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# AN INVESTIGATION OF
# THE METHODS OF ICE MANUFACTURE

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Submitted by

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# INVESTIGATION OF THE METHODS OF ICE MANUFACTURE

## INTRODUCTION - Object of the Thesis

The authors had in view, in writing this thesis, to become familiar with the different methods of refrigeration used in ice manufacture, the machines used for the various processes, the water best adapted for the making of clear ice and the many details of plant operation, so as to be able to decide what process of ice manufacture would be the best for a certain locality when all the factors bearing upon this matter are known and also to be able to decide which will be the most advantageous way of remodeling old ice plants.

## PART I

## REFRIGERATING SYSTEMS AND METHODS OF ICE MAKING

The most important methods of regrigeration used in ice manufacture are the Compression System and the Absorption System.

1. - Compression System.

The principle of the compression system is based on the property of the refrigerant to cool itself as its pressure is reduced. For the purpose of having the refrigerant at a high pressure level, we make use of the compressor; the work of compression heats the refrigerant and therefore use is made of condensers, to cool and liquefy the refrigerant while at a high pressure; as the refrigerant passes through the expansion valve part of it evaporates, thus cooling the rest of the refrigerant which passes through the coils or brine cooler where it abstracts the heat from the cooling medium or brine, thus evaporating; when the refrigerant leaves the coils or brine cooler it is in the state of a saturated vapor, partially saturated or slightly superheated, depending on whether we are working our compressor "wet"or "dry."

Thus the cycle is established, and the refrigerant is constantly circulating in a closed system, being compressed and warmed in the compressor, cooled and liquefied in the condensers, reduced in pressure through the expansion valves and evaporated and warmed in the brine cooler, from where the refrigerant is carried again to the compressors to repeat the cycle of operations.

The apparatus used in the compression system ~~is~~ are:- The compressor built universally of the reciprocating type~~s~~ and classified as vertical or horizontal, single-acting or double-acting, low speed or high speed. The size of the compressor depends on the refrigerant used and on the capacity of the plant. Having decided on the capacity of the plant, the smallest compressor will be that using carbon dioxide ($CO_2$); next in size will be that using ammonia ($NH_3$) and the largest will be the compressor using sulphur dioxide ($SO_2$) approximately in a ratio of 1:4:13. On the other side, with cooling water available at 70° F, the carbon dioxide compressor will be working against a pressure of from 900 to 1000 pounds per square inch while the $NH_3$ compressor would work against 160 to 180 pounds per square inch and the $SO_2$ compressor against 50 to 60 pounds per square inch, under the same conditions.

The condensers may be of the atmospheric or double pipe type, the cooling agent being water. The atmospheric type abstracts heat from the refrigerant by the evaporation of the water as it drips over the condenser tubes. Heat is also abstracted by direct transfer to the cooling water and air surrounding the condenser. In the double pipe condenser, heat is removed only by direct transfer to the cooling water and air. In both types of condensers, use is made of the countercurrent principle, as it insures greatest heat transfer. The expansion valve is simply a throttling device and there are no great differences between the various types. By its means we are able to regulate the back pressure of the refrigerant as it leaves the coils.

The coils are usually made up of 1 1/4" pipe running lengthwise of the freezing tank between each row of cans and connected to headers at the end of the tank. A brine cooler is sometimes used instead of the coils; the brine cooler is essentially the same as a horizontal tubular boiler; the refrigerant enters at the bottom center of the shell, evaporates, and leaves at the top of the shell thus cooling the brine which is circulated through the tubes.

Other apparatus and auxiliaries used in the compression system are: - the high pressure oil trap, put between the compressor and condenser and devised to separate all the oil fed to compressor cylinder and carried away by the refrigerant. The $NH_3$ or $CO_2$ receiver, put between the condensers and the expansion valves. The brine agitator, to keep the cooling medium circulating, thus insuring greater heat transfer. Another oil or scale trap is used in the low pressure side, between the cooling coils and the compressor.

New developments in the compression system have led to the multiple effect compression, used where different levels of low temperature are maintained. Instead of compressing all the refrigerant from the lowest temperature level, the refrigerant is admitted to the compressor cylinder at two different back pressures by means of a special device thus reducing the work of compression. Its originator, Mr. G. T. Voorhees, claims a saving of from 15 to 25 per cent of the work of compression. Special devices have now been pattented which are adaptable to the ordinary compressor and which permit of this multiple effect compression.

For large installations and where a variable capacity is desired the compound compressor has been used extensively. It works exactly on the same principle as the compound air compressor, thus saving much of the work of adiabatic compression. In this case, however, all the refrigerant is admitted to either cylinder at the same time, there being no multiple effect.

2. - <u>The Absorption System</u>.

This system is based on the affinity of cool water for the refrigerant gas and the ease of expelling the refrigerant from the water by the application of heat. The process is similar to that of the compression system, the generator taking the place of the compression stroke, while the absorber replaces the suction stroke. $NH_3$ is used universally as the refrigerant in the absorption system because water absorbs it more readily than any other substance, as may be seen from the accompanying table:

Volumes of gas absorbed by 1 volume of water

| Temp. Degrees Centigrade | $NH_3$ | $CO_2$ | $SO_2$ |
|---|---|---|---|
| 0 | 1299 | 1.71 | 79.8 |
| 10 | 910 | 1.20 | 56.6 |
| 15 | 802 | 1.02 | 47.3 |
| 20 | 711 | 0.88 | 39.4 |
| 25 | 635 | 0.76 | 32.8 |
| 30 | | 0.67 | 27.2 |

From this table, it is easy to see how dependent the absorption system is on the temperature of cooling water.

Essentially, the apparatus used in the absorption system consists of:- the generator, where the strong aqua ammonia is heated by means of steam coils, thus driving out the $NH_3$; (see illustration, Fig. 1) the rectifier or analyzer or both, where the $NH_3$ from the generator passes in order to leave any moisture which it may have (see illustration); the condenser, where the dry $NH_3$ gases are condensed, passing through to a receiver. From the receiver, through a throttle valve, the $NH_3$ goes to the brine cooler where it absorbs the heat from the brine. The $NH_3$ having vaporized in the brine cooler, passes over to an absorber, where it meets the week liquor left in the generator; the weak liquor, having been cooled in the

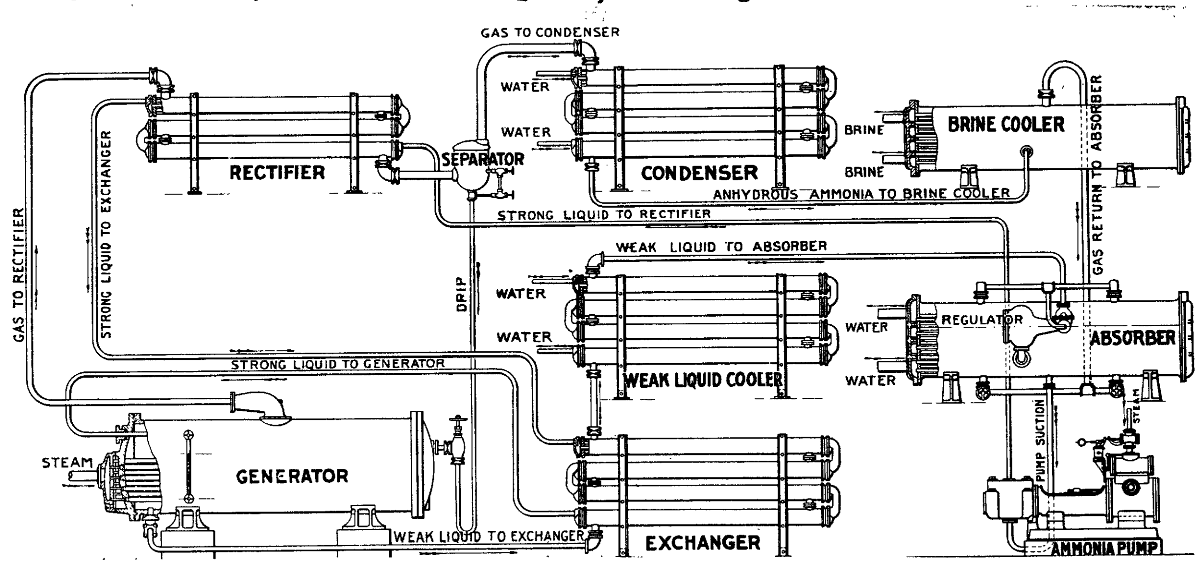



Fig. 1

exchanger and the weak liquor cooler, absorbs the $NH_3$ gas. From the absorber, the strong liquor is pumped to the generator, passing first through the exchanger where it cools the weak liquor.

The cooling water passes first over the ammonia condensers, then through the absorber and then through the rectifier and weak liquor cooler. In each of these apparatus the water is heated; after leaving the weak liquor cooler the water is sent to a cooling tower or spray pond where its temperature is reduced, the water being ready to be recirculated.

For different levels of temperature, the multiple effect invented by G.T. Voorhees is also used in the Absorption System. This is accomplished by means of the multiple effect receiver, where the $NH_3$ is expanded to the highest pressure used; this expanded $NH_3$ goes to the M.E.R. where it partly vaporizes, thus cooling the $NH_3$; part of this $NH_3$ is circulated through the high temperature level to be maintained while the rest is expanded again to a lower temperature.

The effect of the temperature of the cooling water and the pressure of steam used in the generator is very marked. We have seen that if the temperature in the absorber is about 30° C, the weak liquor will ~~not~~ absorb but 70 % of the gas absorbed at a temperature of 10°C. This shows that in summer time, when the plant is worked to full capacity, or sometimes over capacity, the absorption plant will be working to about 70 % of its capacity. This is surely the reason why the absorption machine cannot compete with the compression machine in tropical climates.

Also, when more refrigeration is necessary, we generally increase the steam pressure used in the generator coils thus increasing the pressure of the $NH_3$ and the pump sending the strong liquor into the generator will have to be increased in capacity to be able to work against the higher pressure maintained in the generator.

3. - Advantages and Disadvantages of the two Systems.

If we were asked to decide what system was the best to install in a certain locality for a certain purpose, we would have to consider: first; if there are various temperature levels to be maintained, with large fluctuations in the demand for refrigeration we would install preferably the absorption system. This system automatically regulates itself to variable demands, for refrigeration, as would be the case in an ice plant where the plate system was installed. The temperature of the refrigerant has to be lowered in a plate plant as the thickness of the plate ice grows to take care of the lower heat transfer. Also what low temperatures have to be maintained, as in fish storage, the absorption system is best adapted for this purpose. When there is plenty of exhaust steam available, as in hotels, the Absorption machine may be used in conjunction with the compression machines advantageously. If the cooling water available is small in quantity, with a large amount of chemical contents and of a high temperature the compression system will give better results.

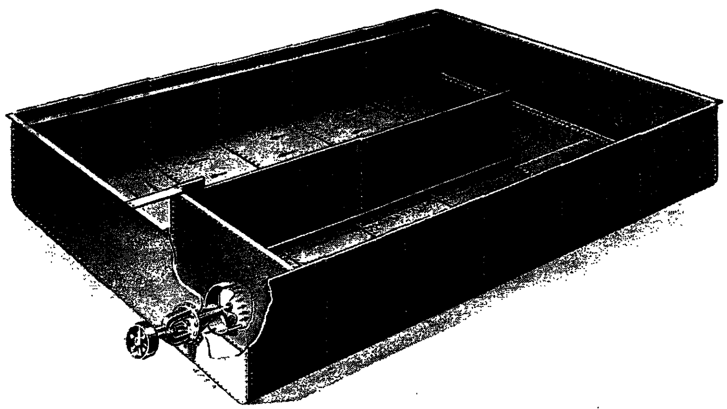
If the space available for the plant is very small and the temperatures to be maintained very low, then the $CO_2$ compression machine will give best results. It must be understood that cooling water must be available, in a $CO_2$ compression plant, at a temperature not higher than 70° to 75° F, as the critical temperature of $CO_2$ is 88° F.

If high temperature cooling water is used in connection with these plants, the $CO_2$ gas in the condensers will not liquefy, thus the heat transfer will be very small and the capacity of the whole plant will be very much reduced. Where plenty of space is available for the erection of the plant at a low cost and the price of $SO_2$ is small, then the sulphur dioxide compression machine may be used advantageously. In the United States this kind of machine is not used, while in Europe it is used extensively.

4. - Freezing Tank, Harvesting Apparatus, Ice Storage.

Having discussed the type of refrigeration best adapted for a certain ice plant we must turn now to the freezing tank, that is, the reservoir where the cool brine freezes the water and turns it into ice.

For the Can Ice System, the tank design is very nearly standardized whether made of wood, concrete or steel. The wooden type may be considered obsolete and was used where wood was of very good quality and of low cost. It had to be calked very carefully to prevent leaks. The concrete tank has also been used, but it is difficult to prevent the appearance of cracks which will, in time, develop leaks. The steel tank is the most reliable, built up of riveted steel plate with partitions for directing brine circulation. For a giv-



Ice Freezing Tank—Assemble

Fig. 2

en refrigerating capacity the tank size will be found as follows:-

$$\text{No. of Cans} = \frac{2000(\text{capacity of compressor})(\text{No. of days for freezing})}{\text{Weight of the ice block}\left(\dfrac{\text{Tank Tonnage}}{\text{Compressor Tonnage}}\right)}$$

All tanks, whether built of wood, cement or steel must be carefully insulated, considering the heat transmission and the moisture resisting quadities of the insulators. (See Fig. #3) Air spaces, cork (granulated, in planks or impregnated), saw dust, wood shavings, etc. are all used as tank insulation. Waterproofing of tanks is done by pouring asphalt or pitch between layers of insulating material.

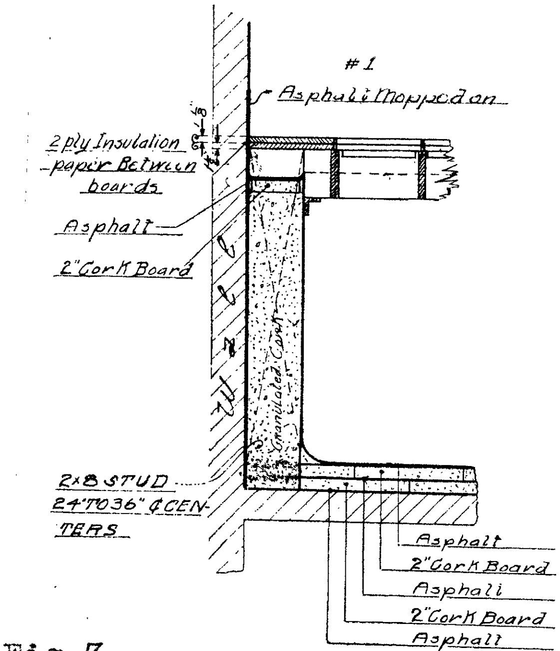



Fig.3

Installation of Freezing Tank.

The top of the tank is made up of longitudinal and transverse wooden strips forming a grill work (See Fig. #4) and leaving rectangular spaces where the cans are inserted; on top of the cans

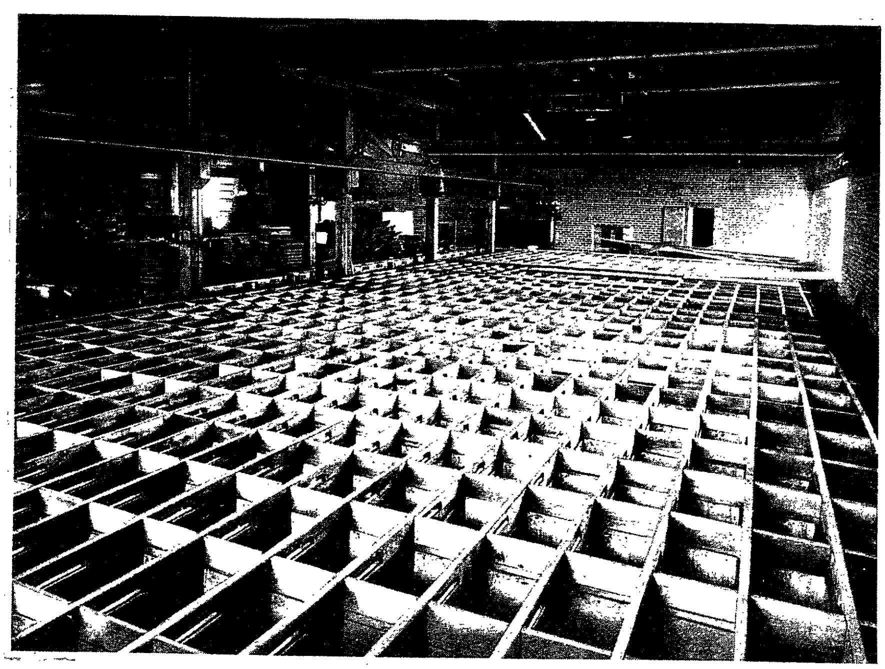
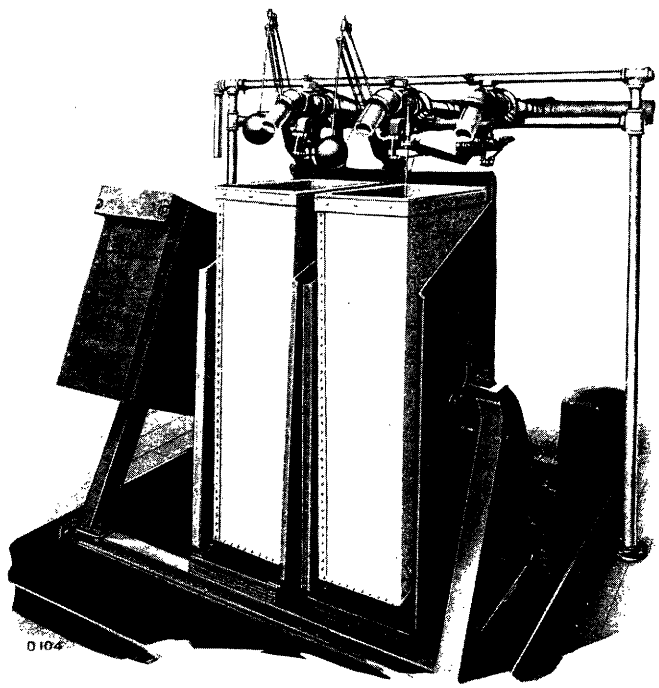


Fig. 4

comes the heavy wooden cover to prevent bacteria depositing on the water and also to prevent the can from tipping.

The brine agitation is accomplished by means of propellers or agitators which may be either vertical or horizontal. The horizontal belted low speed large diameter propeller gives better agitation than the vertical high speed directly motor-driven agitator. The propellers are usually set at the end of the tank, and for large tanks two or more propellers may be used to insure good circulation. When a brine cooler is used instead of the cooling coils the propellers are used to force or pull the brine through the cooler tubes and in general we need more power for agitation with a brine cooler than with coils, even if the brine friction through the coils is much in excess than through the tubes of the brine cooler. Good brine circulation has to be used with brine cooler, because the more dense (the cooler) brine is at the bottom of the tank and no convection currents will be set up within the brine, as is the case with the cooling coils where the colder brine is at the top. Also, the driving apparatus for propeller must be very reliable in case of the plant equipped with brine coolers, as any interruption will freeze the brine in the cooler and thus prevent any heat transfer from $NH_3$ to gas. The brine used for a brine cooler must be a Calcium Chloride brine as the Sodium Chloride brine will freeze or at least will precipitate so much of its contents as to plug the brine cooler.

The freezing tank for a plant working on the plate system will be different in design as that used for the can system. This tank is more elaborate in construction, has to be of a larger size to have the same refrigerating capacity of the tank for the can system, due to the fact that it takes from six to seven days to freeze plate ice instead of two days for the can ice. Other tanks of special design are those used in connection with the different raw water systems (as the stationary can system built by the Arctic-Pownal Co.) or for the double freeze ice can system to insure rapid congelation of water in cans. The harvesting apparatus used in can ice plants consist of cranes to lift the cans and carry them to the dumping device; the thawing and dumping device and the can fillers. The hoists or cranes used for lifting the cans may be operated by means of compressed air or electricity. Lately, the electric cranes are being used extensively to lift two, three or more cans at one time. The thawing and dumping device is all in one apparatus; as the dump is tipped over, the water connections open, the ice is thawed out of the cans and goes to the ante-room by chutes. When the dump is back to its original position, the water connections are closed. The cans may now be filled by opening a valve which brings the water from a reservoir or else the cans may be put back into place and filled with the au-

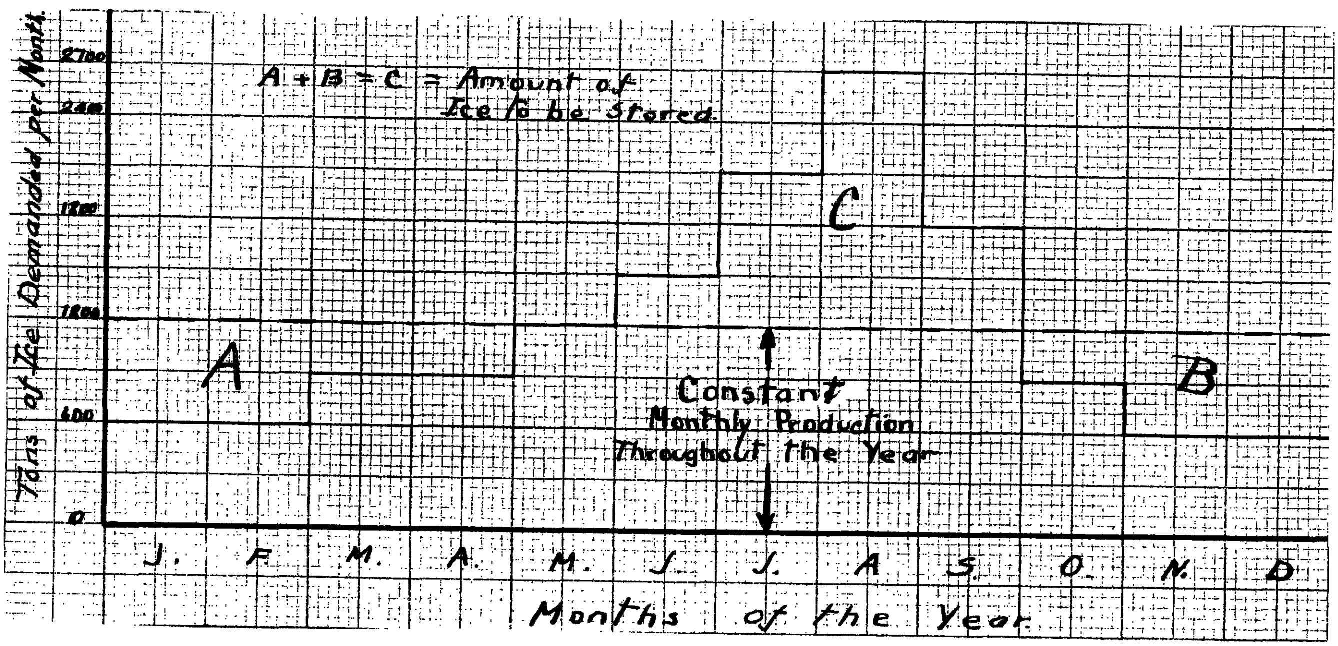


Views of Can Filling Apparatus at Dump

Fig. 5

tomatic can filler. The first method (See Fig. #5) is found more efficient and more clean, as the can filler is usually left on the tank covers and becomes contaminated with dust and bacteria.

For the plate ice plant the harvesting apparatus includes the crane, the thawing for the lifting bars, and the "tipping plate" where the plate ice is cut in small blocks of 300 # by means of electric driven disk saws running lengthwise and crosswise of the plate ice. Ice storage facilities are always provided with the modern ice plant. The reason for its use is the seasonal demand for ice which makes necessary the use of a large reservoir if the machine is to run all year around with a high load factor. The capacity of the storage must be calculated from the demand curve which gives us the total ice consumption for the year; from this value we should get the average amount that must be produced daily or monthly for such consumption (See Diagram).




From such demand diagram the amount of ice that need to be kept in storage can be calculated and then the size of the storage room will be found by allowing from 50 to 55 cu. ft. per ton of ice stored.

The storage house may be built of concrete or brick with cork lining or air spaces to minimize heat leakage. After the area of the house has been found the heat leaking through walls, roof, floor and doors may be calculated and the refrigeration necessary in the storage house figured. The temperature in the ice storage room must be from 22° to 28° F.

5. - Methods of Ice Making.

The usual classification of the methods of ice manufacture are:- the Can System and the Plate System. In the can system distilled or raw water may be used, while in the plate system raw water is always used and is counted among the advantages of this system. Other advantages of the plate system are the low cost of manufacture. But its disadvantages are numerous:- (1) the first cost of the plant is larger than with the Can System; (2) greater tank area than that used in the Can System is needed for the same amount of refrigeration, due to the low rate of freezing; (3) loss due to breakage very large; (4) ice of very irregular thickness ; (5) ice blocks not regular in shape, which makes difficult its storage.

On the other hand, if a Can System is operated to work on raw water as the plate system does, the number of machines and the number of laborers will be far greater than those working in a plant with the Plate System; also the repair and maintenance charges are greater, which accounts for the high cost of manufacture. In the Can system the water is frozen in metal cans which are put inside of the freezing tank; these cans are surrounded by circulating brine which eventually freezes the water in the cans at a rate depending on the brine temperature and size of the can. Cans are made of several sizes, but the one most commonly used is that giving ice blocks of 300 pounds.

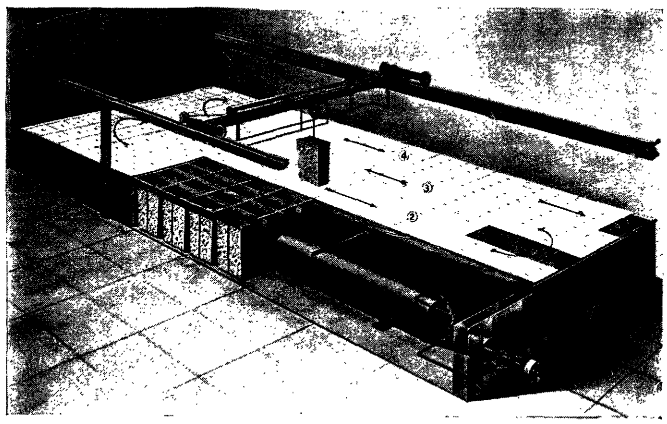


Fig. 6

A typical illustration of the freezing tank for the can system may be seen in Fig. 6. The brine is cooled by means of the cooling coils or brine cooler. In the first case the $NH_3$ brought to the upper coils through a header is expanded through throttle valves connecting the header with the coils; when the gas has been expanded in the coils it is taken away to the compressor through the exhaust header connecting the lower end of the coils. If the $NH_3$ gas reaches the compressor wet, the coils are said to be working under "wet gas expansion" and if the gas reaches the compressor dry or superheated then we say that the coils are working under "dry gas expansion." Much discussion has arisen whether the "wet" or "dry" expansion will give better results. In the case of the "wet" expansion, the heat transfer from brine to coils is better than in the case of "dry" expansion, but the amount of refrigeration is also less. Lately the advantages of "dry" compression have been well understood especially when the coils or brine cooler are working "flooded" with $NH_3$. The flooded system was devised to have liquid $NH_3$ in the cooling coils in order that the heat transfer from brine to coils might be greater. In the flooded system the $NH_3$ from the receiver goes to an accumulator which serves as a separator so that no liquid $NH_3$ might be carried to the compressor and also serves to precool the liquid ammonia in the case of the "gravity flooded system" or as a regulator of ammonia supply to coils in the case of the "combination flooded system." In the "gravity system," the $NH_3$ is precooled and expanded inside the accumulator; this expansion cools the liquid $NH_3$ which flows by gravity from the accumulator to the coils entering at the lower part of the coils; the $NH_3$ vapors are taken away at the upper part of the coils and carried to the accumulator where they leave any entrained liquid; from the accumulator the $NH_3$ gases go to the forecooler and then to the suction of the compressor. In the "combination" system the liquid $NH_3$ from the receiver is fed to the liquid header (connecting to the lower part of the coils) by means of a feed valve; the gases formed are taken to the accumulator where they are dried and the liquid in the accumulator is fed to the liquid line by gravity through a check valve. The "flooded" system has many advantages over the direct expansion system; less coil pipe (about 30%) needed to produce the same amount of refrigeration than with the direct expansion system; better heat transfer secured; less number of feed valves required; supply of $NH_3$ to coils is automatic, thus insuring more even temperature throughout freezing tank; this system specially good when there is need of irregular supply of refrigeration, as in the Plate System. The disadvantages are that we need more $NH_3$ for the flooded system (about twice as much) thus the cost of losing the charge from some accident would also be greater and the agitation in the flooded system must be greater than in the direct expansion system.

In the coilless system, the $NH_3$ cools the brine in a device similar to a tubular boiler (See Fig.7) thus eliminating the necessity of the cooling coils. The brine is circulated through the tubes of the brine cooler and then throughout

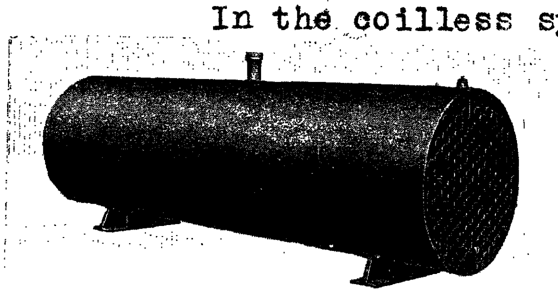

SINGLEPASS BRINE COOLER

Fig. 7

the tank by means of the agitators. In reality this coilless system is an improved flooded system where the $NH_3$ gases are removed as fast as they are formed in the brine cooler. These gases may be taken directly to the forecooler and then to the suction of the compressor, or best, a separator should be installed between the brine cooler and the forecooler to be sure that no liquid $NH_3$ will reach the compressor. Calcium Chloride brine must always be used in connection with the coilless system, to insure against brine freezing in the cooler and also the agitation should be large and reliable to have even temperature throughout the freezing tank.

The Plate System was devised in order to use raw water, as the cost of distilling water in the evaporator was very large or else the plant was very inefficient if the exhaust steam from the engine was used to make ice. In the plate system ice is formed on the surface of steel plates; between two plates are found the coils for the $NH_3$ expansion which cool the brine surrounding them; these plates run all the way across the width of the freezing tank. These plates are surrounded by raw water which freezes to the surface of the plates. When the ice is of sufficient thickness, say 7 or 8 inches, the $NH_3$ is turned out and the ice is allowed to season for two or three hours. The warm $NH_3$ or steam is turned on to the plates and the ice is thawed in this way. Then the plate ice is lifted out by means of cranes pulling on the lifting bars which are thawed off and then the ice out on the tipping table. The lifting bars are then put back in position, the water allowed to enter the freezing tank and the $NH_3$ is turned into the expanding coils again.

The tank is costly in construction, specially due to its large size; the ice is frozen from one surface only instead of four as in the can system, which fact accounts for the long time necessary to freeze ice in the plate system. In order to do away with the "tipping table" which is one of the disadvantages of the plate system, some other methods have been devised to cut the ice. The Hill-Ray system consists in cutting the ice when it is adhered to the freezing plate by means of steam cutters welded to the plate itself. Also, the block may be cut as before with a steam cutter (which is not welded to the plate) handled by the operator. When the blocks have been cut the ice is raised by means of mechanical or pneumatic hoists. To increase the rate of freezing, the "center freeze" method has been devised, where the water surrounds the pipe for $NH_3$ expansion, there being no plate. The rate of freezing increases very much, but this system has the disadvantage that the ice has holes inside the blocks which increase the rapidity of melting and also give a poor appearance; thus the ice becomes of little demand by the consumers and therefore not merchantable. Also the difficulty of storage is large, due to the round surface presented by the ice.

On the whole, we may say that with the great success of the raw water can system, the best advantage of the plate system (that of using raw water) is very much impaired and the plate system is not used very much now and perhaps in the very near future this system of ice manufacture will become obsolete.

## PART II

## WATER FOR ICE MAKING

There are two distinct processes of ice-making,- the distilled water and the raw water processes. The former of these two is now practically extinguished by the latter's competition.

1. The Distilled Water Process.

This process is used at present only in those localities where the raw water has too many impurities, organic or mineral. Its principle consists in freezing the exhaust steam that comes from the engines. Hence, in distilled water plants steam economy is not being sought. The more exhaust steam obtained the greater the capacity of the plant. Sometimes even live steam has to be sent into the condensers to obtain a certain capacity.

A distilled water plant is necessarily an inefficient plant. The exhaust steam passes through a grease separator, where it is cleaned of oil and grease. From the separator it goes to the condenser which is usually of the Atmospheric Steam Condenser type. It consists of a number of flat coils of pipe known as the stands through the interior of which the exhaust steam is made to pass, while the cooling water trickles down the outside. After it passes through the condenser, the condensed steam goes to the Reboiler and

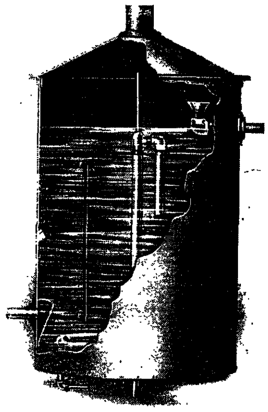
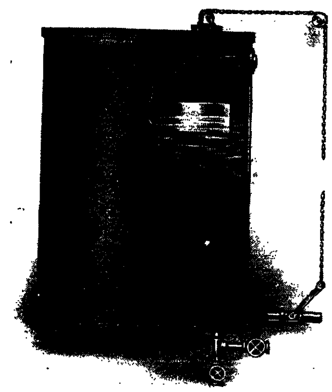


Fig. 1

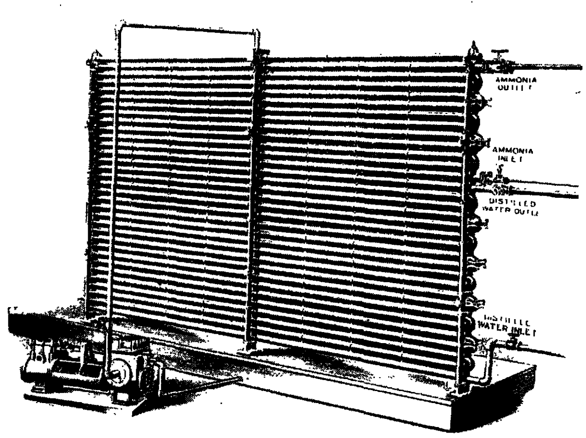
Reboiler.

Skimmer shown in Fig. 1, where the condensed steam is further purified and cleaned. This now goes to the hot water tank shown in Fig. 2, where it is cooled down somewhat before it goes to the Condensed Water Coolers which usually are of the atmospheric type or of the double-pipe type systems. Their construction is similar to the Steam Condenser. If the product that comes from this Water Cooler has bad odor or bad taste, it is made to pass through a deodorizer, which is really a charcoal filter in which the last remaining impurities are left behind, and all odor and bad taste removed. This deodorizer is seldom necessary. The puri-



Hot Water Storage Tank.

Fig. 2



De La Vergne Forecooler.

Fig. 3

fied water goes next to the forecooler, shown in Fig. 3, where its temperature is reduced to about 33° F before it is sent to the cans. As shown by inspection of the illustration, both the ammonia and the water enter their respective flat vertical coils of horizontal pipes at the bottom, and are caused to circulate upwards. The upper coil is a direct expansion ammonia coil into which ammonia is expanded as usual. A small circulating pump serves to provide a shower of water which is continuously sprayed over both coils, dropping down from pipe to pipe, first over the ammonia coil and then over the distilled water coil until it is deposited in a pan below. The over-flowing water is first cooled down by the ammonia coil and it in turn reduces the temperature of the distilled water in the lower coil. Thus the counter current or counter-flow of heat principle is used here. Forecooling the water is important, as it increases the capacity and the economy of the plant. From the forecooler the water goes to the ice cans which are made of six standard sizes - 50, 100, 150, 200, 300 and 400 lbs.

The system described above is based on the principle of using exhaust steam for final freezing. There is another distilled water system which is much better and that is the evaporator system. This system enables one to use the distilled water process and at the same time increase the efficiency of the engines. The exhaust steam from the engines go to evaporators which consist of tanks through which coils carrying the exhaust steam pass, heating and evaporating the water in the tanks which is then condensed and purified as described previously and used in ice-making. The addition of evaporators increases the efficiency of the plant and its capacity.

Undoubtedly with such a pure water very clear cakes of ice are obtained, but the distilled water plant cannot compete where raw water plants can be operated,as the latter are much more efficient and can produce more ice at a cheaper cost.

This system is practically obsolete at present and nearly all plants which were making distilled water ice are now being changed to the Raw Water System, to enable them to compete with their modern rivals.

2.- Raw Water Process.

This is the most economical process for manufacturing ice. It was primarily introduced on account of the high cost of fuel and labor which was so extensively used in distilled water plants. In this system, oil engines, gas engines, electric motors, uniflow steam engines can be used as prime movers, whichever results most economically in the particular locality where the plant is going to be located.

a) Effects on the Quality of the Ice of Carbonates, Sulphates, and of other impurities and their treatment.

One of the difficult problems in the raw water system is to get rid of carbonates and sulphates that may be present in the water. If the water is very hard it must be treated chemically. Calcium Carbonates usually form a gritty, dirty colored deposit in the ice usually in the lower part and center of the cakes. It causes shattering at low freezing temperatures. When such water is treated with hydrated lime the impurities are eliminated. Magnesium carbonate behaves in the same way and is eliminated similarly.

The sulphates and chlorides give a more difficult problem of elimination. Magnesium sulphate and magnesium chloride form opaque greenish or grayish colored cakes, concentrated mostly in the cores and retard freezing. These are corrosive minerals. They also cause dirty colored streaks in white ice. When magnesium sulphate is treated with hydrated lime it changes to calcium sulphate. Magnesium chloride changes to calcium chloride and there is little purification.

Sodium Carbonate and Sodium Sulphate are the worst impurities to get rid of. Sodium carbonate when present, even in small quantities, causes shattering at freezing temperatures below 15° F, and white ice is the result. It concentrates in the cores and retards freezing, but does not form deposit. The purification of the water containing these carbonates improves little when treated with hydrated lime. Water containing much of these carbonates is unsuitable for ice-making. Distillation is the only way to remove sodium salts. This chemical treatment of very hard waters is necessary before they go to the cans. When the water reaches the can, during the period of freezing, it is agitated mechanically by air pressure.

b) Purification of the Water.

The important step which leads toward getting good, clear ice is the purification of the water if it is possible to do so. If the sum of the sulphates, chlorides and nitrates plus the sodium carbonate does not exceed 20 grains per gallon, the water can be purified. If this sum is greater than 40 grains, the water cannot be used satisfactorily. Up to 12 grains per gallon of these mineral impurities the low pressure drop pipe system of air agitation may be used. If the air for agitation is admitted at the very bottom of the can, the sum of these minerals can be up to 20 grains per gallon.

If the iron oxide amounts to 0.02 grains per U.S. gallon, its removal by purification should be done. A very small quantity of iron present is sufficient to badly color other minerals that may be present, and this discoloration is magnified by the ice itself.

c) Core Pumping.

If the water is good, ice can be made without any chemical treatment if cores of sufficient size are pumped at the right time. In some cases two or three cores must be pumped.

If the water is hard and can be purified, good ice can be produced and only one small core removal will be necessary. Usually the cores do not need to be removed with the average water. Treating always saves core pumping and reduces the labor on the can floor.

When a can of water starts to freeze at first the outside generally will freeze free of impurities which are being kept agitated by the air. The impurities start to collect in the unfrozen water that finally becomes the core. As the cake continues to freeze, this matter concentrates more and more. Finally it begins to freeze into the ice causing deposit, discoloration and other trouble, unless the core water is pumped promptly.

Thus if water is treated chemically and these impurities are removed or reduced, the heavy concentration of these impurities will not be so early in the block. A strong concentration of the minerals will not be reached until but a small core remains unfrozen, which is pumped out promptly. The saving in core pumping by using treated water increases the capacity of the plant from 4 % to 10 %.

d) <u>Softeners and Filters.</u>

An "International" hot-flow softener in which the chemicals are fed proportional to the flow of water into the softener is shown in Fig. 4. The chemical solution is diluted in the upper U-shaped receptacle, and then is

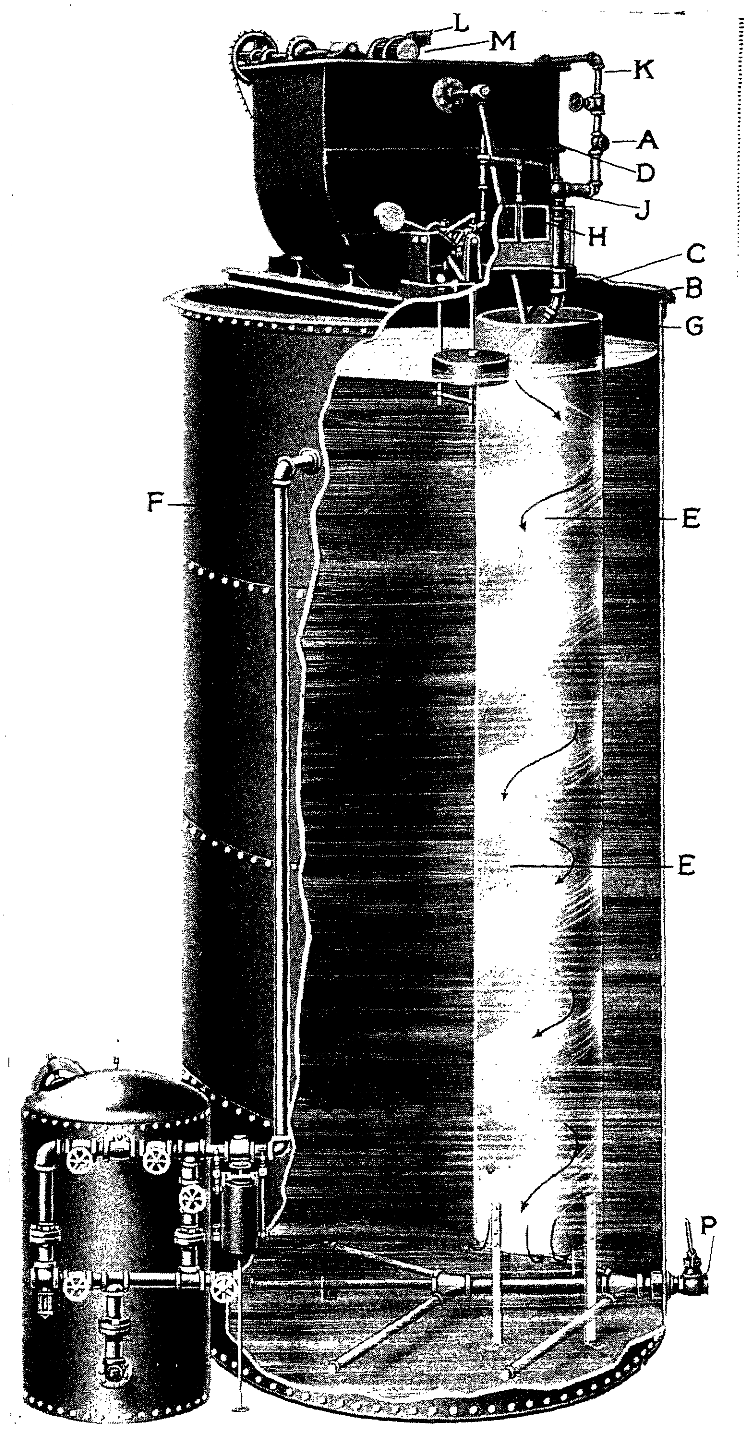


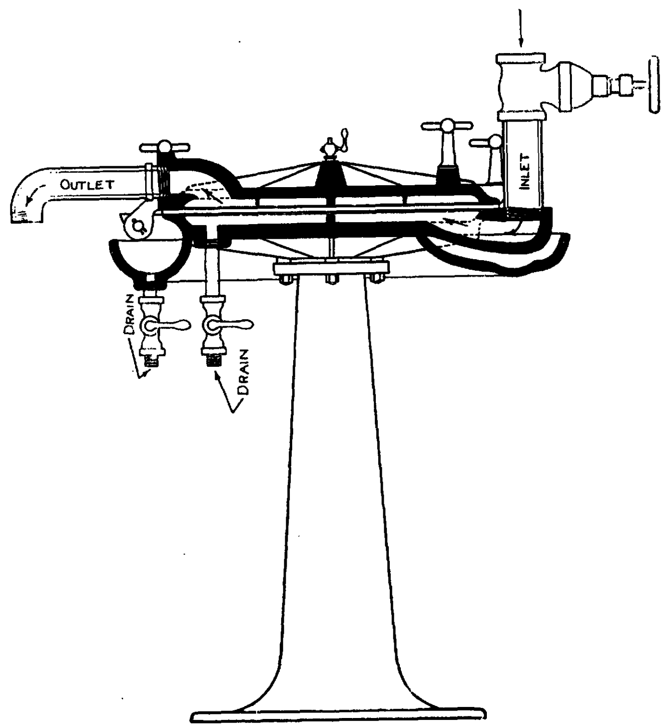

*Fig. 13.—International Water Softeners—Type J —Showing Automatic Control and Interior of Sedimentation Tank.*

Fig. 4

pumped into the hot-flow softener near the top where it mixes with the water to be softened.

Figure 4 shows plainly the operation of the softener. Raw water enters at (A) passing through the control float chamber (H) discharging through an orifice at the deflecting elbow (G). Here it meets the stream of measured chemical (C) from the chemical feed pipe (D). The water and chemicals are thoroughly mixed by the rotary motion which is imparted to the water in the reaction chamber (E). The objectionable dissolved mineral matter is precipitated by the action of the chemicals and settles in the bottom of the tank as the water slowly rises. The softened water passes through (F) to the filter which removes the last traces of suspended matter and colloidal hardness.

Water is extensively purified by means of filters. A common type of filter used is the "International Disk Filter." The filter medium consists of compressed cotton fibre which is inexpensive; this fibre is discarded when clogged and replaced with new one. It is used in filtering comparatively clean waters. For very muddy waters, a combination of the Sand Filter and the Disk Filter should be used. This sand filter is constructed and operates on the same principle as the larger filter plants used for municipal water supplies. It removes the heaviest suspended matter and prevents frequent clogging of the Disk filter. There is no possibility of the filtered and unfiltered water mixing or going around the disks, as the latter extend to the very edge of the filter shells, which tightly hold the disks in between, thus forming their own gaskets. The cross-section shown in Fig. 5




**Cross-section of the International Disk Filter showing Upward Filtration**

Fig. 5

shows clearly the passage of water upwards preventing any undue clogging. This disk can be operated under pressures up to fifty pounds. A pressure regulator and water relief valve should be put in the pipe line to the filters. Filters are also made to operate under greater pressure.

Perfect filtration depends upon the slow and uniform passage of water through the sand bed. A pressure filter should have a capacity of about 3 gallons per minute per square foot of filter area. Fig. 6 shows a pressure filter.

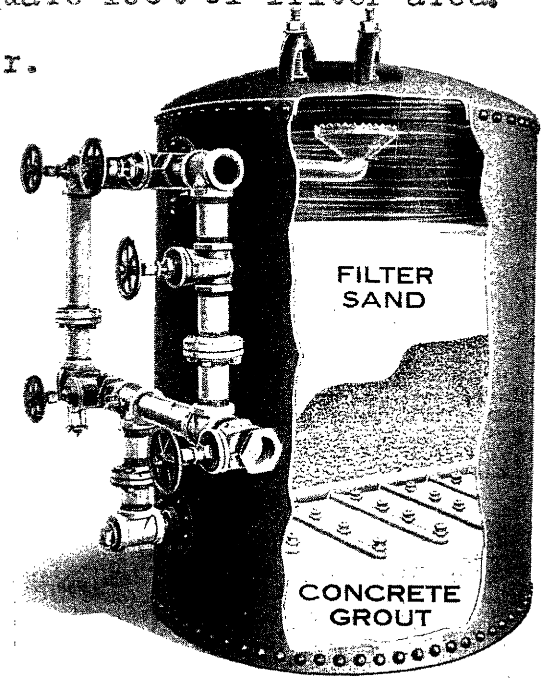



*Fig. 18.—International Sand Filter, a Part of Every International Water Softener.*

Fig. 6

Sand beds should be washed under a pressure of 15 pounds and the rate of flow of the washing water should be about 8 gallons per minute per sq. ft. of filter area. Cooling the water in the fore-coolers after it leaves the filters and before going to the cans is very important and brings economy.

e) <u>Agitation.</u>

If now the water is frozen in the can without agitation, it will be opaque largely due to the presence of air in the form of small bubbles throughout the cake.

By agitating the water during freezing, these small air bubbles are made to rise to the atmosphere and not cling to the surface of the ice.

There are various systems of agitation:-

1. The Low Pressure Air system.

2. The High Pressure Air system.

3. The fixed or Stationary Cell system.

In the low and high pressure systems there are numerous methods and details of introducing the air in the can.

The low pressure has a low initial cost, but the labor cost is greater. The system is simple to install and operate and is the most economical in power.

Sometimes thick cores are obtained due to removing drop pipe too soon, but this can be remedied without materially increasing the cost of production. If the water is hard it should be treated chemically to use with this system.

The high pressure and the cell system claim to produce better ice and a saving in labor, but the initial cost of equipment is greater and requires more power for its operation.

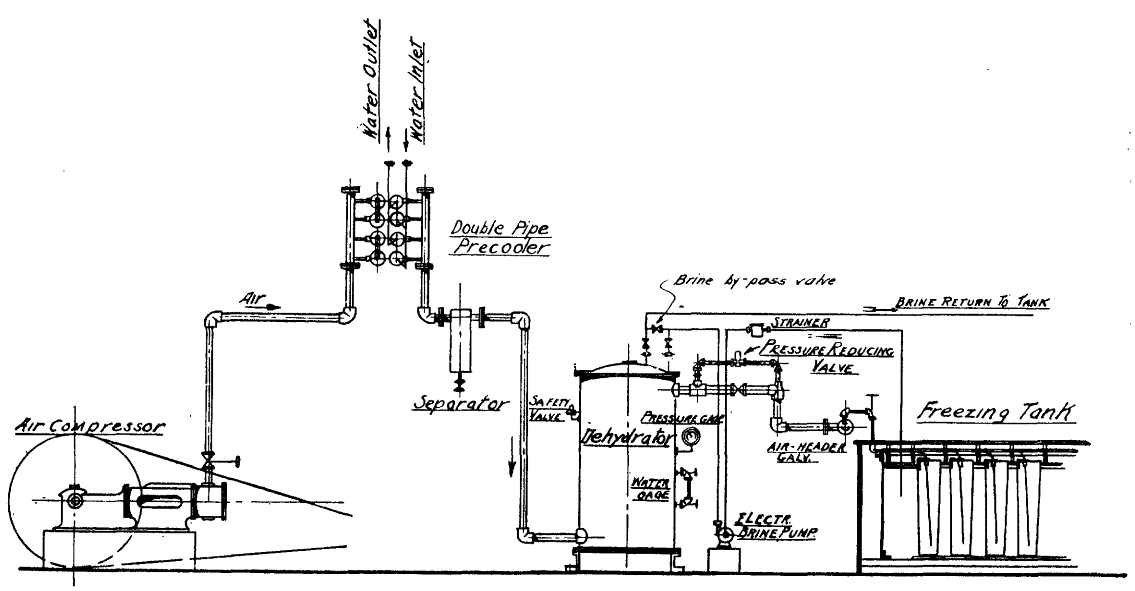



Fig. 15. Typical Arrangement De La Vergne Indico Aerating System.

Fig. 7

Fig. 7 shows a typical arrangement of a De La Vergne Indico Aerating system which is essentially a high pressure system. The air compressor should operate at a discharge pressure of 15 to 30 pounds per square inch, and can be of any type to suit local requirements. Following this sketch will give a clear, concise idea of the system. The temperature of the water in the dehydrater is maintained close to 32° F and the air passing up through this water is cooled, washed and dried before it leaves the apparatus. This is a combined dehydrator, air washer and cooler, is practically automatic in its operation and needs little attention once it is regulated.

The drop tubes are thawed out in but a few seconds while the cans are in the thawing tank, by inserting a thawing needle of very small diameter inside of the tube until it reaches the bottom. By that time the tube may be easily withdrawn with the thawing needle.

The importance of the drop tube location was described in preceding pages. The double drop pipe and the multiple drop pipe systems are now coming into use.

Another very important and quite different method of air agitation in the cans is the Pownell System as manufactured by the Arctic Co. In this system there is no drop pipe into the cans. The latter have the water and air inlet at the bottom of the cans, which are fixed in position.

Moderate air pressures are used and the agitation may be continued until the end of freezing as there are no pipes to be removed. The air and water connections are so arranged that one valve will control the filling of a battery of cans, another valve will control the emptying of the core water, and a third valve regulates the air for the whole battery. Practically all operations here are mechanical. The freezing process, treatment after freezing, refilling and the construction of the Pownell-Arctic Tank are new features in ice-making. A single man can harvest an entire compartment of 66 cans in a compartment in about 1 1/2 hours. This system is arranged so that one compartment is harvested every three hours during the day and night, saving an enormous amount of work and labor.

Another important system of air agitation is the York high-pressure system. Here, in order to avoid freezing up the air tube, when the filler is opened before the air is turned on, the combination air and water hose connection is employed, the air tube being inside the water hose and connected through the can filler head to the air hose. The pipe is soldered in position, in a crimp in the side of the tank, avoiding damage to the pipe. Also, as the tube is flat it will not burst if frozen up. There are also other systems in use of the low and high pressure like the Triumph, Frick, Jewel which are used, but more or less they work like the ones described above and on the same principle.

## General Comparison between the Distilled Water Process and Raw Water Process.

When the water available is liable to contain dangerous disease, germs or other impurities which make it difficult to produce a clear grade of raw water ice, the distilled water will prove an advantage. If there is a steam plant already installed and the labor of looking after a raw water system is thought undesirable, the distilled water has the advantage. In hospitals, appartment houses, etc. where the ice product is in very small blocks, the distilled water plant will answer the requirements. But at present, with the apparatus a raw water system has for purifying water, the distilled water plants would be at a disadvantage unless fuel and labor are cheap and the water so bad that merchantable ice is impossible to make by the raw water process.

Raw water plants allow the use of more economical prime movers and this materially affects the cost of manufacture. Raw water ice has a natural taste and can be manufactured just as clear and of as good quality as distilled water ice, though its appearance may not be as good.

## PART III

## LATEST DEVELOPMENTS IN ICE PLANTS

In recent years great improvements have been made in making the ice plant an efficient one. With the successful commercial application of the raw water can system, the good results of treating water chemically and the great efficiency of prime movers, we may say that almost in any locality the modern ice plant may be designed to give a high plant efficiency as compared with the old distilled water plants. The problem of remodeling old ice plants is more difficult, but is one that has to be solved for each plant individually in order that these plants may compete with the ice plants of modern design.

1. - The Modern Ice Plant.

In the design of a modern ice plant the most important questions to decide are:- the method of refrigeration to be used, either the absorption or the compression system, and the prime movers, which may be those working on steam, oil, gas or electricity. Assuming that the plant is to work on the raw water can ice system, as it is very improbable that any modern plant would work on distilled water or with the plate system, then we would have to decide also which method of air agitation will be best suited for the locality in question. We have stated above that it will be very improbable that a plant of modern design will make ice from distilled water, as this plant will only be able to compete with the raw water can system in localities when fuel is exceptionally cheap and where water is exceedingly hard. Even under those conditions, with the improved methods of water treatment, it is improbable whether the distilled water plant will be able to face competition with a raw water can ice system.

To be able to decide the best method of refrigeration to use, we have to know the amount and temperature of cooling water available, the temperature level or levels at which refrigeration will have to be supplied, the difference in cost from producing low pressure or high pressure steam and the kind of labor which will be hired. If a large amount of cooling water at low temperature is available, if the refrigeration is to be supplied at a low temperature and at different levels (of temperature), if skilled labor is found and large amounts of low pressure steam may be produced at a low cost, then the absorption system should be used, as it will give better results. In this case ammonia shall be the refrigerant as any other substance would make the apparatus exceedingly large. Perhaps the most important item under consideration is the cooling water available and if the temperature of this water is high, as for tropical climates, we will surely adopt the compression system of refrigeration.

When we have decided to use the compression system, the next question to decide would be what refrigerant to use. For tropical climates the $CO_2$ compressor will be discarded, as it is improbable that during summer time, when the plant should be working at its highest capacity, the $CO_2$ will be liquefied in the condensers. If the $CO_2$ is not liquefied then the refrigeration produced will be much smaller; so we shall have to decide on $NH_3$ or $SO_2$ as the refrigerant. Our decision will be based on the ease of acquiring the refrigerant and on its cost; also if the land for the plant is high in cost, we shall decide on the ammonia compressors as they take much less room than the $SO_2$ compressors. Where space is of prime importance, as in the case of ships, then the $CO_2$ plant will show the greatest advantages.

To decide about the best prime movers to use in the ice plant the question will be of an economic character, and the final decision will be in favor of that prime mover which will give the amount of power necessary for the least overall cost, that is, investments, first cost, operation, taxes, labor and repairs. The electric drive has many advantages and should be used when current is supplied at a low cost, as is the case in regions where water power developments exist. To the central station, the ice plant is an ideal consumer, as the manufacture of ice is a continuous process, all throughout the year, at 24 hours a day. This accounts for the low cost at which the current is sold to ice plants, but we must be sure that the central station will be able to supply continuous energy even in the case of breakdowns. The current rates are usually based on the highest demand for a period of 15 minutes, and this rate will apply for a certain small period of time, usually a week. It is therefore, the work of the engineer in charge of the ice plant, to have the consumption of current for a week's period as near to the highest demand as possible; in otherwords, he should try to maintain as high a load factor as possible. Another reason for the adoption of the electric drive is that the cost of producing ice is less than the cost of distribution; this being the case, our ice plant should be located as centrally as is found permissible and this means a very high cost of land. Now the electric drive will give the highest capacity per square foot of land and also we shall avoid the troubles of smoke present in the steam plant or the regulations for oil reservoirs in the case of an oil burning plant. Other advantages of the electric drive are the low cost of labor, depreciation, maintenance and repairs. It must be understood that the plant in general must be very elastic in its capacity or have a large ice storage in order to maintain a high load factor by varying the speeds of the motors and compressors to meet the weekly conditions of demand.

If current is not available at a low cost (not more than 1 1/2 cents per K.W.H.) then we must choose between the oil, gas or steam drive. In case the oil is cheap compared with the value of coal and sure supply may be had with good conditions for its storage the oil plant will prove very economic. It is true that the plant has a very high first cost, but the maintenance charges are very small, as a good oil engine will burn from 0.4 to 0.5 pounds per I.H.P. hour. There must always be at least one idle engine so that the whole oil plant shall not be working continuously for 24 hours any long period of time. This seems to be the only disadvantage of the oil plant, that up to the present time it is not reliable for continuous operation during long periods of time, say two or three months. When the first cost of the oil plant is excessive, while the difference in price between oil and coal is not great, then we must choose between the gas or the steam plant, both of them using coal as their fuel. Very good performances have been obtained lately with the producer gas plant in connection with ice making, as high as 22 to 25 tons of ice per ton of coal having been obtained when high class coal is available. The space occupied by this plant is less than that required for the steam plant, tho' much larger than for the oil or electric plant. The first cost of the plant is also larger than that of a steam plant, but the operating expenses are smaller. Though the gas engine is more reliable than the oil engine, still it requires more time for repairs and cleaning than steam engines and is not as reliable as the latter for long periods of continuous service. The steam plant of modern design with all the new auxiliaries devised in later years, is without doubt the most reliable for continuous operation through long periods of time and is therefore still used profusely in connection with ice plants. The very high performance of the unaflow engine (as high as 12 lbs. of steam per I.H.P. hour) has accounted for its general use in ice plants. This engine also provides for a wide range of capacity of the plant, as its efficiency at part load is very nearly the same as that accomplished at full load. This engine is essentially a high speed engine, therefore we should, as well as with the oil, gas or electric motor, need high speed ammonia compressors. When ammonia compressors of the slow speed type are used, then the connection with these high speed prime movers can be made by means of belting.

The question of the method of air agitation to use in the ice plant will depend entirely on the water available for ice making. In case the water is of good quality with little impurities and small amounts of dissolved or suspended chemicals in it, then a low pressure system could be used advantageously, but the water should be previously filtered. When very hard water is found then it should be treated chemically before it is sent to the fore-cooler. This chemical treatment should remove most of the ~~chemicals~~ impurities in water, specially those causing temporary hardness which cause the whitening of the ice; chemicals producing permanent hardness have been proven not to affect very much the quality of the ice produced. In case of hard waters, it is better to use the high pressure system of air agitation. Other important questions in this connection are that of labor and first cost of the system. The high pressure system is more expensive in first cost, maintenance and repair charges as there are a greater number of apparatus used, but the labor employed in freezing tank is nearly half as much as that employed with the low pressure system; on the other hand, the low pressure system is less expensive in maintenance and first cost. Due to the seasonal demand for ice a careful study must be made of curves of ice demand to be able to decide in which way shall the plant be designed to maintain the highest possible load factor throughout the year. If the plant were designed to give a capacity based on the demand for summer time, then we shall have our plant working on part load during spring and autumn while perhaps more than half of the machinery in the plant will be idle during the winter season. This means that the capital invested on the plant will be idle for a long time, thus the fixed charges will be very great. The best way to solve this difficulty is to have an ice storage of such capacity that the excess ice produced in the low-demand season will be stored for use during the summer season. In this way the plant shall work continuously during the year, (except for the time devoted to overhauling) the ice storage serving the purpose of a regulator of the output while the production is constant. For this reason, all new plants should have an ice storage to take care of the unequal demand for ice through the year.

2. - Modernizing the Old Distilled Water Plant.

The question of modernizing an old plant is much more difficult to answer than that of designing a new plant. In this matter, the last decision will be based on financial and economic problems, as they are the ones most important in this case. Another important point to have in view is that we may safely say that up to the present time no raw water can system gives as clear ice as that made with distilled water, and most of the ice manufacturers had given a great deal of advertising to the "clearness and transparency" of the ice. In case the plant were to be changed to a raw water system, all this advertising should be discarded and propaganda should be made to the effect of impressing upon the consumers the fact that the purity and healthful qualities of ice are not to be measured in terms of its transparency and also that all ice when in the process of freezing eliminates all the impurities that may previously have been found in the water. If this precaution is not taken the new raw water ice may not be as merchantable as the first. It must also be impressed here that the problem of remodeling ice plants is one that has to be solved individually for each plant and no general rules can be laid down. Nevertheless, a good method to be able to judge which will be the best way of changing old ice plants into new ones is to make a detailed study of the conditions in the locality, as temperature of cooling water and amount available, quality of water to be used for the making of ice, labor costs and other points. From these data we must design the complete raw water ice plant which will suit best the conditions found and then calculate the cost of the ton of ice as delivered to the consumer. Then make a detailed list of all the available machinery in the old plant that may be of future use and calculate the cost of the new machinery needed, together with the cost of installation; then compute the cost of ice with the plant as remodeled and compare this cost with that found for an entirely new plant in the same locality; this comparison will give an idea of what to do with the old plant, whether it is better to sell it out for any price and install an entirely new plant, or whether it is possible to remodel the old plant and still make of it a paying investment. If the old plant had non-condensing steam engines with slow speed single-acting ammonia compressors, the exhaust steam being used for ice making, it will probably pay to discard all this machinery, sell it at any price and install new high speed compressors with an efficient type of prime mover. If the plant were working with good prime movers and relatively new compressors using evaporators for distilling water, then the best thing will be to send back the condensate to the boiler and use that raw water system as will suit better the quality of water to be used.

Great improvements can be made in the old distilled water plant; in the freezing tank, by installing a "flooded system" instead of the old direct expansion system; by improving the method of agitation and by going over the freezing tank insulation. Specially in the old plants, very little attention was paid to the question of insulation and this is one of vital importance as far as freezing tank, storage house and low pressure $NH_3$ pipes are concerned. The methods of harvesting can be greatly improved by the use of large capacity electric hoists to handle three or more cans at a time; by filling the cans at the dump or while traveling back to their former position instead of using the automatic can filler; these two simple items may sometimes cut down the labor force in the freezing tank to one-half of the number previously employed. The cooling water system im ice plants is of course one of great importance. In the old plant the cooling water from the cooling tower or river was sent to a tank in the roof of the building and sent over by gravity to the condensers and water coolers; sometimes more than one or two pumps were used and the water circulated more than necessary, incurring in losses of head and thus increasing the power taken up by the auxiliaries. The cooling water system should be centralized and water cooling apparatus should not be laid down at any long distance from the water supply; that is, this system should be as compact as possible and also as near to the floor level as can be designed, in order that the circulating pump necessary should be as small as possible; use in this connection a high-efficiency pump (of the centrifugal type) coupled to an electric motor.

The compressor room then should be investigated; try always to use, if possible, high speed double-acting or compound compressors coupled to electric motors or high speed engines. The compound compressor has been very recently introduced and is used extensively in connection with electric prime movers as they permit of great variation in capacity with little change in efficiency. A great many of the old plants were designed to give the capacity desired at the maximum demand peak, with the result that during the winter season the plant works at a small-part capacity. In order to balance the plant, a study should be made of the advisability of erecting a storage house for ice with a reduction of the plant's capacity. In this way a great deal of saving can be realized. If the surplus machinery were to be sold at a great loss, then investigation should be made to the effect of enlarging the scope of the plant by erecting storage houses for fish, eggs, meats or by supplying refrigeration to nearby places for other uses, specially for air conditioning. In this way, for nearly the same expense in running the plant, the sales can be increased largely.

Again it must be pointed out that this problem of modernizing old ice plants is one to be solved not only from an engineering point of view, but specially from the monetary standpoint. The engineer should discuss at length his plans with the manager or with those responsible for the financial and economic activities of the plant and from this discussion the engineer should be able to devise those methods which produce, in the long run, the best results from the business point of view.

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