REFRIGERATION AND ICE-MAKING MACHINERY

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Object

In taking up this subject of Refrigeration and Ice Machines the writer had in mind these objects:—

a. A Review of the Processes of Refrigeration
b. A Comparison of the Different Processes
c. A Study of the Practical Economical Workings of a Modern Ice-Plant.
d. An Estimate of the First Cost of a Modern Ice Plant.
e. A collection of References to Literature and of Important Data Relating to Refrigeration.

Introductory Remarks.

Before attempting to examine into the subject of Refrigeration, it is proper to review for a moment the fundamental principles of heat. When a body is heated, these three things happen:— (1) The temperature rises. (2) The body expands so that the molecular attraction is overcome through a certain distance
i.e. "Disregation work" is performed. (3) The outer pressure is overcome through a certain distance—i.e. "Outer work" is performed. A part of the heat added goes to each of these three operations—heat and work being equivalent—and the quantity of heat going to each operation is dependent on the physical conditions and properties of the body. Heat always 'flows' from a hot to a cold body.

It takes one heat unit (British Thermal Unit) or B.T.U. to raise a pound of water one degree F in temperature. The number of B.T.U. necessary to raise a pound of any other substance one degree is the Specific Heat of that substance. The number of B.T.U. necessary to change a pound of a solid into a liquid of the same temperature is the Latent Heat of Fusion and the number necessary to change a pound of a liquid into vapor of the same temperature is the Latent Heat of Vaporization. Absolute temperatures (T) are 460° more than the thermometers (F).

Table I gives some of the important data concerning specific heat.
temperature, density, pressure, and latent heat of vaporization of various well-known refrigerating agents. Table II gives the pressures of vapors for different temperatures. Plate I gives the data of plate II in graphical form.

Review of the Processes of Refrigeration.

There are three general methods or processes of reducing temperature as follows:

1. By the dissolution of a salt in a liquid.
2. By the vaporization of a volatile liquid.
3. By the expansion of air or other permanent gas against a resistance.

Method (1). Dissolution of a Salt.

In every solid body, the molecules are held close together by their mutual attraction. When a soluble salt is brought into contact with a liquid, for some reason which no one pretends to know, the salt is dissolved. Something must overcome
the molecular attraction in the salt and this something is heat which is abstracted from the liquid itself if the dissolu-
tion be rapid enough so that the heat may not come in from outside bodies.

This method has been known and used for ages. The people of India, being of a scientific turn of mind, knew a great deal about chemical phenomena and early learned that certain salts, when dissolved in water, produced cold. The oldest existing record of any process of artificial cooling is that of Blasius Villafranca, a Roman physician, who in 1550, produced cold by dissolving salt-petre in water. It is said that the Romans cooled their wine bottles by rotating them in a vessel of water into which salt-petre was thrown. This is the method which was probably used by the Citho-
rians, a Russian tribe, who, about 400 A.D. preserved the bodies of their dead by freezing.

A common illustration of this principle is used the
world over today:—viz., in freezing cream in a mixture of common salt and pounded ice—a mixture which produces a temperature of \(-5^\circ F\) or \(37^\circ C\) below the freezing point of water. Many machines have been brought out for the manufacture of ice on this principle. The Siemens machine uses calcium chloride as the salt. This salt produces a reduction of only \(30^\circ F\) in temperature. For this reason it is necessary to have three vessels of fresh water, placed one within the other. In the outer vessel, salt is dissolved reducing the temperature and cooling the water in the inner vessels. Fresh salt is then dissolved in the second vessel, producing a reduction of temperature sufficient to freeze the water in the third vessel.

The apparatus in the Tosselli machine consists of a vessel where the solution of the salt takes place, and an ice can made up of several removable cones or moulds of uniform taper but of different sizes. These moulds being filled with wa
ter, are placed in the cold brine and in a few minutes ice is formed on the inner surfaces of the moulds to a thickness of an eighth of an inch. These cones of ice are placed one within the other so as to build up a solid stick.

Method (2) Evaporation of a Liquid

The method of cooling by evaporation is familiar to all. Everyone knows that if the wet face be exposed to the wind, it is rapidly cooled. Another familiar illustration is seen in the use of an ordinary fan. A sudden sweep of a fan before the face removes for an instant the air pressure and the perspiration is quickly evaporated producing a cooling effect.

In India and especially in Bengal, the natives have produced ice for ages, by exposing water at night in an open vessel, insulated from the earth by a pile of straw. The cool dry air passing over the water reduced the pressure sufficiently to cause it to evaporate at the expense
of its own heat while the only source of heat was the non-conducting straw beneath and the air above.

When a liquid is evaporated, it is believed that the molecules are pulled apart so that they may swing freely and independently. It takes a great deal of heat to overcome the molecular attraction and this heat must come from surrounding bodies, which bodies will, in general, be cooled if the supply of heat from surrounding bodies be insufficient to meet the demand, the temperature of the liquid itself will be reduced to such a point that the influx of heat is just equal to the efflux.

Evaporation can be effected in two ways:—first by raising the temperature of the liquid, i.e. by adding heat. Second, by diminishing the pressure, in which case heat need not necessarily be added. Conversely, condensation is effected by cooling or by compressing.

There are four different systems of refrigeration by
vaporation, in each of which a peculiarity in the form of apparatus gives to the system its name. The classification is as follows:

A. Apparatus in which the cooling agent is thrown away as soon it has absorbed its share of heat.

B. Apparatus in which the heat only is rejected, the cooling agent being restored to its liquid condition by mechanical compression and cooling under compression.

C. Apparatus in which the heat only is rejected, the cooling agent being made to change its form by solution with a liquid from which it is afterward recovered by evaporation.

D. Apparatus in which heat only is rejected, the refrigerating agent being brought back to its original condition by both mechanical compression and solution with cooling.

System A. This is known as the Vacuum System. Since
the cooling agent is thrown away as soon as it is evaporated, it is evident that this agent must be something very inexpensive. Water is the only thing cheap enough to use on a commercial scale.

It is well known that water evaporates at all temperatures and pressures, but that for a low temperature, the pressure must be very low indeed in order to produce anything like a rapid evaporation or ebullition. The curve of vapor tensions for water, plate I, shows that in order to produce ebullition or boiling at 32°F, the pressure must be .089 pounds per sq.in. absolute. For this reason, this system has long been known as the vacuum system.

The air must first be removed by the air pump, as it will ordinarily be found. It will be readily seen that the vapor of water then formed cannot be removed by the air pump since it will be condensed when the compression stroke of the piston is made. In order to remove these
vapors, concentrated sulphuric acid is employed. The rarified air is drawn out over the surface of the acid which takes up the moisture. When the pressure has been reduced to 0.89 pounds per sq.in. the water in the vessel freezes. A compound pump and many modifications of the simple apparatus just described have been used and are still being used for some purposes which are described later in this paper.

System 13. This is known as the compression system. In the latter part of the eighteenth century, chemists discovered that certain gases, such as sulphur dioxide, ammonia, and carbon dioxide could be reduced from a gaseous to a liquid or even a solid condition by compression and cooling. When the pressure is reduced, the liquid quickly evaporates, each pound taking up a definite quantity of heat.

In order to make a complete cycle of operations, as-
During a gas under atmospheric pressure and at ordinary temperature, we must have (1) compression, (2) cooling and condensation, (3) expansion. During the compression, the temperature of the gas always rises. The expansive force of the gas is overcome through a certain distance—i.e., work is done on the gas and that work is transformed into heat which raises the temperature of the gas. For this reason the gas can be readily cooled by ordinary water at 60° or 70° F. During the third operation the pressure is reduced and the liquid evaporates. Plate II shows the cycle of operations in its simplest form.

This system of refrigeration is very popular today and is by far the most common. The refrigerating agent first used was ether, but sulphur dioxide, carbon dioxide, and ammonia, especially the last, are now used most extensively. System 10. This is known as the Absorption System. It depends upon the principle that all gases are more or
less soluble in a liquid, and that when so dissolved, these
gases can be readily driven off by heat at a temperature lower
than the boiling temperature of water or the solvent liquid
whatever it may be.

Assuming a gas at a low pressure and an ordinary
temperature the cycle of operations is as follows:—(1) The
gas is dissolved by the liquid which carries it to the gen-
erator or boiler, in solution. (2) The solution is heated un-
til the gas is driven off at a pressure of 150 pounds per
sq. in. (This is the pressure in case ammonia is used.) (3) The
high tension vapor is condensed in coils over which cool-
ing water is continually running. (4) The condensed vapor
is drawn off, and the pressure is reduced until it suddenly
vaporizes, taking up the latent heat of vaporization, and
producing the refrigerating effect. Plate III shows a simple
diagram of the apparatus.

System D. This is known as the Binary Absorption System
About 1870, François Jules Pictet, of Genève, Switzerland, discovered some very interesting properties of sulphur dioxide and carbon dioxide mixtures. Above a certain temperature, a mixture of these two vapors may be condensed at a lower pressure than either of the vapors alone. This is shown for Pictet's liquid by the curves of vapor tension in plate I., the curve of sulphur dioxide crossing that of Pictet's liquid, while the pressures for carbon dioxide were too great to be represented on the diagram. The latent heat of vaporization for Pictet's liquid is also different from what we should naturally expect, this quantity being greater than the sum of the latent heats of its constituents.

Following up the investigations of Pictet, Rossi and DuMousty, chemists of New-York City, found that many of the ethers, when mixed with sulphur dioxide behaved as did the carbon dioxide, and they first applied these discoveries to refrigeration
as follows:

Assuming the two gases or vapors under ordinary conditions of pressure and temperature, the cycle begins with the compression and cooling of the vapors until a pressure is reached at which one of the vapors is condensed. Suppose the other vapor to be condensed. This necessitates a pressure of about 20 pounds absolute at 110°F. The sulphur dioxide is then taken into solution by the liquid ether, and the temperature is corresponded by cooling water. The new compound liquid reevaporates when the pressure is sufficiently reduced, and the cooling is effected.

Method (3) Expansion of a gas.

If we assume a certain weight of a permanent gas, as for instance 2 pounds of air at a pressure of p pounds per sq. ft. absolute, a volume of x cubic feet per pound, and a temperature of T, absolute (T = 460 + t), the relation be-
between these quantities is expressed by the combined laws of Mariotte and Gay-Lussac \( pV = kRT \), where \( R \) is a constant depending upon the gas. For air in the above units \( R \) is 53.35. If we first raise the pressure and keep the temperature constant by a cold water jacket, we have then \( p_1V_1 = kR \). If we now allow the gas to expand against a resistance, but without adding heat, we get the final condition \( p_2V_2 = kR \).

The final temperature \( T_2 \) will be lower than \( T_1 \) because some of its heat has gone to do the outer work or has been transformed into outer work. The gas will then be capable of cooling bodies of a temperature \( T_1 \). It is, in practice, however, impossible to keep the temperature constant during compression, however perfect the water jacket may be, because air is a poor conductor of heat. This fact makes no difference in the final result as the air after compression may be allowed to stand in the receiver until its temperature falls, after which it may be
expanded. In any case, the cooling effect produced is the heat equivalent of the work performed during the expansion.

Comparison of Refrigerating Processes.

Dissolution of a Salt

Cooling by the Dissolution of a Salt is a very expensive process. The cost of the salt need not be great, as the solution, when saturated could be evaporated and the salt recovered. The evaporating process, however, would be long and expensive, would require large apparatus, meaning a high first cost and much space, while the forming of ice would be slow and unsatisfactory.

There are times, however, when this method is very convenient if not absolutely necessary. In freezing cream, for instance, the temperature could not be reduced below 32°F without salt and pounded ice. If when making ice or refrigerating a store room
by any of the modern methods, the apparatus should get out of order, there would generally be a great loss of produce, such as fruit, meat, and other perishable food-stuffs, were this method not resorted to. It is also a convenient method of producing low temperatures in experimental work. In Table III is given the formulas for various frigorific mixtures, the composition by weight and the temperatures that are obtainable all of which temperatures are sufficiently low to produce ice.

Vacuum System

The vacuum system of refrigeration is not used at the present time for producing ice on a commercial scale on account of the following facts:

1) It is absolutely impossible to obtain a temperature low enough to produce thick ice on account of the extreme high vacuum that would be necessary.

2) It is impossible to make a machine that will withstand the corrosive action of the concentrated sulphuric
acid and the vapos arising from it. This concentrated sulphuric acid has always been found necessary for the working of the machine.

3) The high vacuum which must be maintained is so difficult that in order to prevent leakage, the packing must be screwed down until friction absorbs most of the power required to run the machinery.

For simply cooling, however, where a very low temperature is not required, the vacuum system is quite often used. It is the vacuum system that cools the restaurants, cafes, soda fountains, etc., where a small exhaust fan is used. The drinking fountains, in some places, are cooled by the use of a small vacuum pump.

The important objections just raised to the above methods are sufficient to throw them out of consideration for a comparison with the other and more efficient methods now used for commercial refrigeration and ice-making. It may
be said here that any strictly mechanical method of producing cold has these disadvantages incidental to machinery.

(1) It means a high first cost.
(2) It requires constant attention and care.
(3) Leaks, breakdowns, and repairs with their attendant losses, which with ice-machinery are very great, are common. In order to produce ice cheaply, coal must be cheap, and water must be pure, cold and abundant.

Expansion of Air.

The method of cooling by the expansion of air naturally suggests itself to the mind for these reasons:—

(1) Air is the most common fluid with which we deal, hence, it is always available and costs us nothing.

(2) Since the air must always expand against a resistance in order to be cooled, we are always able to get from it, not only the cooling effect, but also the mechanical equivalent of the heat absorbed, so that the cooling effect might prop...
erly be termed a by-product.

(3) It is perhaps the simplest mechanical method of cooling.

The following considerations, however, are very important.

(1) The space occupied by the machinery for a given refrigerating effect is very large. To see more definitely why this is, consider the heat which disappears when a given weight of air expands. When $C$ pounds of air expand against a resistance, without receiving heat, from a temperature $t_1$ to a temperature $t_2$, the number of heat units that are transformed into work is $C \cdot c(t_1 - t_2)$, where $c$ is the specific heat of air at constant pressure. The numerical value of $c$ is about 0.24. The cooling effect of one pound of pure dry air is then $c(t_1 - t_2)$. Now, in order to begin cooling water on a hot day must be as low as 50°F. The final temperature $t_2$ sometimes goes as low as -70°F. The heat abstracted, then, can never exceed $c(t_1 - t_2) = 30$ B.t.u. per pound of air used. Going a
little further into the calculation, it is found that about 5 pounds of air must be expanded to take up 142 heat units or to freeze a pound of ice. This means a volume of 60 cu ft. at atmospheric pressure and 50°F.

(2) Another argument against the cold air expansion process is the fact that air has a low thermal conductivity, i.e., receives and parts with its heat very slowly. This is especially true of air that is of a uniform temperature throughout such as the exhaust from a compressed air engine. For this reason it is difficult to keep down the heat of compression and thus minimize the work of compression and difficult also to quickly cool surrounding objects by the cold air. A great difference in temperature must be maintained between the cooling air and the body to be cooled, and a great extent of cooling surface is necessary.

(3) The moisture which is suspended in the air when it
enters the compression cylinder is always deposited in the passages and this, freezing up, greatly interferes with the working of the apparatus. The freezing up, however, is eliminated by drying the air and using it over and over again.

[4] By an actual test of a machine at work, it has been found that the fuel cost with this method is somewhat greater than with the evaporation process.

The cold air expansion process has been used very extensively on shipboard and is still being used a great deal although it is being replaced by small ammonia compression machines. Cold air refrigeration has been studied pretty thoroughly and the apparatus has reached a high state of development. It is advantageous in breweries and in places where compressed air is used as a motive power or for any purpose whatever. The cooling is then a by-product and is not expensive. For making ice, it is evidently inferior to the evaporation process.
Evaporation Process.

It may be shown that the evaporation process requires a smaller space than the air expansion process. The heat represented by a pound of vapor is $q + f + Ap_u$, where $q$ is the vibration work or sensible heat of the liquid, $f$ the disgregation work and $Ap_u$ the outer work. $A$ is the heat equivalent of a foot-pound of work, $p$ is the pressure of the vapor and $\gamma$ is the difference between the volumes of a pound of the vapor and a pound of the liquid. If we have a pound of the liquid at a pressure $p_1$ and reduce the pressure to $p_2$, then the liquid may vaporize at a temperature $T_2$, the heat which may be taken up from outside bodies is $(q_2 - q_1) + (f_2 + Ap_{2u_2})$.

Here, $(f_2 + Ap_{2u_2})$ is the latent heat which is necessary to vaporize the liquid and $(q_1 - q_2)$ is the part of this heat which comes from the liquid itself. In the above expression $f_2$ is the important term; its value ranging from 100
to 900 B.T.U. according to the liquid used. This shows that a much smaller weight of the refrigerating agent is necessary with this process than with the expansion of air. If we take for a specific case, ammonia, condenser pressure 150 pounds per sq. in. absolute and expansion pressure 30 pounds from a table \((q_2 - q_1) + (p_2 + Ap_{2u_2}) = 475.5\) \[\left(\frac{q_2-q_1}{s(t_2-t_1)} = 1.02(t_2-t_1),\right\left(p_2 + Ap_{2u_2}\right)\text{ is the total latent heat}\] One pound of the vapor occupies a space of 9 cu. ft. at 30 pounds absolute. To freeze a pound of ice, then will require \(\frac{142}{475.5}\) pounds \(= \frac{142}{475.5} \times 9 = 2.7\) cu. ft. This is only \(\frac{2.7}{60} = \frac{1}{22}\) as much space as is required for air to do the same work.

Again, from the expressions for the cooling effect it is evident that a smaller range of temperature is required with a vapor than with air. For air the expression is \(c(t_1-t_2)\), an expression whose value increases with the range of temperature. For a vapor,
the expression, \((q_2 - q_1) + (p_2 + Ap_{2u2})\), shows, when placed in the form \((p_2 + Ap_{2u2}) - s(t_1 - t_2)\) that the less the range of temperature, the greater the cooling effect.

The effect of decreasing the range of temperature is to lessen the loss due to radiation and conduction from bodies not intended to be cooled.

Finally, a short time is required for affecting the cooling.

The disadvantages of the evaporation process are:

1. Escaping of the refrigerating agent which is often offensive or even dangerous to health. The liquids are also more or less expensive.

2. There is more or less difficulty experienced in keeping the apparatus in repair, on account of the corrosive action of the vapors.

3. Some of the refrigerating agents are inflammable and highly explosive.
The first of these objections is the only one which has much weight, or which applies to all refrigerating agents, and it is almost entirely overcome by good workmanship.

From the above discussion, it is clear that the method of cooling by evaporation is superior to any other for commercial ice-making. The different systems of effecting the evaporation, no doubt have their individual advocates. Some of these may yet be improved upon so that it is impossible to say which is the best. A discussion of the merits of each system, however, will be interesting.

Compression System. In the compression system, the most expensive part of the apparatus is the compressor. As this system involves a change of heat into work through a prime mover, it must necessarily give a low efficiency. However, it is safe to say that, in most plants, less than one fourth of the entire work done is done in compressing the vapor, consequently, a very little more
fuel will be used with this system than with any other. In fact, an actual test has been made which showed 25 pounds office per pound of coal (according to the official report) which is much better than any other system has given. An excellent performance of a 50-ton compression machine is 12 pounds of ice per pound of coal.

Absorption System. In the absorption system there is always more or less trouble experienced on account of the formation of water vapor. When the refrigerating agent, ammonia, for instance, is driven off under a pressure of 150 pounds per sq. in. at a temperature of 80°F, it carries with it a small quantity of water vapor. This water vapor condenses in the condensing coils and absorbs a great amount of ammonia. This solution, when admitted to the expansion coils, not only does not evaporate, but it also gives up a part of its heat to the ammonia which does evaporate and thus reduces both the capacity and the efficiency of the apparatus. A device, termed the rectifier, is used to sepa-
rate the water vapor from the ammonia, but this far has not proven entirely satisfactory.

Further, in this system, twice as much cooling water must be used as by compression, because the ammonia must be twice condensed—once in the absorber and again in the condenser. About 10 pounds of ice per pound of coal have been obtained by this system under the most favorable conditions.

Binary Absorption System.—Very few experimental results of tests of the Binary Absorption System have been published. The fuel cost is given by Mr. H. J. Potter in Transactions of American Society of Mechanical Engineers, Vol. II, 1881, as 8-10 pounds of ice per pound of coal.

Taking all of the known facts into consideration, it may be safely said that at present, the compression system has the fewest disadvantages and is likely to remain the most popular. Practically all of the ice machines that are being built are the
Comparison of Refrigerating Agents.

It now remains to compare briefly the various volatile liquids which have been employed as refrigerating agents. Of these, the most important are ammonia, sulphur dioxide, carbon dioxide, alcohol, ether, methyl ether, sulphuric ether, carbon bisulphide, gasoline, ethylene, and methyl chloride. All, except the first three of these - ammonia, sulphur dioxide, and carbon dioxide - are more or less explosive and have been discarded as dangerous. For this reason, it is evident that the relative merits of these three agents only, need be discussed.

Table IV shows a comprehensive comparison between the agents in question at 0° F. The column of pressures favors sulphur dioxide somewhat, although it is a question whether a vacuum of 5 pounds can be maintained easier than a pressure of 15 pounds above the atmosphere. The pressure for carbon dioxide is extreme. The vol-
The volume of a pound is smallest for carbon dioxide. In the heat of vaporization, the ammonia has much the advantage. The volume of compressor is moderately small for ammonia, while the loss due to cooling the liquid is smallest. The important items, viz. the pressure, the volume of compressor for a given refrigerating effect, and the loss due to cooling, taken together, give a decided argument in favor of ammonia.

The loss due to cooling the liquid was found from the expression already explained, viz:

\[ \text{Cooling effect} = (q_2 - q_1) + (s_2 + A_p_{142}) \]

If the liquid did not require cooling, the refrigerating effect of a pound would be \( (s_2 + A_p_{142}) \). The percentage loss by cooling is then

\[ \frac{-q_2 + q_1}{s_2 + A_p_{142}} \times 100 \]

From tables of the properties of these agents, the above values were calculated.

The ammonia, however, is not without its disadvantages. It is very penetrating at the high pressures used—viz. from 150 to 180 pounds in the condenser and 30 pounds absolute in the expansion coils. It is continually leaking past the piston and stuff—
ing glands, and requires extra heavy pipes which seriously interrupt for the transmission of heat both for condensing and vaporizing the gas. It rapidly corrodes copper so that the use of that metal is prohibited.

Most of the compressors now on the market have patented features by which they avoid the difficulty of leaking in the compressor cylinder. Notable among these is the feature of the De La Vergne Lee compressor, in which oil is injected into the cylinder at the end of the stroke. This, they claim, with apparent good reasons, serves four distinct purposes:—(1) It discharges all of the vapor from the compressor, thus doing away with the effect of clearance. (2) It prevents leakage of the ammonia past the stuffing box, piston, and valves. (3) It cools the vapor during compression. (4) It lubricates the moving parts. Other manufacturers have devices which probably accomplish the same results.

Applications to Refrigeration

Refrigerating machines are used for cooling store rooms and for
making ice, the first use requiring about three-fourths of all the machines employed. The cooling is done in two ways, viz.: (1) By allowing the ammonia coils which run directly to the storage rooms. (2) By running the expansion coils through tanks of brine and then circulating the brine through pipes in the storage rooms.

The first of these systems is called the direct expansion system. For the refrigerating of store rooms, this is undoubtedly the more efficient method, since there is but one interchange of heat. In order to effect a cooling in a reasonable length of time, there must be a temperature difference of about 15°F between the two surfaces of an ordinary wrought iron pipe. The temperature of the brine, then, should be 15° below that of the room to be cooled and the ammonia should be 15° below the brine temperature, or 30° below the room temperature. In the direct expansion system, however, the ammonia need be but 15° colder than the store room. The refrigerating effect of a pound of the liquid has been shown to be $(q_2 - q_1) + (p_2 + A_{p_{212}})$ or $5(t_1 + t_2) + (p_2 + A_{p_{212}})$, which ex-
pression increases in value as the final temperature increases. The work of compression may be shown to be \( \frac{Q}{A} (T_f - T_z) \), an expression which decreases as the final temperature increases.

This reasoning shows that a considerable saving may be effected by working with the highest possible final temperature, i.e., by direct expansion.

The brine circulation system is generally used for ice-making because of its convenience. The direct expansion system could not well be used, as the water to be frozen must be kept clean and away from the ammonia coils. The water would freeze to the coils and, ice being a poor conductor of heat, the cooling surface would be impaired, and the removal of the ice would present difficulties. Another important point in favor of brine circulation is the fact that the circulation could be kept up for a considerable length of time after the compressor was stopped and thus the temperature could be maintained. In some plants, the compressor is run only during the day, the temperature of the brine...
being sufficiently reduced to run overnight without further cooling. Where the brine circulation system is used, the ammonia coils are passed through a large tank of brine, and the brine is circulated, by a pump, through the tank and the storage room coils. The brine solution generally used is that of common salt in water, about 3 pounds of salt per gallon giving good results. Other salts such as calcium chloride are used to some extent.

Ice is made in three ways, viz:— (1) In cans (2) On plates (3) In cells. The first of these is used most extensively. Steel or iron cans filled with fresh water are immersed in the cold brine. After a certain time, ice begins to form around the sides of the can and if left long enough, a solid block of ice will be produced. The can is then lifted out and sprinkled with warm water until the ice melts away from the edges of the can, when the block is removed. The sizes and shapes of these cans vary greatly, the weights of the blocks running from 50 to 400 pounds. A common form is a square can about 14” x 14” and 30” deep slightly smaller at the bottom.
than at the top.

In the plate system, the brine tank is made of boiler iron, the fresh water being contained in a large wooden tank and surrounding the brine tank. The expansion coils circulate the ammonia through the brine and the ice forms on the outside of the iron plates, in pieces weighing a ton or more. To remove the ice, warm brine is supplied to the brine tank, the large pieces of ice are loosened and can then be hoisted by means of cranes, and cut up into pieces of any desired size.

The system using stationary cells is simply a modification of the can system for in this the cans are not removable. To remove the ice, tepid brine is run into the tank to loosen up the blocks, when their removal is easy.

The plate system is continuous and the freezing comparatively rapid on account of the great cooling surface, although the ice is not so pure and clear as that made by the plate system. There is always a small, more or less porous core in the center of the top of
the block, which contains the impurities. To prevent this, air, oil, and impurities are removed from the water to be frozen. The best plants use condensed steam from the engine for making ice, and in order to have none of these impurities, no oil is used in the steam cylinder, and the condensed steam is reboiled and recondensed before its introduction into the ice-cans.

Test of the Twin City Ice Plant.

The objects of this test were:—(1) To study the workings of the plant, (2) To determine the capacity of the plant in tons of ice-making effect per 24 hours, (3) To determine the ratio of ice produced to coal consumed, (4) To determine the amount of water necessary to run a plant of this size, and (5) To determine if possible where a saving of money could be effected.

The Plant

The Twin City Ice and Cold Storage Plant is located at Shapaign, Ill., on Washington, Walnut, and First Streets. It has a switch
connecting to the Illinois Central, the Wabash, and the Big Four
railroads. In the plant, are eight cold storage rooms cooled by
drime circulating in pipes which are either suspended from the
ceiling or fastened to the side-walls. In these rooms are stored
butter, cheese, cider, apples, cabbage, potatoes, eggs, etc., and also
meat during the warm summer months. Two of these rooms
are used for storing ice made during the cold winter months. The machine is run day and night throughout the
year except for about two weeks during the winter. Two engi-
ners and two tankmen are employed, the former at a
yearly salary, the latter as common day laborers.

Equipment
The equipment comprises the following:— One 40 horse-power
York and St. Clair compound refrigerating machine, of the single-act-
ing vertical type. One primary and three secondary ammonia
condensers. One Locke deep well pump. Four direct-acting duplex
steam pumps of the Deane of Holyoke manufacture. Two hori-
gorted return-tubular boilers of 60 horse-power each, and a
iner in connection for purifying the feed water. A reboiler for
purifying the water to be frozen. A hot well and a surface con-
denser for utilizing the heat of the exhaust steam.
Plate IV shows a plan of the building, Plate V, the ammonia-
circulation. Plate VI, steam circulation, Plate VII, the water cir-
culation from the moment it enters until it leaves the system
for the sewer or enters the boiler.

In investigating the economy of an ice plant, it is neces-
sary to follow out (1) the course of the ammonia, (2) the course of the
steam, and (3) the course of the water and to find out where
leaks and other losses may occur, and to determine those
losses, if possible. The course of the ammonia is shown in
plate VI. That of the steam is shown in plate VII, while that
of the water is shown in plate VII. These diagrams are self-ex-
planatory. The bulk of the water comes from the deep well pump
plate, passes through the primary condenser 4, the seconda-
my condensers 6, the compressor jacket 5, the exhaust steam condenser 7, and thence either the hot well 8, or the sewer 9. The water from the hot well 8 is forced by the pump 11 thru the meter 13 into the boiler 14. The exhaust steam from the engine passes into the condenser 7, thence through the pump 13 up into the reboiler 3, where it is reevaporated by means of live steam, the vapor is recondensed and cooled and finally sent to the cooler 10 where its temperature is reduced to about 45°. All of the pipes have by-passes to the sewer which may be closed by valves. Water is taken by a pipe from primary condenser 4 to the thawing apparatus 16 where the cakes of ice are made to sweat loose from the cans. Plate 17 shows that the exhaust steam from the pumps is allowed to escape into a pipe which opens into the air about 150 feet from the building.

In order to get rid of the impurities from the water, everything must be full and overflowing. This accounts for the
large amount of water which is continually going to the sewer.

One of the important rules for economical cooling is to force all cooling agents from bottom to top, all matter to be cooled from top to bottom. This is simply the natural law for if it were otherwise, the cold condensing water would be discharged while the hot water would gradually accumulate at the top of the vessel.

The engine and the compressor cylinders are run without lubrication of any kind in order to keep the distilled water pure and clean. The skimmer is another device for getting rid of the impurities and scale-forming material found in the water. The water is taken from the bottom of the boiler, and, entering at the top of the skimmer, is met from below by hot water and steam from nearly the middle of the boiler. This precipitates the scale in the skimmer where it may be readily blown off.
Table I. Properties of Refrigerating Agents

<table>
<thead>
<tr>
<th>Liquid or Gas</th>
<th>Water</th>
<th>Pictet's Liquid</th>
<th>Anhydrous Ammonia</th>
<th>Sulphuric Ether</th>
<th>Methyllic Ether</th>
<th>Sulphur Dioxide</th>
<th>Carbon Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity of Vapor (Air = 1000)</td>
<td>0.622</td>
<td>0.59</td>
<td>0.59</td>
<td>2.24</td>
<td>1.61</td>
<td>2.24</td>
<td>1.52</td>
</tr>
<tr>
<td>Boiling Temperature at Atmospheric Pressure</td>
<td>212°F</td>
<td>-22°F</td>
<td>-375°F</td>
<td>96°F</td>
<td>-105°F</td>
<td>14°F</td>
<td>—</td>
</tr>
<tr>
<td>Latent Heat of Vapor at Atmospheric Pressure</td>
<td>966BTU</td>
<td>575BTU</td>
<td>165BTU</td>
<td>473BTU</td>
<td>182BTU</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Table II. Pressures of Saturated Vapors of Refrigerating Agents at Different Temperatures, Fab.

<table>
<thead>
<tr>
<th>Temperatures, F</th>
<th>Absolute Pressure of Vapor in Pounds per Square Inch.</th>
<th>Water</th>
<th>Anhydrous Ammonia</th>
<th>Sulphuric Ether</th>
<th>Methyllic Ether</th>
<th>Sulphur Dioxide</th>
<th>Pictet’s Liquid</th>
<th>Carbon Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20</td>
<td>—</td>
<td>19.4</td>
<td>—</td>
<td>12.0</td>
<td>5.7</td>
<td>11.6</td>
<td>224.4</td>
<td>—</td>
</tr>
<tr>
<td>0</td>
<td>—</td>
<td>30.0</td>
<td>1.5</td>
<td>18.7</td>
<td>9.8</td>
<td>15.4</td>
<td>319.7</td>
<td>—</td>
</tr>
<tr>
<td>20</td>
<td>—</td>
<td>47.7</td>
<td>2.6</td>
<td>28.1</td>
<td>16.9</td>
<td>22.0</td>
<td>413.4</td>
<td>—</td>
</tr>
<tr>
<td>32</td>
<td>.099</td>
<td>61.5</td>
<td>3.6</td>
<td>36.0</td>
<td>22.7</td>
<td>27.0</td>
<td>520.4</td>
<td>—</td>
</tr>
<tr>
<td>40</td>
<td>.122</td>
<td>73.0</td>
<td>4.5</td>
<td>42.5</td>
<td>27.3</td>
<td>31.3</td>
<td>585.5</td>
<td>—</td>
</tr>
<tr>
<td>60</td>
<td>.254</td>
<td>108.0</td>
<td>7.2</td>
<td>61.0</td>
<td>44.4</td>
<td>44.0</td>
<td>756.0</td>
<td>—</td>
</tr>
<tr>
<td>80</td>
<td>.503</td>
<td>152.4</td>
<td>10.9</td>
<td>86.1</td>
<td>60.2</td>
<td>60.0</td>
<td>1009.0</td>
<td>—</td>
</tr>
<tr>
<td>100</td>
<td>.942</td>
<td>210.6</td>
<td>16.2</td>
<td>118.0</td>
<td>84.5</td>
<td>79.1</td>
<td>1280.3</td>
<td>—</td>
</tr>
<tr>
<td>120</td>
<td>1.685</td>
<td>283.7</td>
<td>23.5</td>
<td>—</td>
<td>117.5</td>
<td>99.7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>140</td>
<td>2.879</td>
<td>—</td>
<td>33.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>160</td>
<td>4.731</td>
<td>—</td>
<td>45.6</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>180</td>
<td>7.511</td>
<td>—</td>
<td>62.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>200</td>
<td>11.526</td>
<td>—</td>
<td>81.8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>212</td>
<td>14.7</td>
<td>—</td>
<td>96.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</table>
### Table III. Freezing Mixtures

*From Wallis-Tayler’s “Ice Machines.*

<table>
<thead>
<tr>
<th>Composition</th>
<th>Parts by Weight</th>
<th>Temperature Fall</th>
<th>Composition</th>
<th>Parts by Weight</th>
<th>Temperature Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>From</td>
<td>To</td>
<td>Fall</td>
<td></td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>5</td>
<td>50</td>
<td>10</td>
<td>40</td>
<td>Snow or Pounded ice</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>Sodium chloride</td>
</tr>
<tr>
<td>Water</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>Ammonium chloride</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>1</td>
<td>50</td>
<td>4</td>
<td>46</td>
<td>Snow or Pounded ice</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>Sodium chloride</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>5</td>
<td>50</td>
<td>3</td>
<td>46</td>
<td>Snow or Pounded ice</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>Sodium chloride</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>Ammonium chloride</td>
</tr>
<tr>
<td>Water</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>Potassium nitrate</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>47</td>
<td>Snow or Pounded ice</td>
</tr>
<tr>
<td>Sulphuric acid, dilute</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Sodium chloride</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>8</td>
<td>50</td>
<td>-3</td>
<td>50</td>
<td>Ammonium nitrate</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>Snow</td>
</tr>
<tr>
<td>Sodium nitrate</td>
<td>3</td>
<td>50</td>
<td>-7</td>
<td>53</td>
<td>Sulphuric acid, dilute</td>
</tr>
<tr>
<td>Nitric acid, dilute</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>Snow</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>1</td>
<td>50</td>
<td>-10</td>
<td>57</td>
<td>Nitric acid, dilute</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>Snow</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>Hydrochloric acid</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>6</td>
<td>50</td>
<td>-10</td>
<td>60</td>
<td>Snow</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Calcium chloride</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>Snow</td>
</tr>
<tr>
<td>Nitric acid, dilute</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Calcium chloride, crys</td>
</tr>
<tr>
<td>Sodium phosphate</td>
<td>9</td>
<td>50</td>
<td>-12</td>
<td>62</td>
<td>Snow</td>
</tr>
<tr>
<td>Nitric acid, dilute</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Potassium</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>6</td>
<td>50</td>
<td>-40</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitric acid, dilute</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It will be seen from Plate VIII, that the water used in the boiler comes from the overflow which collects in the hot-well. This warm water is further heated in the hot-well by live steam from the boiler. This precipitates a great deal of scale-forming material in the hot-well where it can do no harm.

The cold storage rooms are well insulated, having 12-inch wood walls lined with mineral wool, and have no windows and no ventilation. Rooms nos. 2, 3, 4, and 5, Plate IV, are storage rooms cooled by brine circulating in pipes which are suspended from the ceiling. Sheets of galvanized tin just below these pipes collect the drip and protect the fruit and produce below. Rooms 6, 7, 8, and 9, are cooled by side brine pipes below which are suitable troughs for collecting the drip. Room 10 is for general storage and is not cooled. In winter it is heated by steam radiator coils. Room 11 contains the boilers, exhaust steam condenser, and
the hot well. Room 12 contains the deep well pump and the skimmer. The office of the company is in the second story, directly above rooms 3, 4, and 5.

The Test. Starting and Stopping.

The test was made with reasonable completeness and precision, although the object was to get general results within four or five per cent. On account of the rush of business, the engine could not be stopped for more than a minute or so, consequently some important data could not be obtained. The steam consumption of the separate pumps could not readily be determined as all were connected to one discharge pipe. The compressor was running at 1½ times its normal speed, consequently, the average conditions was not obtained.

Boiler. The fire was cleaned and allowed to burn low and the amount of coal on the grate was estimated at the start. Wind readings of the water meter, steam gauge, and water gauge were taken at the same time. In closing, the readings were
made to conform as nearly as possible to the corresponding readings at the start, corrections being made for slight differences of water level and boiler pressure.

**Engines.**—When the signals for starting and stopping the test were given, readings of the stroke counters were taken on the engine, the boiler feed pump, the brine pump, and the deep well pump in order to determine piston displacement.

**General Observations.**—Every 15 minutes, the following observations were taken simultaneously:

- Steam engine indicator diagrams from each end of the cylinder, and readings of stroke counters.
- Gauge pressures of the steam, draught, and high, intermediate, and low ammonia.
- Temperatures of entrance well water, condenser, boiler feed water, compressor jacket, primary and secondary ammonia condensers, ammonia entering compressor, condenser, and tank brine inlet and outlet, flue gas, external air, engine room, boiler...
room, and storage rooms.

The exhaust from the pumps was condensed for one hour and measured in a tank. Balunometer determinations of moisture were made at frequent intervals. The amount of water blown off was estimated by noting the fall of water in each case. The coal was weighed in wheel-barrow lots on a platform balance and then dumped upon the floor. To avoid errors, the weight of coal was recorced when the load was dumped and no more was weighed up until the last had been fired. The water fed to the boiler was metered as shown at 12 in plate, its temperature obtained from a thermometer in an oil cup inserted in the feed pipe on top of the boiler. The amount of water used by the entire plant was determined by piston displacement of the deep well pump. The amount of steam used by the coils in the hot well and the reboiler was not measured, but was taken as the difference between the water evaporated and the sum of the steam consumptions of the stee
engine and pumps. The steam consumption of the engine was calculated from
the indicator diagrams by applying a correction for initial condensation. The
piston displacement of the brine pump gave the quantity of brine circulated. The
piston displacement of the high pressure ammonia compressor gave the vol-
ume of ammonia circulated. From Prof. DeVolson Wood's equation of ammo-
nia gas \( \frac{PV}{T} = 91 - \frac{16920}{V^{0.97}} \), the volume of a pound was determined, and thus
the weight was readily found. The water used for thawing out the
blocks of ice was measured in a barrel and dumped in the
sewer a barrel full at a time. The capacity of the barrel was
known and the weight of water determined by the number of
barrels emptied. The weight of water going to the sewer was the
difference found by taking from the water pumped, the wa-
ter evaporated and the water used for thawing out the ice.
Apparatus used — The draught gauge was the ordinary U-tube which
is commonly used for measuring small pressures. The tempera-
ture of flue gases was taken by a thermometer reading up to 700°F
placed in a pipe of oil extending about 24" into the flue just above
the boiler setting. The thermometers were of Queen & Co.'s make. One of carpenter's separating calorimeters made by Schaeffer & Budenberg was used for determining moisture in the steam. The square counters used for counting revolutions were also of Schaeffer and Budenberg's manufacture. Two Absorby indicators were used on the engine with a pantograph reducing motion for the drum connection. A Worthington piston water meter with \( \frac{3}{4} \) in. inlet and outlet pipes was used for measuring feed water. Oil cups were inserted into all pipes except the ammonia pipes for determining temperatures. For ammonia temperatures were found by binding oil cups to the pipes and covering them with asbestos insulation. All apparatus used belonged to the Mechanical Engineering Department and had been calibrated many times in the laboratory so that by the use of calibration curves correct readings could be obtained. These connections have been applied wherever they were important enough to be considered.
Local, Water, and Brine Analyses

Analyses of local, Water, and Brine were made by the department of chemistry under the supervision of Profs. Palmer and Farr. The approximate results are given below. The water was taken from the 160 ft. well at the plant.

<table>
<thead>
<tr>
<th>Local</th>
<th>Distilled Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Du Jour Slack</td>
<td>Percentage by weight</td>
</tr>
<tr>
<td>Moisture</td>
<td>6.95</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>35.95</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>42.80</td>
</tr>
<tr>
<td>Ash</td>
<td>15.20-100.00</td>
</tr>
<tr>
<td>B.J.U. per pound</td>
<td>9.400</td>
</tr>
<tr>
<td>Brine</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.17</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>0.805</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Percentage by weight* | *Nitrites* | *Parts per Million* |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>6.95</td>
<td>Nitrites</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>35.95</td>
<td>Chlorides</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>42.80</td>
<td>Aluminumoid Ammonia</td>
</tr>
<tr>
<td>Ash</td>
<td>15.20-100.00</td>
<td>Free Ammonia</td>
</tr>
<tr>
<td>B.J.U. per pound</td>
<td>9.400</td>
<td>Total Solids</td>
</tr>
</tbody>
</table>

*Parts per Million* | *Weight* |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.036</td>
</tr>
<tr>
<td>Chlorides</td>
<td>0.20</td>
</tr>
<tr>
<td>Aluminumoid Ammonia</td>
<td>0.01</td>
</tr>
<tr>
<td>Free Ammonia</td>
<td>1.29</td>
</tr>
<tr>
<td>Total Solids</td>
<td>0.144</td>
</tr>
</tbody>
</table>
Water Analysis
Nitrogen as free Ammonia 2.00 Parts by weight per million
Nitrogen as Albuminoid .08 " " " " " "
Nitrogen as Nitrites None " " " " " "
Nitrogen as Nitrates .03 " " " " " "
Chlorine as Chlorides 2.30 " " " " " "
Total Solids by Evaporation 22.65 lbs. per gallon
Fixed Residue (mineral solids) 21.61 " " " " " "
Volatile Matter (loss on ignition) 1.24 " " " " " 

Displacement of Pistons

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Area</th>
<th>Stroke</th>
<th>R.P.M.</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Ammonia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 1/2&quot;</td>
<td>54.34</td>
<td>20&quot;</td>
<td>70</td>
<td>42.04</td>
</tr>
<tr>
<td>Low Pressure Ammonia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14&quot;</td>
<td>151.54</td>
<td>20&quot;</td>
<td>70</td>
<td>122.8</td>
</tr>
<tr>
<td>Deep Well Pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6&quot;</td>
<td>28.27</td>
<td>36&quot;</td>
<td>15.4</td>
<td>4.16</td>
</tr>
<tr>
<td>Boiler Feed Pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 1/2&quot;</td>
<td>21.84</td>
<td>4&quot;</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>Brine Pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 1/2&quot;</td>
<td>59.15</td>
<td>6&quot;</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Distilled Water Pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3&quot;</td>
<td>10.21</td>
<td>3&quot;</td>
<td>100</td>
<td>2.232</td>
</tr>
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</table>
### Boiler Test

<table>
<thead>
<tr>
<th>Average Pressures</th>
<th>Average Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam in boiler, gauge</td>
<td>External Air, degrees F.</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>93</td>
</tr>
<tr>
<td>Absolute steam</td>
<td>Boiler Room, degrees F.</td>
</tr>
<tr>
<td>Draught in inches of water</td>
<td>14.7</td>
</tr>
<tr>
<td>Fuel</td>
<td>Feed Water, degrees F.</td>
</tr>
<tr>
<td>Moist coal consumed, lbs</td>
<td>107.7</td>
</tr>
<tr>
<td>Moisture in coal, per cent</td>
<td>Blue gases, degrees F.</td>
</tr>
<tr>
<td>Dry coal consumed</td>
<td>32</td>
</tr>
<tr>
<td>Total dry refuse, pounds</td>
<td>British Thermal Units</td>
</tr>
<tr>
<td>Total dry refuse, per cent</td>
<td></td>
</tr>
<tr>
<td>Total combustible, pounds</td>
<td></td>
</tr>
<tr>
<td>Dry coal per hour, pounds</td>
<td>To generate a pound of steam</td>
</tr>
<tr>
<td>Combustible per hour</td>
<td>1037</td>
</tr>
<tr>
<td>B.T.U. per pound of coal</td>
<td>Absorbed by boiler</td>
</tr>
<tr>
<td>Moisture in steam, per cent</td>
<td>19995000</td>
</tr>
<tr>
<td>Water, pounds</td>
<td>Absorbed by boiler per pound coal</td>
</tr>
<tr>
<td>Total pumped into boiler</td>
<td></td>
</tr>
<tr>
<td>Water actually evaporated</td>
<td>6962</td>
</tr>
<tr>
<td>Equivalent water from and at 212°</td>
<td></td>
</tr>
<tr>
<td>Equiv. water from and at 212° per</td>
<td>8440</td>
</tr>
<tr>
<td>Equiv. water from and at 212° per</td>
<td></td>
</tr>
<tr>
<td>pounds</td>
<td></td>
</tr>
</tbody>
</table>
Boiler Test, concluded.

Evaporative performance

Water actually evaporated per pound of dry coal, pounds

| Water actually evaporated per pound of dry coal | 6.62 |
| Equivalent water from and at 212°F per pound of dry coal | 7.09 |
| Water actually evaporated per pound combustible | 8.03 |
| Equivalent water from and at 212°F per pound combustible | 8.64 |

Commercial Horse Power

On basis of 34.5 pounds of water per hr., from and at 212°F

| Number of sq. ft. of heating surface per commercial horse power | 74.1 |
| Horse power per sq. ft. of grate surface | 11.7 |
| Horse power, builder’s rating at 14.5 sq. ft. per horse power | 3.1 |
| Per cent. developed above rating | 60. |
| Per cent. developed above rating | 23. |

Rate of combustion, coal per hr.

| Rate of evaporation, water from and at 212°F per hr |
| Rate of evaporation, water from and at 212°F per hr |
| per square foot of grate | 15. |
| per square ft. of tube opening | 10. |
| per sq. ft. of heating surface | 412 |
| per sq. ft. of grate | 106.4 |
| per sq. ft. of tube opening | 639 |
| per sq. ft. of heating surface | 2.9 |

Cost of coal at boilers per 2000 pounds $1.00.
Engine Test.

Cylinder 16"x20". Piston rod 2 7/16". H.P. = PLAN, 33 000

Revolution per minute H, average

Mean piston speed in feet per minute

Indicated horse power, average

Indicated horse power, minimum

Indicated horse power, maximum

Steam consumed per indicated horse power per hour lbs.

determined from indicator diagrams

Initial condensation for ratio of expansion = 8 (Kent)

Total steam consumption per I.H.P. pounds

Total steam consumption per hour

Total heat in 1250# steam above feed temperature B.I.U. 1,296,250

Heat changed to work per hour B.I.U. = 49.5 x \[\frac{1,980,000}{778}\] = 126,000

Thermodynamic efficiency of engine per cent

Coal consumed by engine, per hour, pounds

Percentage of coal used on account of engine

70.

233.3

49.5

42.1

53.2

18.0

31%

25.0

1250

9.72

138

38.4
Compressor
Number of cylinders, single acting, 2. Length of stroke 20" 70.
Pistons 14" and 8½", piston rods, each 1½", area piston rod 24" 56.74.
Area of head end of piston, high pressure 153.94.
Area of head end of piston, low pressure 70.
Revolutions per minute, average 70.
Temperature of ammonia entering 37.5°, leaving comp. 120°
Pressure of ammonia, initial, 13.2#, final, 133#, gauge 124.7.
Average piston displacement per stroke, two pistons, cu. ft. 1.22.
Piston displacement per hour, two pistons 1624.8.
Volume of low pressure ammonia compressed per hour 124.7.
Weight per cu. ft. = .092 lbs. Weight compressed per hour, lbs 11.47.
Condensers, Ammonia
Type of condensers, submerged, one-inch pipes, 150 ft. 12000.
Water used per hour by condenser, assumed 2500.
Temperature of cooling water leaving coils, degrees F 70.
condensers - continued

<table>
<thead>
<tr>
<th></th>
<th>B.T.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat carried away by condensing water per hr.</td>
<td>19,200</td>
</tr>
<tr>
<td>Heat carried away by jacket water per hr.</td>
<td>4,000</td>
</tr>
<tr>
<td>Total heat removed per hour</td>
<td>232,000</td>
</tr>
<tr>
<td>Total heat removed per 24 hours</td>
<td>5,568,000</td>
</tr>
<tr>
<td>Capacity of machine, tons of ice-making effect per 24 hrs.</td>
<td>196</td>
</tr>
<tr>
<td>Gallons of water used per ton of refrigeration</td>
<td>2,200</td>
</tr>
</tbody>
</table>

**Average Pressures, psig**

- Ammonia entering compressor, low pressure: 13.2 psig
- Ammonia between compressors, intermediate: 71.4 psig
- Ammonia entering condensers, high pressure: 133 psig
- Steam, boiler: 93 psig

**Average Temperatures, degrees F**

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water from deep well</td>
<td>54</td>
</tr>
<tr>
<td>Water entering ice-cans</td>
<td>48</td>
</tr>
<tr>
<td>Water entering cooler</td>
<td>61</td>
</tr>
<tr>
<td>Water entering condensers</td>
<td>54</td>
</tr>
<tr>
<td>Water entering boiler</td>
<td>177.7</td>
</tr>
<tr>
<td>Water entering thawing apparatus</td>
<td>70.0</td>
</tr>
<tr>
<td>Water entering jacket</td>
<td>54.0</td>
</tr>
<tr>
<td>Water entering sewer</td>
<td>110</td>
</tr>
</tbody>
</table>
Average Temperatures, continued

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water leaving skimmer</td>
<td>333</td>
<td>Brine inlet</td>
<td>20</td>
</tr>
<tr>
<td>Water leaving hot well</td>
<td>180</td>
<td>Ammonia entering compressor</td>
<td>37.5</td>
</tr>
<tr>
<td>Water leaving condensers</td>
<td>70</td>
<td>Ammonia entering condenser</td>
<td>118</td>
</tr>
<tr>
<td>Water leaving jackets</td>
<td>69</td>
<td>Ammonia entering refrigerator</td>
<td>-4°</td>
</tr>
<tr>
<td>Brine outlet</td>
<td>12</td>
<td>Steam in boiler</td>
<td>333</td>
</tr>
</tbody>
</table>

Wastes

- Water blown off through skimmer, average per hour, lbs. 200
- Equivalent B.T.U. above temperature of condensers 52,600
- Equivalent coal thrown away through skimmer per hr. 5.6
- Water sent to sewer, per hour, pounds 390.00
- Equivalent heat above initial temperature, B.T.U. 1,950,000

Temperatures of cold storage rooms

<table>
<thead>
<tr>
<th>Room no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>78</td>
<td>35</td>
<td>30</td>
<td>23</td>
<td>28</td>
<td>35</td>
<td>35</td>
<td>34</td>
<td>35</td>
<td>42</td>
<td>75</td>
<td>82</td>
</tr>
</tbody>
</table>

Length of Brine pipe 5,000 feet.
Steam consumption per hour: pounds

- Pumps, combined (measured in square tank) approx. 1000
- Engine, calculated as shown on page 51: 1250
- Boils in hot well, assumed: 50
- Radiators not in use: 75

Steam produced by boiler, per hour: 2377

Cost of coal at boiler per 2000 pounds: $1.00

Combined horse power of pumps: 10

Ice Production

- Per hour, pounds: 1125, Per day, tons: 13.5
- Per pound of coal burned: 3.13
- Per thousand heat units expended: 3.33

Refrigerating Effect, ice-making capacity

\[ \text{Tons} = \left( \frac{\text{Time} \times (\text{Pounds of brine}) \times (\text{Specific heat}) \times (\text{Range of temperature})}{\text{(Latent heat of)}} \right) \]

\[ 16.9 = \left( 24 \times 30261 \times 0.826 \times 8 \right) \div (142 \times 2000). \quad \text{Per ton of coal} \]

\[ \text{Tons} = 3.91 \]
General Conclusions

By a comparison with the results of tests made in 1896 by Mr. M.E. Whitham, it is seen that the plant is running more economically, and at a forced capacity considerably above the capacity at that time. Two things are accountable for this. First, the boiler is much more efficient. Second, the engine speed has been increased from 53 to 70. Just what the effect the speed has on the efficiency of the plant would be an interesting study.

The pumps have recently been overhauled and their steam consumption may have been decreased. The scale forming material seems to cause less trouble than it did in the tests reported. The quality of coal used was such that the efficiency of the plant played a very small part in the cost of ice, the coal cost amounting to less than $4.50 per 24 hours, while the cost of labor exceeded 3 times this amount. Were coal an
important item, it would be absurd to run all of the
pumps as they were. The business of the plant has in-
creased about 20% since 1896, hence the forced capacity
No trouble is experienced with the compressor or any
of the machinery, chiefly because the engineers under-
stand their business and exercise the utmost care
with the machinery.

References to Literature on the Subject of Refrigeration
Refrigeration and Ice-making Machinery by A. J. Wallis-Taylor.
A complete work on the subject devoted extensively to descrip-
tion of Machines. London, Crosby Lockwood & Son.
Ice Machinery, translated from the French of M. Sedou.
A valuable mathematical treatment of the subject. Pub-
dlished by Van Nostrand & Co.
An elementary discussion of the principles and a complete
Description of cold air machines.


Summary of Results of Principal Experimental Measurements of Refrigerating Machines. A.S.M.E. vol. XIII

Performances of a 35-ton machine of the Ammonia Absorption Type. J.E. Denton in A.S.M.E. vol X.


Notes on the Refrigerating Process and its Proper Place in Thermodynamics. A.S.M.E. vol XIV.

Kent's Mechanical Engineer's Pocket-book.

Catalogues of De La Vergne Co., Frick Co. etc contain some valuable tables of data and useful information.
Indicator diagrams from engine.

Form D—2-10-98—5 M.—W.
SCALE
BOILER PRESS.
END
R. P. M.
VAC. GAUGE

M. E. LABORATORY U. OF L.
SIZE CYL.
ENGINE
DATE
TIME OR NO.

Indicator drum connected to valve rod. Travel of valve 5".

Outside lap of valve
Inside lap of valve

NOTE: TAKE DIAGRAM ON THIS SIDE OF PAPER.
Plate II Compression Process.

- Compressor Cylinder
- Condenser
- Steam Cylinder
- Expansion Coils and Brine Tank
Plate IV.

Plan of Building

Rooms:
1 Contains Ice Machinery
2 Ice Store Room
3 " " " "
4 " " " "
5 Fruit " "
6 " " " "
7 Ice " "
8 " " " "
9 Fruit and Vegetables
10 General Store Room
11 Deep Well Room
12 Boiler Room

Scale 1" = 20'
Ammonia Circulation
1 Compressor
2 Primary Condensers, Coils
3 Secondary Condensers, Coils
4 Ammonia Receiver
5 Brine and Ice Tank
6 Distilled Water Cooler
7 Expansion Coils
Red Lines Indicate Ammonia Pipes.

Plate VI.
Plate VII

Steam Circulation
1. Boiler
2. Deep Well Pump
3. Engine
4. Reboiler
5. Distilled Water Pump
6. Boiler Feed Pump
7. Brine Pump
8. Radiator Coils

For Engine Exhaust; See Plate VIII. Red indicates Live Steam, Blue, Exhaust.
Water Circulation.
1. Deep Well Pump
2. City Water Meter
3. Reboiler
4. Primary Condenser
5. Compressor Jacket
6. Secondary Condensers
7. Exhaust Steam Condenser
8. Hot Well
9. Sewer
10. Cooler for Distilled Water
11. Boiler Feed Pump
12. Feed Water Meter
13. Distilled Water Pump
14. Boiler
15. Shimmer
16. Thawing-out Pipe

Plate VIII