine standing, say at 28° F., get the compressor going again thus lowering the brine still further, and when ready, to put the water into the moulds; then not to stop the compressor until the water has frozen solid in the moulds, so taking continuous readings throughout the period during which the water is being frozen, but no readings either before or after. This will very probably mean a much longer run than six hours, and entail special arrangements regarding the Students, but I have no doubt that with advice and suggestions from the Professor, I shall be able to get some more satisfactory figures. I am personally much indebted to the author for his paper which has suggested a means of getting out of some of the difficulties, and I think his temperature curves are most instructive. I have always made it a rule to plot the brine temperatures, but I must confess that I have not actually plotted the other temperatures to examine the correlation between them. I have always relied on watching the gauges and adjusting the regulating valve to suit the prescribed conditions. The author is mistaken in taking the specific heat of the brine as unity; it depends on the density, and would be about 0·75 (according to figures in the University Record Book) for this density.