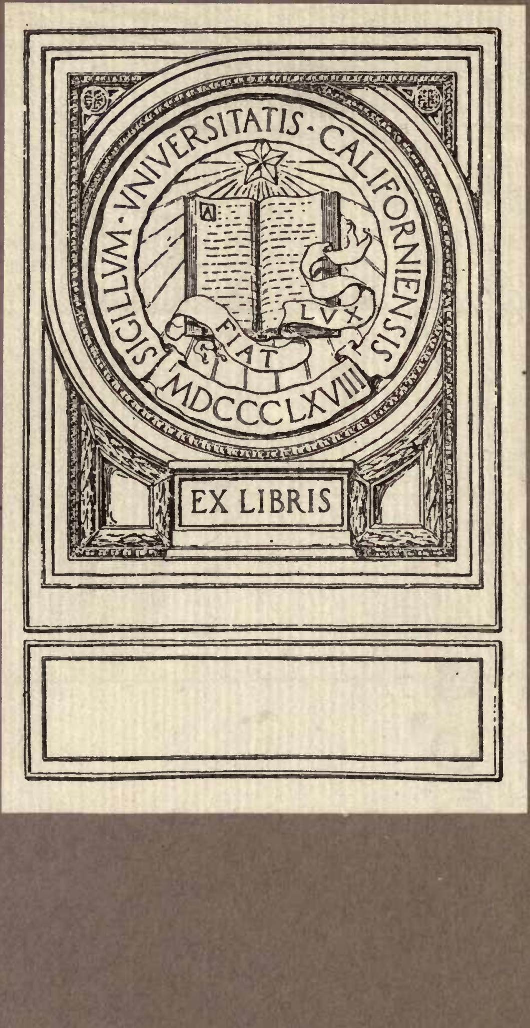

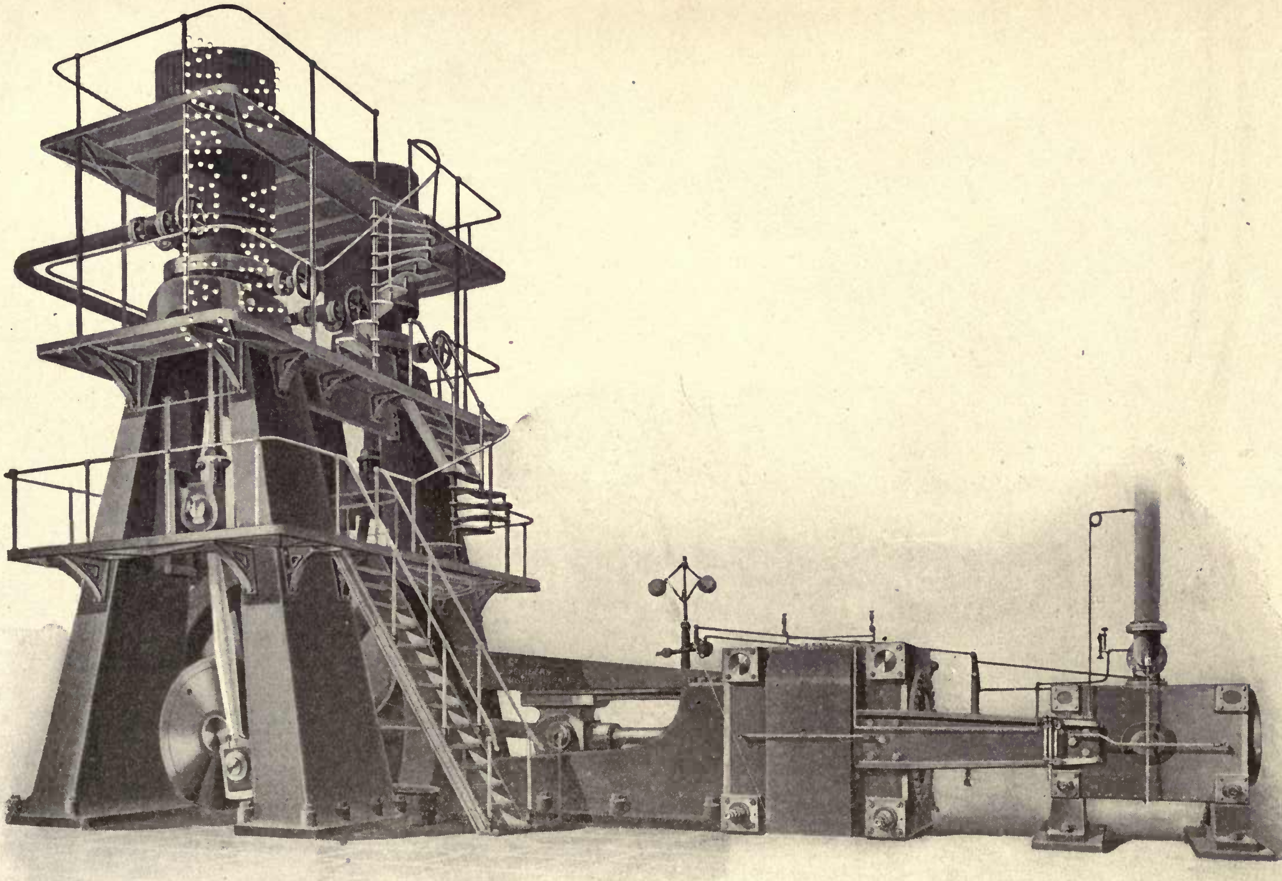

A LARGE REFRIGERATING MACHINE.
Frick Company.

American School of Correspondence
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Refrigeration Red

A Practical Treatise
ON THE SCIENTIFIC PRINCIPLES, MECHANICAL OPERATION, AND MANAGEMENT OF REFRIGERATING PLANTS BASED ON THE VARIOUS MODERN SYSTEMS OF ARTIFICIAL COOLING

By CHARLES DICKERMAN
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and

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Constructing Engineer

ILLUSTRATED

CHICAGO
AMERICAN SCHOOL OF CORRESPONDENCE
1909

Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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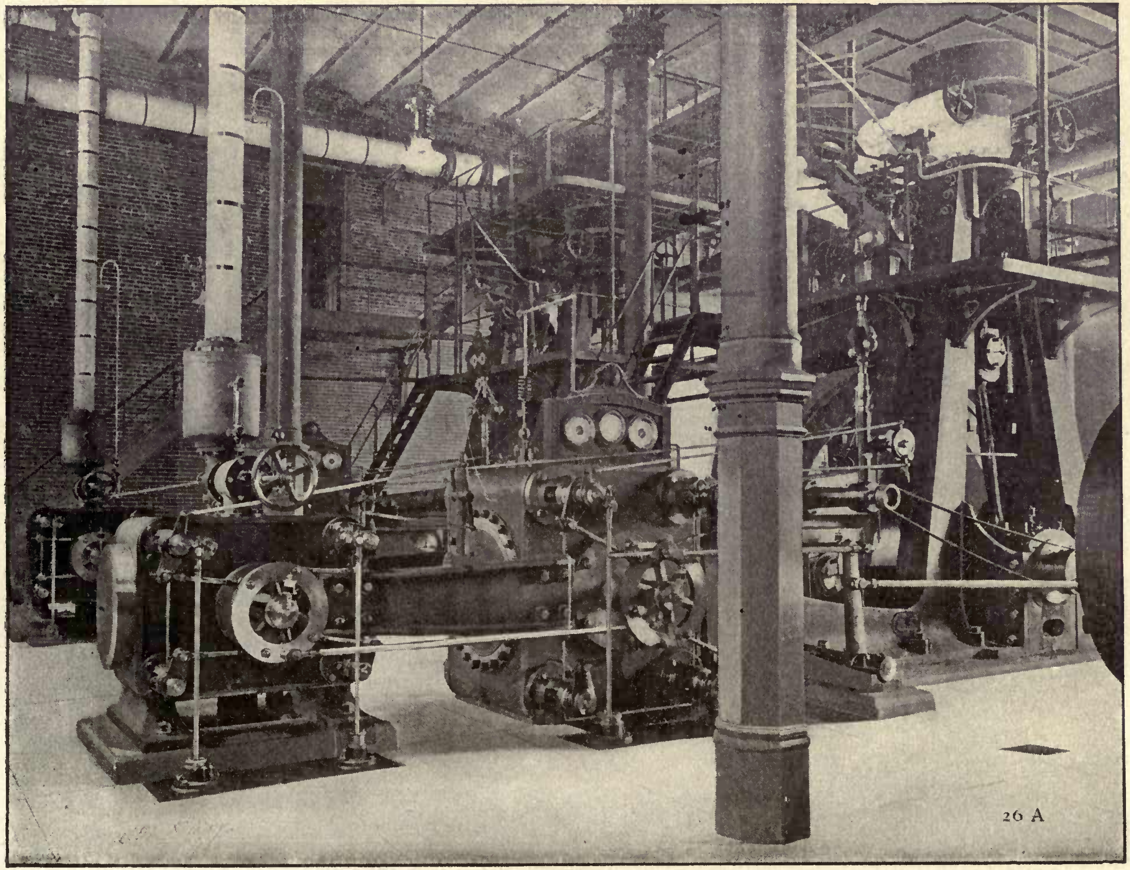


ENGINE ROOM ST. LOUIS REFRIGERATING AND COLD STORAGE CO.

REFRIGERATION

PART I.

Refrigeration may be defined as the process of cooling. It is artificially or mechanically performed by transferring the heat contained in one body to another, thereby producing a condition commonly called cold, but which is in fact an absence of heat. This transfer of heat is most rapidly and economically accomplished by evaporation, but before considering the apparatus used a few important definitions should be reviewed.

Unit of Refrigeration. The unit or basis of measurement of refrigeration, is the unit of heat, and in the United States and England is the British thermal unit (B. T. U.) which is equivalent the amount of heat to raising or lowering the temperature of one pound of water 1° Fahrenheit when at or near 60° Fahrenheit.

Specific Heat. Specific Heat, or capacity for heat, is the relative capacity of a substance for heat, and is stated or expressed relative to that of water, since water has the greatest heat capacity of any known substance except Hydrogen.

Latent Heat. When a body changes from a solid to a liquid, or a liquid to a gaseous state, a certain amount of heat must be supplied to it in order to effect the change. This amount is called its latent heat, and is expressed in thermal units. Thus we have in the melting of one pound of ice a latent heat of 142 thermal units, and we understand by this that in order to melt a pound of ice it must absorb into itself, in making the change, 142 B. T. U., or the equivalent of one pound of water changing 142 degrees Fahrenheit.

Units of Machines or Plants. The unit (or capacity) of refrigerating plants is ordinarily stated in tons, that is, the equivalent of so many tons of ice (of 2000 pounds) at 32° F melted into water at 32° F. The unit is equivalent to $142 \times 2000 = 284,000$ British thermal units.

Thermometers. For ordinary use, a mercury tube having a graduated surface or scale at its back with a bulb at its lower end and containing a quantity of mercury is used to denote the temperature of its surroundings.

Two different scales are commonly used in the refrigerating industries: the Fahrenheit and Reaumer. The Centigrade or French standard is used for chemical or technical purposes. In the United States and England the Fahrenheit scale is generally accepted as standard except in breweries where the German or Reaumer scale is quite often found.

The **Fahrenheit** scale is divided in such manner that the boiling point of water at atmospheric pressure is 212° and the freezing point 32°. It is said that 0° F was the lowest temperature Fahrenheit was able to produce by the melting of ice by salt.

The **Reaumer** scale is graduated by making the boiling point of water 80° while the freezing point is at 0°.

The **Centigrade** has the freezing point of water at 0° as the Reaumer, while the boiling point is fixed at 100°. This graduation is typical of the French system of measurement.

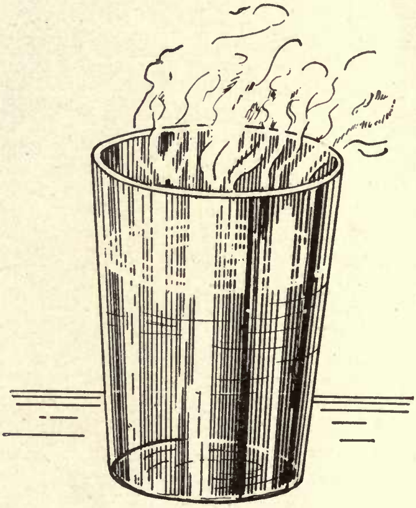


Fig. 1.

To transpose the temperature of one scale to that of the others the table on page 77 will be found convenient.

Let us now take an illustration from a branch of engineering with which almost every one is familiar.

If we place a glass of water in contact with heat at a temperature of 212° F or more, heat will pass from the source and be absorbed by the water until its own temperature reaches that of 212°, after which evaporation of the water commences and continues until the water has all been transformed into steam. During this time an amount of heat corresponding to this duty has been transferred from the source of heat to the water and its vapor called steam. This process is familiar to all engineers, in the steam boiler, and is similar to that of refrigeration as ordinarily applied, except that the one is going on at or above a temperature of 212° F (the boiling point of water) while refrigeration is accomplished by the evaporation of a liquid having a boiling or evaporporating point sufficiently low to obtain the desired temperature.

Agents. Among the most commonly used agents for obtaining artificial refrigeration may be mentioned Ammonia, Carbonic Acid, Sulphur Dioxide and Compressed Air, the first named being the most generally used and approved, while the others have advantages for use on ship-board and other places where the fumes of ammonia would prove objectionable. Ammonia, however, appears to present the most favorable qualities for general use, and will, therefore, be the principal agent considered.

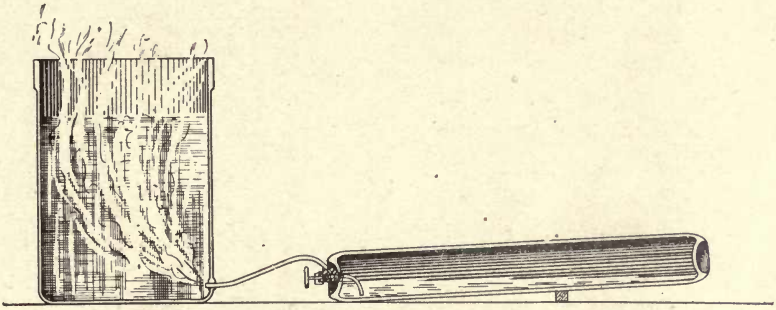


Fig. 2.

Of the two types of ammonia machines, the absorption and the compression, the latter will be the first described. The primitive process of refrigeration is represented by a glass or receptacle (Fig. 1) in which a quantity of anhydrous ammonia is placed, and which, so long as its own temperature and that of its surroundings remain at or above—28° F or 28° below zero (its boiling point) will continue to take heat over to itself, and therefore continue to evaporate and produce a cooling effect upon its surroundings, or what is commonly known as refrigeration in the body or substance with which it is in contact.

In Fig. 2 we have such a receptacle to which is attached a drum or flask filled with the refrigerating agent; if it were possible to procure a cheap volatile liquid, having a sufficiently low

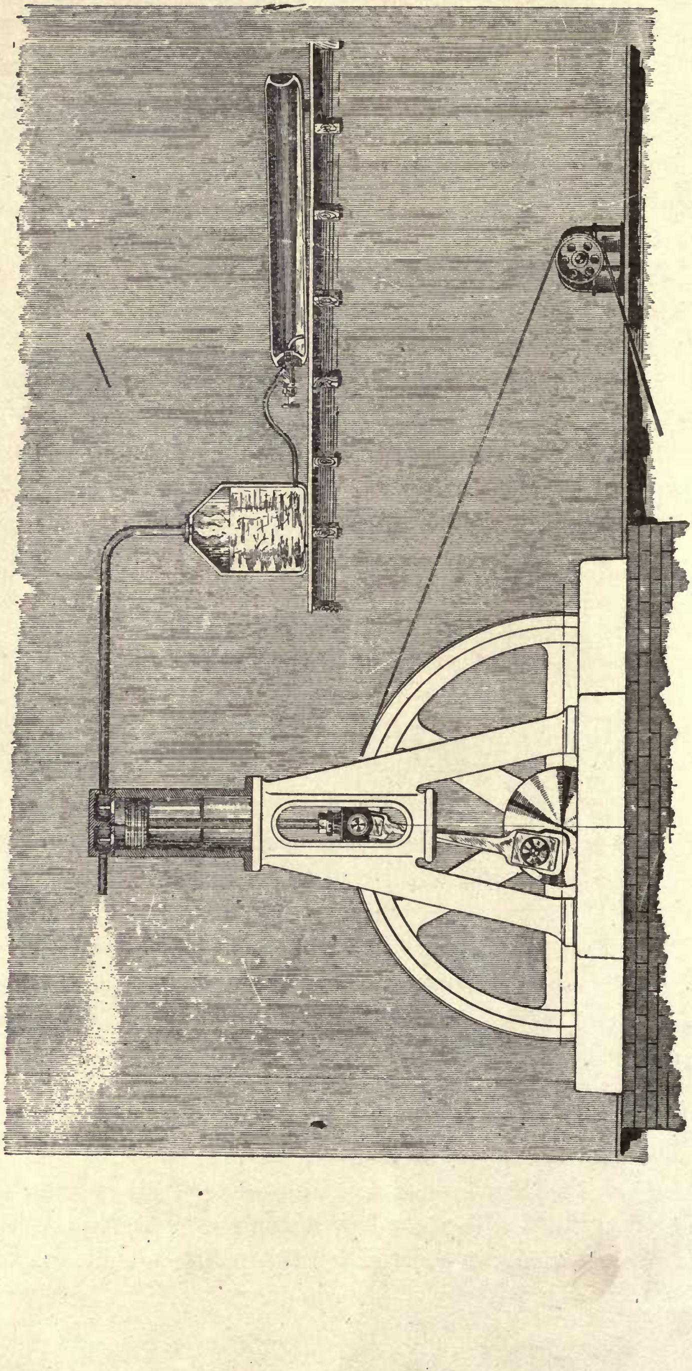


Fig. 3.

boiling or evaporating point, the complex systems of refrigeration would be reduced to the above parts, or equivalent simple system. The system would consist of an evaporator, and a receptacle for the refrigerant, with a connecting pipe between, provided with an expansion valve to regulate the flow of the liquid to the evaporator. The cost of ammonia or the refrigerating agent renders this waste impracticable, at least at the present time; and to make refrigeration a commercial success it becomes necessary to recover and put in condition to be used again the gases arising from the evaporating ammonia. We have seen how the ammonia absorbed a certain amount of heat from its surroundings during evaporation; it is evident that this heat must be taken from it before it can be again effective as a refrigerant, and for this purpose the compressor, condenser and other adjuncts to the plant are required.

The gas pump or compressor is the means employed to recover and compress the gas from the evaporator. In order, therefore, to continue the process of refrigeration in a commercial manner, it becomes necessary to connect to the evaporator and ammonia tank shown in Fig. 2, a gas pump with its engine or other form of power. This is illustrated by Fig. 3. The top of the evaporator is closed and provided with a connecting pipe to the compressor; upon the downward stroke of the compressor piston the gas from the evaporator follows and fills the cylinder above the piston, and upon reaching the bottom of its stroke this valve is closed by a spring, preventing the return of the gas to the evaporator. The return or upward stroke of the piston discharges the gas through the outlet valve and pipe.

Having described the evaporation of the ammonia and recovery of its gases by the compressor, we now supply the apparatus necessary to extract the heat with which it is laden, and thereby cause it to resume its initial state ready to again enter the evaporator and continue the cycle. The apparatus referred to is called the Ammonia Condenser. Fig. 4 illustrates its construction and connection with the balance of the apparatus.

The discharge of the ammonia gas from the compressor is continued through the pipe E, the oil separator F, and into the condenser C, which is composed of a series of pipes over which water flows to take up the heat given out by the compressing of the gas, and which combined effect causes the gas to liquify and flow from the bottom pipe of the condenser through the pipe H to the receiver or storage tank I. This completes the cycle and performs the practical process of refrigeration.

The principle or method of refrigeration has now been described without going into details of construction. The next step is the construction, proportion and combination of the several parts making up the refrigerating plant, and as the evaporator is the foundation or basis of the system, let us first consider this part of the plant.

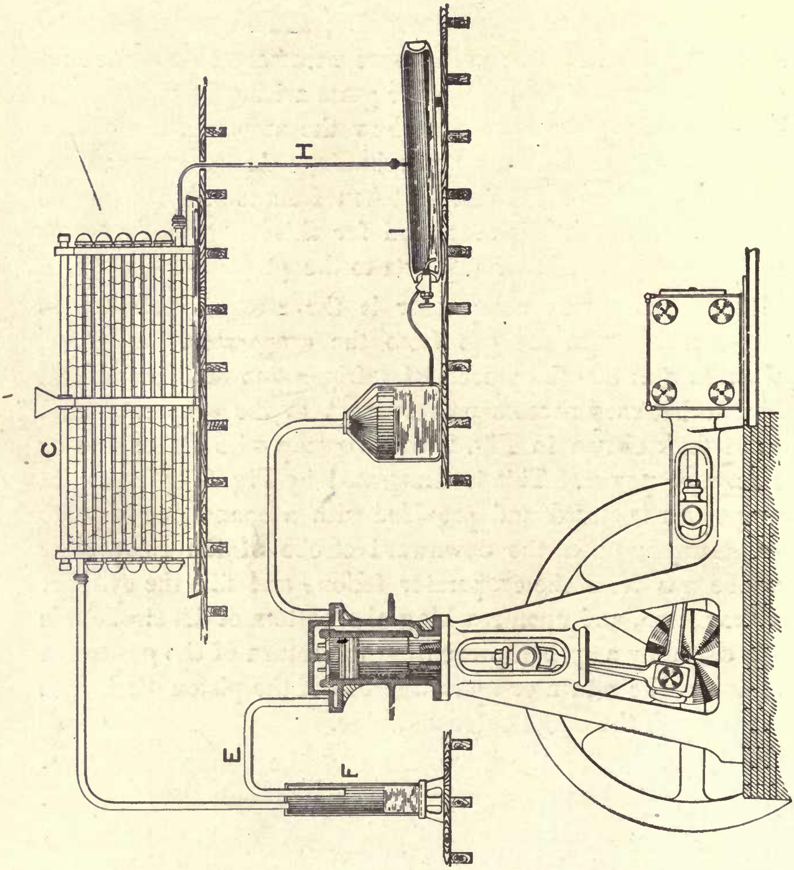
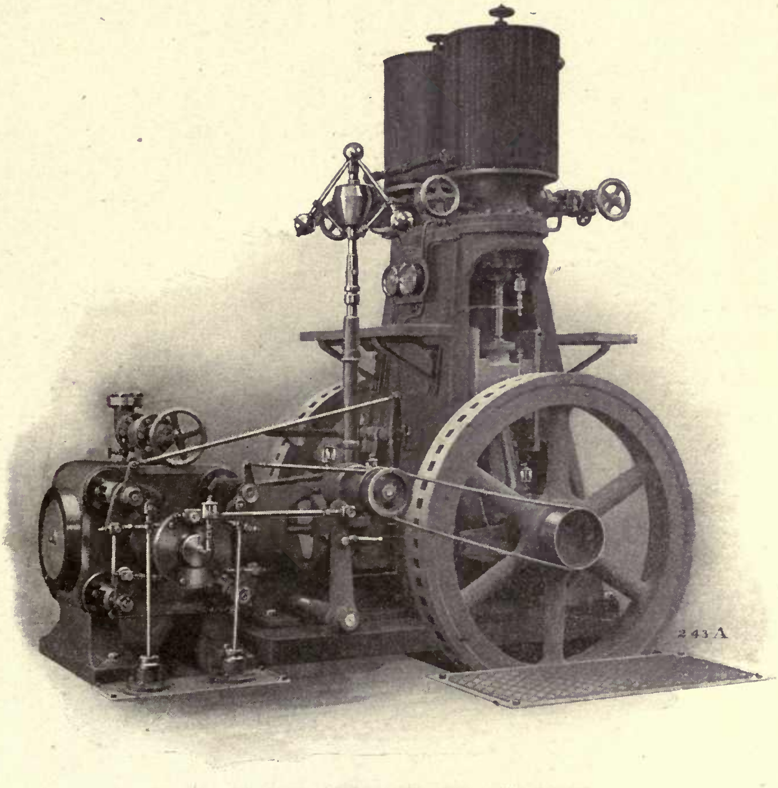


Fig. 4

EVAPORATORS.

Evaporators may be divided into two classes: The first is



15 TO 20 TON REFRIGERATING MACHINE.
Frick Company.

operated in connection with the brine system. In this evaporator salt brine (or other solution) is reduced in temperature by the evaporation of the ammonia or other refrigerant and the cooled brine circulated through the room or other points to be refrigerated. In the second, the direct-expansion system, the ammonia or refrigerant is taken directly to the point to be cooled, and there evaporated in pipes or other receptacles, in direct contact with the object to be cooled. Which of the two systems is better, is a much disputed and debated point; we can state, in a general way, that both have their advantages, and each is adapted to certain classes of duty.

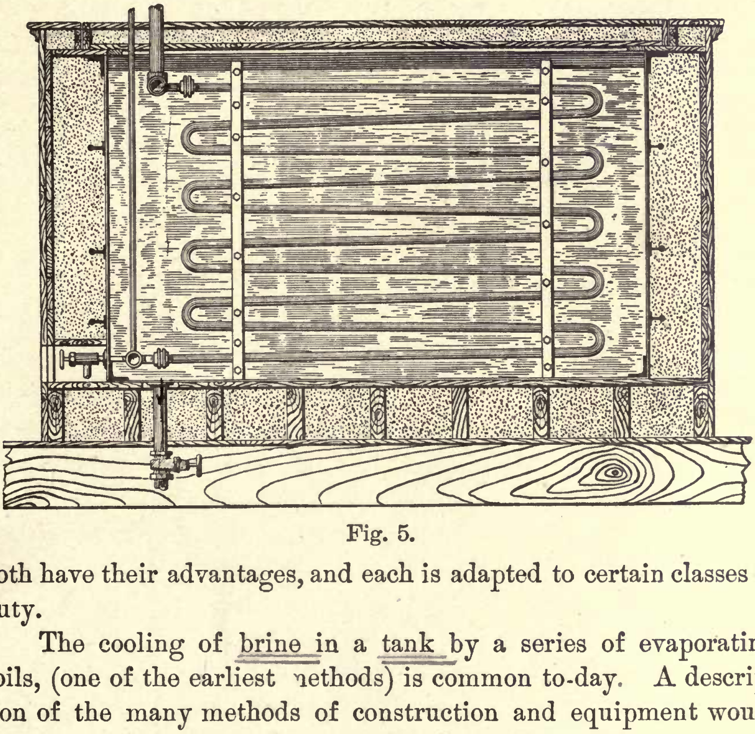


Fig. 5.

The cooling of brine in a tank by a series of evaporating coils, (one of the earliest methods) is common to-day. A description of the many methods of construction and equipment would require much space. Let us, therefore, discuss the two most general types only, viz: the rectangular with flat coils, and the circular with spiral coils.

Fig. 5 shows a sectional view of a brine tank. Flat or zigzag evaporating coils are connected to manifolds or headers; the pipe connections leading to and from these manifolds for the proper supplying of the liquid ammonia and the taking away or return of the gas to the compressor are also shown. For coils of this type, 1-inch or $1\frac{1}{4}$-inch pipe is preferable, owing to the impossibility of bending larger sizes to a small enough radius to get the required amount into a tank of reasonable dimensions. It is possible to make coils of this construction of any desired length or number of pipes to the coil, "pipes high," the bends being from $3\frac{1}{2}$ inches to 4 inches centers for 1-inch pipe, and 4 inches to 5 inches for $1\frac{1}{4}$-inch pipe. It is preferable to make the coils of moderate length, (not less than 150 feet in each) and there is no disadvantage (other than in handling) in making them to contain up to 500 or 600 feet each. It will be observed that there is a slight downward pitch to the pipes with a purge valve at the lowest point of the bottom manifold, which is, undoubtedly, valuable and an almost necessary provision. This valve is for removing foreign matter, which may enter the pipes at any time, and by opening the valve and drawing a portion of their contents, the condition of cleanliness can be determined without the necessity of shutting down and removing the brine and ammonia for inspection. The coils are usually strapped or bound with flat bar iron about $\frac{1}{4}$ inch × 2 inches (or a little heavier for the longer coils) and bolted together with $\frac{1}{2}$-inch square-head machine bolts. The coils are painted with some good water-proof or iron paint.

The brine tank is usually constructed of iron or steel plates, varying from $\frac{3}{16}$ inch to $\frac{3}{8}$ inch in thickness; the average being $\frac{1}{4}$ inch for tanks of ordinary size. The workmanship and material for a tank for this purpose should be of the very best; without these the result is almost certain to be disastrous to the owner or builder. The general opinion with iron workers (before they have had experience) is that it is a simple matter to make a tank which will hold water or brine, and that any kind of seam or workmanship will be good enough for the purpose. On the contrary the greatest care and attention to detail is necessary. It is customary, and good practice, to form the two side edges at the bottom by bending the sheets, thereby avoiding seams on two sides, while for the ends an angle iron may be bent to conform to this shape and the two sheets then riveted to the flanges of the angle iron. The edges of the sheets should be sheared or planed bevel, and after riveting, calked inside and out with a round-nosed calking tool. The rivets should be of full size, as specified for boiler construction and of length sufficient to form a full conical head of height equal to the diameter of the rivet and brought well down onto the sheet at its edges. An angle iron of about 3 inches should be placed around the top edge, and riveted to the side at about 12-inch centers.

One or more braces (depending on the depth) should extend around the tank between the top and bottom, to prevent bulging; without these it would be impossible to make the tank remain tight, as a constant strain is on all its seams. A very good brace for the purpose is a deck beam. Flat bar iron placed edge-wise against the tank with an angle iron on each side and all riveted through and to the side of the tank with splice plates at the corners or one of each pair long enough to lap over the other makes a good brace; heavy T-iron is also used to some extent. It is usual to rivet up the bottom of the tank and a short distance up the sides, then test by filling with water; if tight lower to its foundation and complete the riveting and calking. It may then be filled with water and tested until proven absolutely tight, when it may be painted with some good iron paint; it is now ready for its equipment of coils and insulation.

A washout opening with stop valve should be placed in the bottom at one corner; for this purpose it is well to have a wrought iron flange, tapped for the size of pipe required and riveted to the outside of the bottom. If the brine pump can be located at this time, it is well to have a similar flange for the suction pipe riveted to the side or bottom of the tank, as a bolted flange with a gasket is never as durable as a flange put on in this manner.

Assuming that the tank is now absolutely tight and painted, the insulation may be put around it, the insulated base or foundation having been put in previous to the arrival of the tank. The insulation should be constructed of joists 2 inches or 3 inches × 12 inches on edge and filled in with any good insulating material and floored over with two thicknesses tongued and grooved flooring with paper between. In putting the insulation on the sides and ends of the tank, place joists 3 inches × 4 inches resting on the projecting edges of the foundation about 2 feet apart. The upper ends should be secured to the angle iron at the top of the tank, its upper flange having been punched with $\frac{5}{8}$-inch holes 18 inches to 24 inches centers and to which it is well to bolt a plank, having its edge project the required distance to receive the uprights. Between the braces around the tank blockings should be fitted to secure the frame work at the middle, as the height of some tanks is too great to depend on the support at top and bottom alone.

After the frame work has been properly formed and secured to the base and tank, take 1-inch flooring, rough, or planed on one side, and board up on the outside of the uprights, filling in as the work progresses with the insulating material which may be any one of the usual materials, granulated cork being about the best, all things considered, although charcoal, dry shavings, saw-dust, or other non-conductors may be used with good results. When the first course of boards is in place it is well to tack one or two thicknesses of good insulating paper against the outer surface, care being taken that the joints lap well and that bottoms and corners are filled and turned under at the junction with the bottom insulation. It is then in shape for the final or outer course which is very often made of some of the hard woods in 2½-inch or 3-inch widths, tongued, grooved and beaded and finished off with a base board at the bottom and moulding at the top, and given a hard wood finish in oil or varnish. If the tank is located in a part of the building in which appearance is of no importance, the outer course may be a repetition of the first, except that the boards are put on vertically instead of horizontally.

It is well to make the top of the tank in removable sections to facilitate examination or cleaning; for this purpose make a number of sections about 2½ to 3 feet wide of the length or width of the tank, using joists about 2 inches × 6 inches placed on edge, floored over top and bottom and filled in with the selected insulating material. It is also well to have a small lid at one end of each (preferably over the headers or manifolds) which will allow of internal examination of the tank to ascertain the height or strength of brine without removing the larger sections. The tank is now fully equipped and ready for testing and filling with brine.

For a circular tank the general instructions regarding construction and insulation may apply as with the rectangular tank just described; therefore only its special features will be considered. If the tank is small and there is sufficient head room above it for handling the coils there cannot be serious objection to this type as its cost is lower than that of the rectangular tank. This is often an important item in a small installation, but when the tank is of considerable size and the coils large it is not as readily

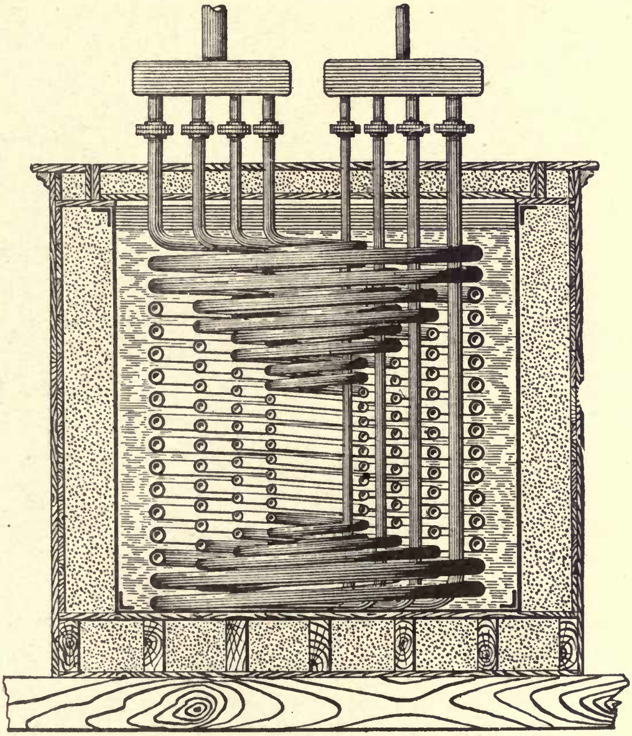


Fig. 6.

handled and taken care of as the other type. The usual construction of a nest of coils for a round tank is to bend the inside coil to as small a circle as possible, which, if it be of 1-inch or $1\frac{1}{4}$-inch pipe may be 6 to 8 inches. Increase each successive coil enough to pass over the next smaller until the required amount of pipe is obtained. The ends may then be bent up or out and joined to headers at top and bottom and the tank insulated in the manner previously described; it is then ready to test and charge with ammonia and brine. Fig. 6 represents an evaporator of this type.

Other constructions of tanks and coils are too numerous to describe in detail, and with one exception may be properly classed in one of the preceding types. The one exception referred to is illustrated in Fig. 7. It is quite common and is adopted for large pipe and is often called oval, although not of that shape, but rather a combination of the flat and circular form. It has some good features; it allows the maximum amount of pipe in the smallest space and a large amount of pipe in a single coil.

The Brine Cooler at present is a popular and efficient method of cooling brine for general purposes. Owing to mechanical defects and the impossibility of obtaining a brine solution which would not freeze, it was abandoned only to be taken up again, and with the aid of modern ideas and better material it has become highly successful. Unlike the brine tank and coil method of refrigeration, in which the ammonia is evaporated within the coils while the brine surrounds them, the brine passes through a series of coils and the ammonia evaporates within a wrought or cast shell surrounding the coils. Thus the action is reversed.

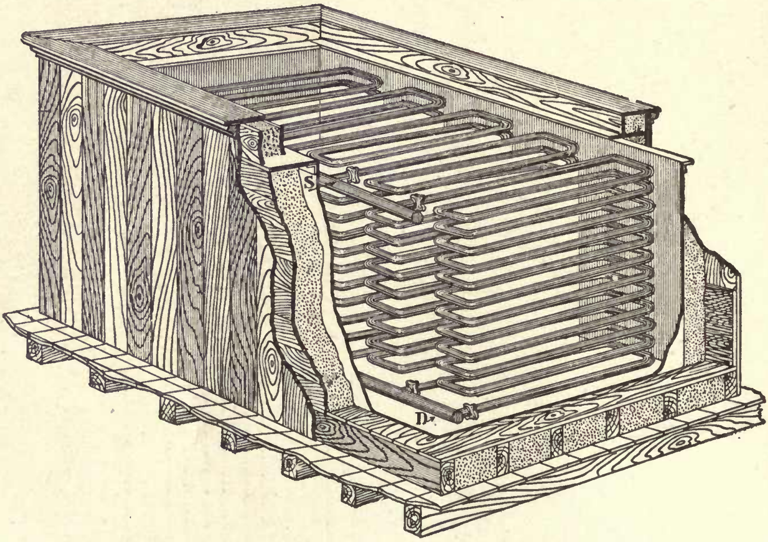


Fig. 7.

Fig. 8 is what is known as the **enclosed-shell type** of brine cooler, A representing a cast or wrought-iron shell, flanged at each end, to which heads are bolted; a tongue and grooved joint between, makes the closed cylinder gas tight. B is a series of welded extra strong pipe coils, one within the other, having their ends project through the heads and joined to headers at each end with proper unions; a stop valve is supplied to each coil. Lock nuts or glands are placed around each coil at its opening through the heads and one or more glass gauges with the usual gauge fittings are tapped into the side of the shell to indicate the amount of ammonia. Liquid ammonia is fed into the shell by an ordinary expansion or feed valve near the lower end of the shell at C and the gas taken off through the opening and pipe D to the compressor. A purge valve E for drawing off impurities is placed at the lowest point in the bottom head and a second one F for gas or air in the top head.

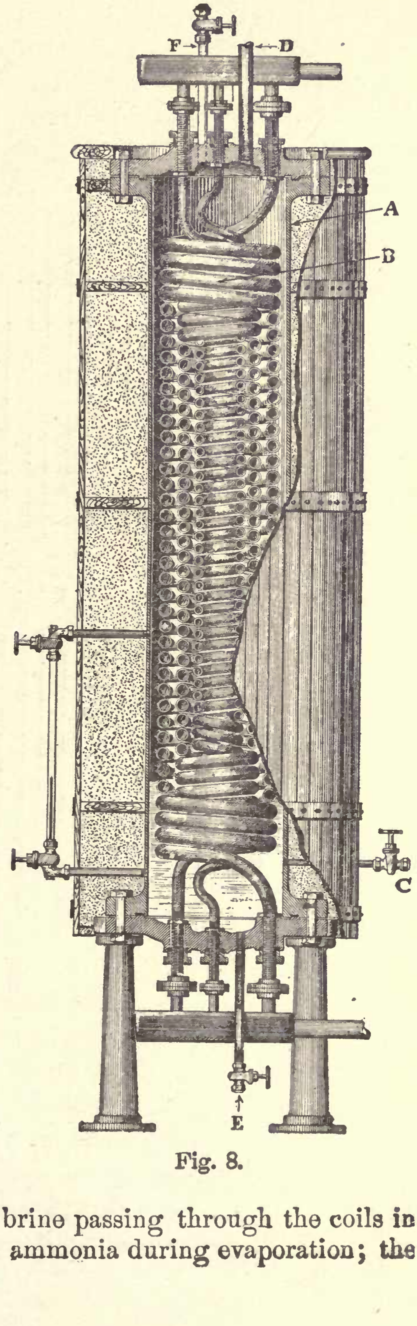


Fig. 8.

In operation, the discharge pipe from the brine pump is connected to the top header or manifold, and the bottom header is connected to the main leading to the refrigeration to be performed; the return from the cooling system is generally brought to a medium-sized brine tank without coils to which the suction of the pump is connected, thereby completing the brine circuit. The heat of the brine passing through the coils in the cooler is taken up by the ammonia during evaporation; the

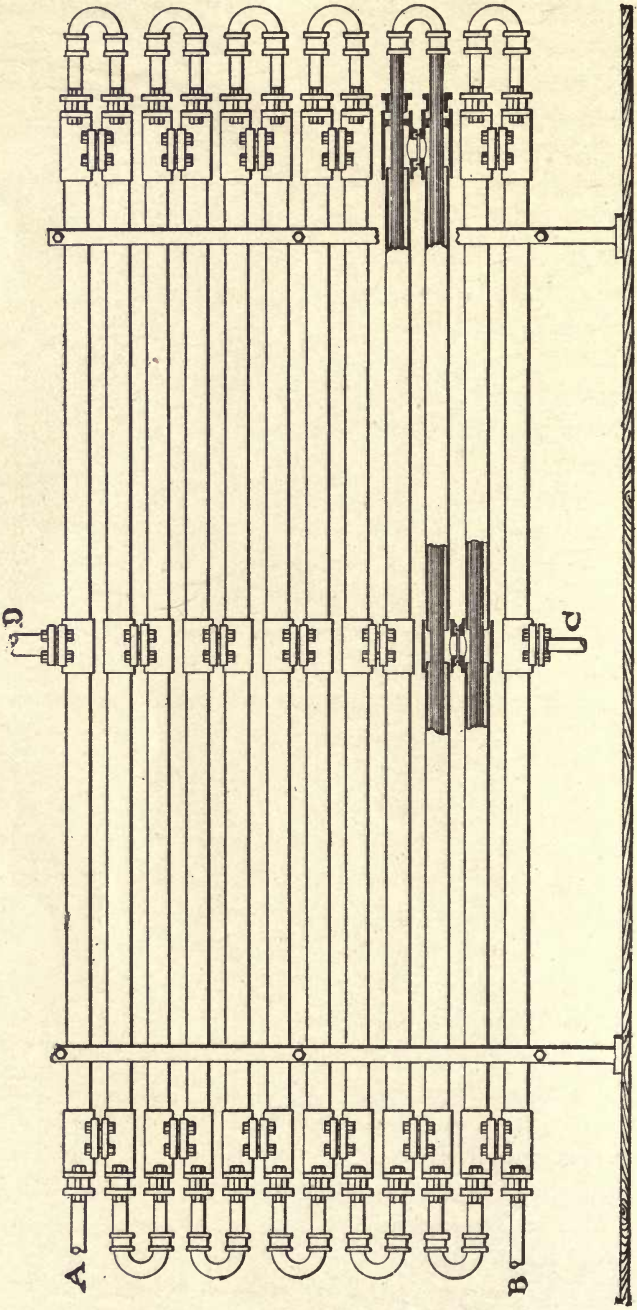


Fig. 9.

gas is taken away from the top of the shell to the compressor, and discharged to the condenser and into the receiver to be re-used, as with the system illustrated by Fig. 4.

The advantages of the brine cooler over the brine tank are due to two features of construction. The brine in passing through the coils is divided into a number of small streams, and while flowing rapidly through a coil of considerable length is churned to such an extent that it is all brought in contact with the coil, of which the outer surface is exposed to the temperature of the evaporating or boiling ammonia, and thereby gives up its heat much more rapidly to the ammonia than in the brine tank. In the brine tank there is a large body of brine with scarcely any movement; the brine immediately in contact with the pipe may be quite cold, but becomes warmer as the distance from the pipe increases.

The second advantage is that during the evaporation of the ammonia a violent ebullition is taking place, and if this is confined within the pipe coil a certain amount of the liquid is carried forward by the escaping gas, and the evaporation within the coil is limited. This limit is reached when the vapor enters the compressor in such quantities as to cause too great an expansion in the compressor, or when it becomes difficult to keep the stuffing-box tight, while in the brine cooler properly constructed, the larger diameter of shell allows evaporation to take place place up to practically the theoretical boiling point of the ammonia, without the liquid being carried forward through the gas pipe to the compressor. This permits a much higher evaporating pressure or "back pressure" as it is commonly called, than with the brine tank and coils. Also the concentrated or compact shape and construction of the cooler allows greater economy than the large radiating surface of the brine tank. The sides and end of the cooler are insulated by some one of the usual methods and very often lagged with finished hardwood strips, tongue, grooved and beaded and bound with finished brass or nickel plated bands.

Salt brine is commonly used in the brine tank and coil form of refrigerator, but it is unsafe to use it with the brine cooler because when passing through the coil it may freeze and burst the coil. A solution of chloride of calcium is commonly used, its freezing point being 54° below zero Fahr. while salt brine is practically 0° Fahr.

The second form of brine cooler is what is known as the **double-pipe type**, the construction of which is illustrated in Fig. 9, In this type one pipe is within another, the brine being discharged from the pump into one or more pipes at A and issuing at B. This connection leads from the main to the point to be refrigerated and the ammonia is expanded or fed into the annular space between the two pipes, and takes up the heat of the brine in evaporating and issuing as gas from the opening D at the top of the cooler From thence the ammonia passes to the compressor and through the cycle of compression, condensation and return to the liquid ammonia receiver as before. The ammonia evaporating between the two pipes will naturally absorb as much heat from the outside surface as from the inner or brine if allowed to do so, and it therefore becomes necessary to insulate the outside of this from exterior influences. As it is practically impossible to cover the bends and irregular surfaces it becomes necessary to build an insulated room in which the cooler is erected. This is commonly done, but some authorities do not consider it the most practical form. The cooler is equipped with the necessary stands, manifolds and stop valves to properly control the action of any one section when more than one is used.

As with the enclosed brine cooler, previously described, chloride of calcium brine should be used, as there exists the same liability to freeze, and it is unsafe to operate either type with the ordinary salt solution. These two types of brine coolers and brine tanks and coils are the usual means of cooling or refrigerating brine.

COMPRESSORS.

The next step in the process is the recovering of the evaporated ammonia and its return in liquid form. Compressors may be divided into two principal classes, single acting and double acting; and each class subdivided into vertical and horizontal. They are of the vertical type if single acting, and of both vertical and horizontal if double acting, although the majority of the double acting are of the horizontal type. Machines may also be classed according to the form of driving. The engines used may be horizontal or vertical, and within this classification comes almost any machine of modern build.

Fig. 10 illustrates the vertical single-acting type of compressor, two in number, in combination with and driven by a horizontal Corliss engine. It embodies the necessary and usual requisites of an efficient gas pump or compressor.

As already stated, the function of the compressor is to recover the gas from the evaporator and compress it into the condenser at a pressure which will cause it to liquify under the action of the cooling water. It is evident that the gas must follow the piston in its downward stroke and fill the compressor, and upon its reaching the end of its stroke and the pressure being balanced, the strength of the spring in the suction valve causes it to close and the piston begins its return stroke. The compression of the gas within the compressor takes place until its pressure equals or slightly exceeds that above the discharge valve; it then opens and the compressed gas flows into the discharge pipe and thence to the condenser. Two compressors of the single-acting type are almost always used in a machine of this type, and the cranks set opposite, or at 90° to one another, so that one compressor is filling and one compressing and discharging at each half revolution of the crank shaft, and the load is accordingly divided into two units, either one of which may be operated independently if necessary.

As the evaporator is the heart of the refrigerating system, so the piston and valves are the heart of the compressor, and the principal, almost the only, cause of difficulty in the action of the compressor will be found to be in one of the two.

In the compressor in which the valves operate in a cage, there must of necessity be a gas-tight joint between the bottom of this cage and the compressor head or piston in which it is located; this joint is made in a variety of ways, any one of which will prove effective. A square shoulder is cut into the head with a corresponding shoulder on the cage to match, and a lead gasket about $\frac{1}{16}$ to $\frac{1}{8}$ inch in thickness placed between the two. This makes a durable joint, except in cases where the joint between the two is of such an amount that the lead is constantly pressed through (a disadvantage of lead as a gasket material). Without

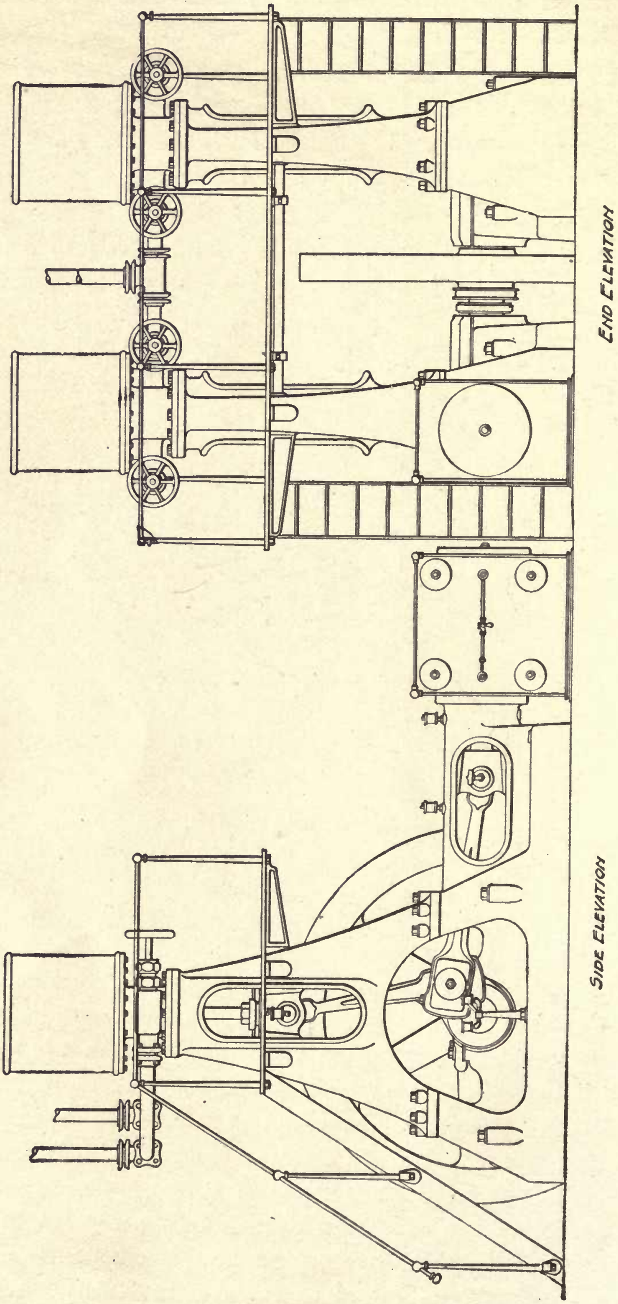


Fig. 10.

one's being aware of the fact, the gasket is gone and a leakage exists. Another objection to a lead gasket is that it compresses and *knits* into the interstices between the cage and the head. This often makes it impossible to remove the valve or cage from the head without the aid of some kind of a chain block or tackle. Another form of gasket for this purpose, but not popular from a lack of confidence in its permanency, is common lamp or candle wicking saturated with oil and wound tightly and smoothly in the corner against the shoulder on the cage. It is put in place and fully compressed by pulling down on the valve cap until the cage is at the desired height. It is good practice to wind enough on until, when the cage is pressed down by hand, it stands about $\frac{1}{16}$ inch above the surface of the head at the top; this amount of compression would make it about even when pulled down. As already stated, this kind of packing is not very popular on account of lack of durability, but it gives very satisfactory results when properly applied, and the valve and cage may be easily removed. Recently the gasket has been omitted and a ground joint made between the cage and the head. Although its efficiency has not yet been proven, from present indications it should be both satisfactory and permanent.

Assuming that we have made the joint between the cage and the compressor head gas-tight, we must also be certain that the compressor valve forms a perfect joint in closing against the cage. In a vertical compressor, in which the action of the valves is also vertical within their cages, the conditions naturally favor this to the greatest possible extent, as in closing they drop to their seats and it is only necessary to provide for the slight wear taking place in the stems and on the seats due to the rapid opening and closing of the valves. The valve stem must necessarily fit the guides in the cage as closely as possible and still allow free movement, and the seat between the valve disc and cage (preferably made at an angle of 45°) must first be machined to the proper angle and then ground in the usual manner. Having made it impossible for the gas to pass the valves and cages, means must be provided for closing the valves at the proper time to prevent loss, as a valve which is slow in reaching its seat presents a double evil—loss of efficiency and improper or irregular action on the balance of the machine. The spring is the usual means of opening the compressor valve, and, on the suction or inlet, is commonly placed between the top of the cage and underneath a washer placed at the end of the stem and held in place with one or two nuts; it is frequently reinforced with a buffer spring, or one of greater strength, enough shorter than the length of the stems to allow its opening the proper distance, and then stopping the travel of the valve gently.

Valves. Fig. 11 illustrates a type of inlet valve which has stood the test for years and embodies many good qualities. The different points referred to are indicated by the following letters: A, the joint between the cage and head; B, the contact between the valve disc and the cage; C, the spring for actuating the valve, and D, the buffer or stop spring to stop the travel of the valve at the proper point of opening. In the use of this valve the requirements are that it shall admit the gas to the compressor during the downward stroke of the piston, and close while the piston is at the bottom of stroke and the crank pin is passing the bottom center. It will, therefore, be readily understood that if the spring is stronger than necessary, it will require a certain amount of the pressure of the gas to overcome the strength of the spring, and prevent the filling of the compressor to its fullest limit. In the closing of the valve it would be driven with considerable force against its seat, making a noise in so doing and causing excessive wear. Considerable skill and experience are required to obtain perfect results, but with good judgment and a few trials most of the imperfections can be overcome. Generally the closing spring should not be stronger than is necessary to close the valve when held vertically in the position in which it naturally rests. By taking the valve and cages in the hands and pressing down on the top of the stem with one of the fingers, it will be readily ascertained when the springs are of proper strength to close the valve. When put on the compressor, so far as the operation of the inlet valves is concerned, the machine will be practically noiseless and effective in the admission and retention of the gas from that side.

The discharge valve operates in the reverse direction to that of the suction valve. We know that the suction valve closes while the compressor piston is at its lowest position in the compressor and while the crank is passing its bottom center. The piston now moves upward compressing the gas until it reaches the pressure in the ammonia condenser, and as it passes this point far enough to overcome the tension of the spring on the discharge valve, it causes it to lift and the contents of the cylinder in its compressed state are discharged through the discharge pipe into the condenser. This continues until the piston reaches its highest point and the crank is passing its top center, at which point the valve closes and the suction valve again opens to admit an additional amount of the gas. This process is continued during the operation of the apparatus.

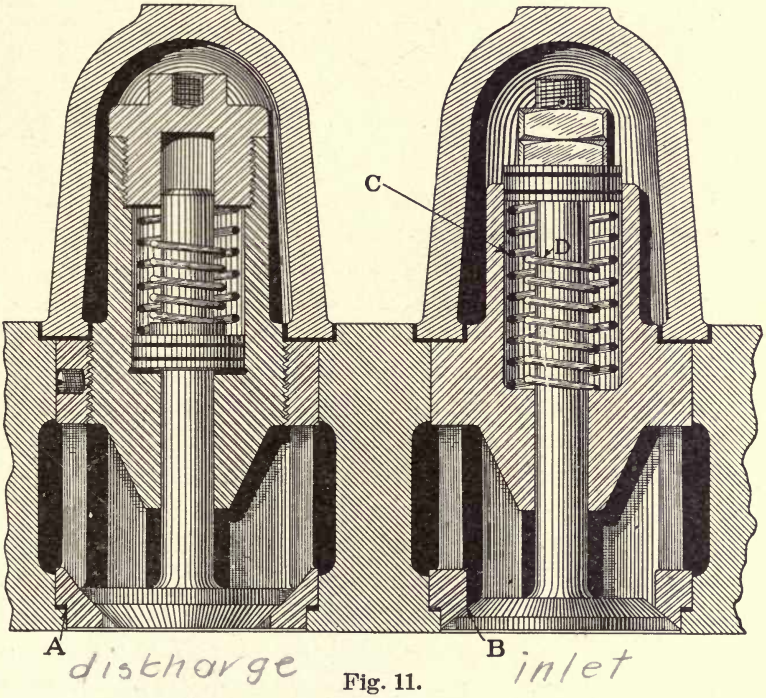


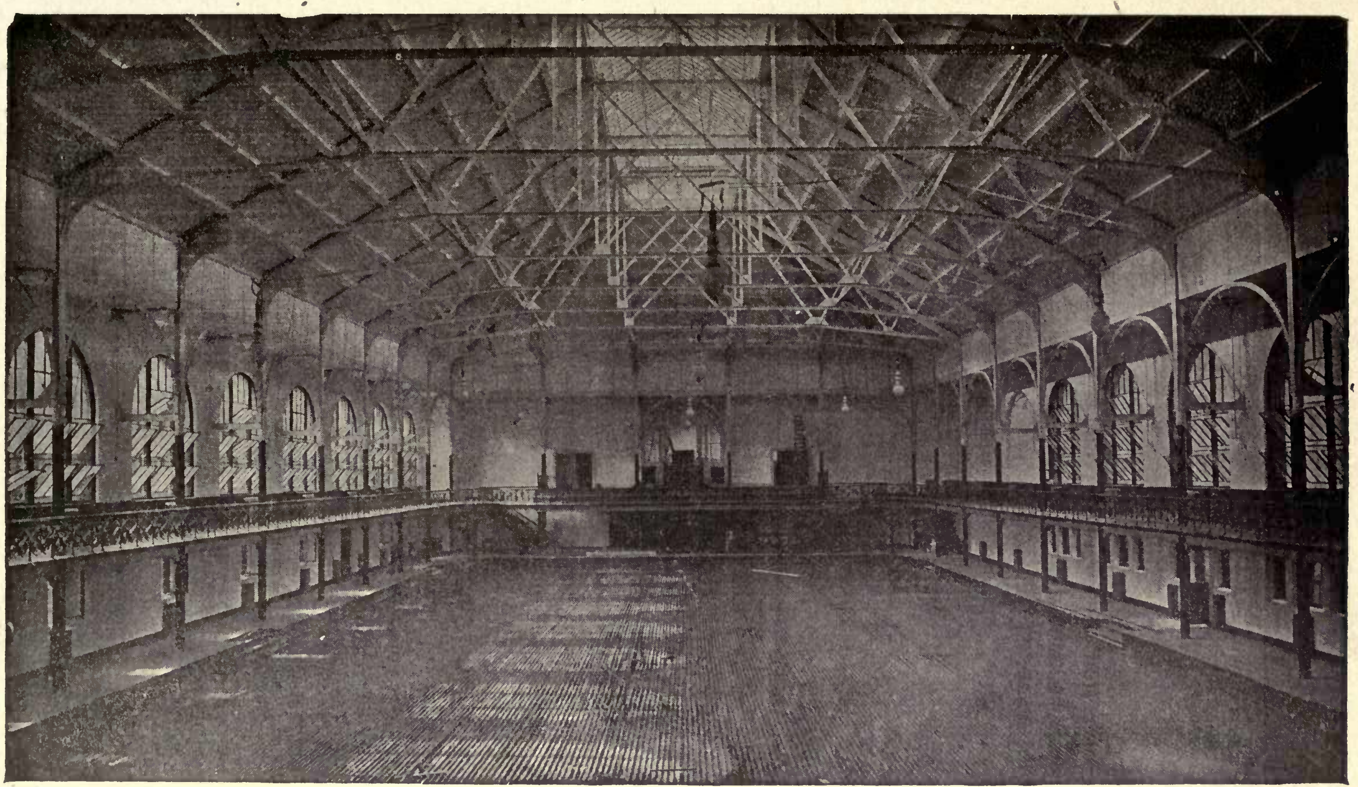
Fig. 11.

It will be noticed that the suction valve opens and closes while the piston is practically without motion, but the discharge valve opens while the piston is nearly at its maximum, and closes while the piston is at the minimum speed. From this it will be apparent that the thrust or effort on the discharge valve is much greater than on the inlet, that is, in an upward or outward direction; hence the device for arresting the upward motion of the valve must be more effective than the other. Also the valve must close in a shorter space of time because the great pressure above the valve would cause it to fall with considerable force were it not to reach its seat while the piston was still at the top of its travel, and the pressure above and below equal. Should the piston begin its return or downward stroke before the valve closes it would have the condensing pressure above, and the inlet pressure below, a difference of from 150 to 175 pounds. This pressure would cause it to seat with an excessive blow which would soon cause its destruction, and also cause the escape of a portion of the compressed gas into the compressor resulting in great loss in efficiency of the machine.

To stop the valve in its opening and prevent shock, it is necessary to provide a buffer or cushion in addition to the spring used to close it. The cushion, as usually constructed, is a piston fitting closely in a cylinder and provided with openings for the escape of the gas in front of the piston until it reaches a certain height, which should conform to the lift of the valve; at this point the piston is prevented from traveling farther by the compression of the gas and the valve is brought to a stop without noise or jar.

The strength of spring for closing the discharge valve must be nicely gauged; if too light the valve will not be brought to its seat until the piston has started on the return stroke, causing a return to the compressor of a portion of the compressed gas, and the striking on the seat with considerable force due to the pressure of the gas above the valve and the removal of the pressure below; while if the spring is too strong the valve is returned with such force as to cause a harsh sound and rapid wearing. This necessitates more frequent renewals than if moved with a spring of the proper tension.

Inasmuch as the weight of the moving part of the valve is a factor in determining the required strength, and the diameter, pitch, temper, gauge of spring and material, determine the strength, it becomes practically impossible to lay down a rule for the selection of the proper spring for each condition. Experience shows that one can better determine what spring to use by the sense of feeling than by any rule or standard.



SKATING RINK BEFORE FLOODING, SHOWING BRINE PIPES

Piston. Having provided the inlet and outlet valves with proper opening and closing devices and made them capable of retaining the gas passing them, a piston for compressing the gas and discharging it from the compressor must be provided. For the vertical type of single-acting compressor in which both inlet valves are in the upper compressor head, the piston is best made as a ribbed disc with a hub at the center for the piston rod and a periphery of sufficient width to be grooved for the necessary snap rings. Three to five of these rings are generally used.

Fig. 12 illustrates the simplest form of piston of this type, A being the cast head, B the snap rings, and C the piston rod. The surface is faced square with the bore of the hub, and the rod forced in and riveted over, filling the small counterbore provided for this purpose. The cast head and rod having been previously roughed out, is now finished in its assembled condition, the rod made parallel and true to gauge, threaded to fit the crosshead and the grooves turned for the snap rings, which are made slightly larger than the bore of the compressor. A diagonal cut is made through one side and enough of the ring is cut out to allow it to slip into the cylinder without binding. It is then scraped on its sides until it fits accurately the groove in the piston. It is also well to turn a small half-round oil groove in the outer face of the piston between each ring which gathers and retains a portion of the oil used for lubrication, thus increasing the efficiency

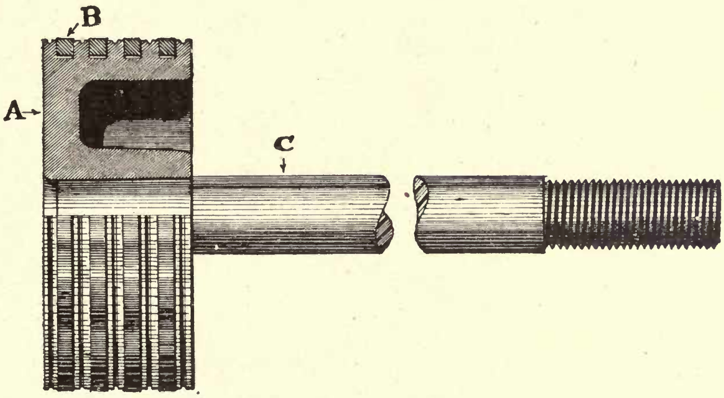


Fig. 12.

of the piston and collecting dust or scale and lessening the liability of cutting of the cylinder due to any of the usual causes.

The piston rod requires special care both in workmanship and material. In order to be effective it must be true from end to end and to be lasting under the variety of conditions which it operates, should be of a good grade of tool steel. The end which is usually made to screw into the crosshead is turned somewhat smaller, usually from $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter, than the portion passing through the packing or stuffing box principally to allow of returning or truing up the rod when it becomes worn, and also to allow it to pass through the stuffing box. After the rod is screwed into the crosshead it is secured and locked with a nut to prevent turning. The nut also allows the position of the piston to be changed to compensate for wear on the different parts of the machine by simply loosening the lock nut and turning the piston and rod in or out of the crosshead.

The stuffing box of the compressor, shown in Fig. 13, is one of the most difficult parts to keep in proper order. This is owing principally to one of two causes: not being in line with the crosshead guide or bore of the compressor, or the great difference of temperature to which it is subjected owing to the possible changes taking place in the evaporator. However, with the compressor crosshead guides, and stuffing box in perfect alignment, and a constant pressure or temperature on the evaporating side, it is a simple matter with almost any kind of packing on a machine of the vertical single-acting type to keep the stuffing box tight and in perfect condition. If, however, either of the above conditions are changed it becomes practically impossible to accomplish this. We have learned that perfectly constructed and operating valves is one of the essential features of a perfect machine. We also know that the alignment of the machine is equally important.

Erection. Experience in the building, erecting and operation of this class of machinery, shows that more machinery is condemned, more complaints made and difficulties encountered owing to these two points than all others put together. It is all important to the erecting and operating engineer that they be absolutely certain of these two points.

After the A frame, the compressor cylinder and its lower head have been placed in position, a fine hard line should be passed through the cylinder and stuffing box down through the guide and to the crank pin in the shaft, drawn tight and secured in some manner at each end and then callipered at each point. The different parts should be brought into perfect alignment before the rest of the machine is assembled.

Fig. 14 illustrates the methods of obtaining the proper results. Assuming that the brasses are central with the connecting rod and the connecting rod with the crosshead, the line should of course be central with the crank pin and this condition should exist when the pin is at its top and bottom positions. In other words, when the line is placed midway between the collars on the crank pin when at the bottom stroke, and the shaft is revolved one-half revolution to its top stroke, the line should be exactly midway between them; or the top moved until such is the case, and this should be determined as absolutely correct before proceeding further. When this is accomplished we may proceed to the guides and caliper first at the bottom and then the top between the line and each side of the bore, moving the A frame by dressing the bottoms of the feet or packing under, as may be most desirable.

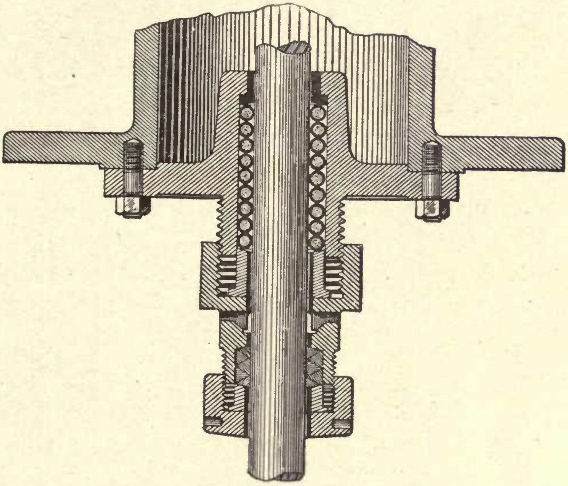


Fig. 13.

We may now examine the top of the compressor and the bottom of the stuffing box to determine whether or not these are central. By shimming or packing under the side of the compressor, the cylinder and the stuffing box may be moved in the required direction; this will be found all that is necessary to correct the small inaccuracies. Of course, should objection be raised to the method, the other remedy is to dress the surfaces.

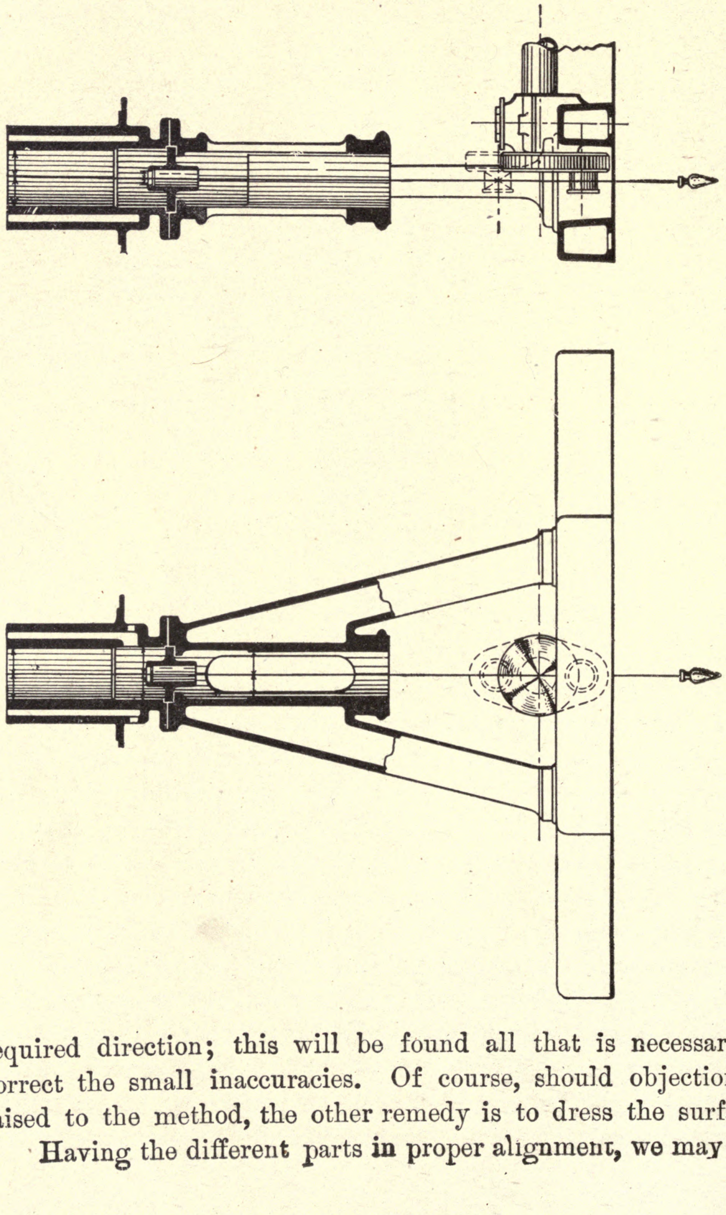


Fig. 14.

Having the different parts in proper alignment, we may now proceed with the assembling of the balance of the machine, feeling assured that with reasonably good workmanship and material, we will have a good running machine. It is well to have a compressor stuffing box of any of the several types in two parts or double packed (see Fig. 13), the inner to be of proper proportion to hold the packing against the loss of ammonia and the outer of only slight depth to retain the lubricating oil within the annular space provided between the two, and through which the rod passes in its travel. The packing may be drawn up or tightened by any one of several common devices, although a parallel device or one which causes the gland to move uniformly by tightening at one point is to be preferred. Although three or four separate bolts are very often used they are undesirable from the fact that they may cause a tipping or "cocking" due to the tightening or loosening of one.

There are innumerable materials for packing, and the "packing man" is encountered every day extolling the "good qualities" of his packing. It is probable that all have good points, but it is doubtful if any one make or kind would meet with the unqualified indorsement of all engineers; also no one packing is best for all conditions or duties. The condition and packing must be suited to one another; this will generally be accomplished by the good engineer.

In the construction of the stuffing box it is well to bush the bottom of the glands with Babbitt metal, because the rod is often pressed to one side crowding it against the side of the gland or bottom of box, causing the same to cut. When it becomes necessary to turn down the rod, a new bushing is all that is necessary to reduce the openings correspondingly.

Water Jacket. In the vertical single-acting type of compressor, it is usual to provide a water jacket, which may be cast in combination with the compressor cylinder or made of some sheet metal secured to an angle, which is bolted to a flange cast on the cylinder. It is usual to have this water jacket start at about the middle of the compressor (or a little below as shown in Fig. 15) and extend enough above to cover the compressor heads, valves and bonnets with water; the principal object of which is to keep these parts at a normal temperature and thereby improve the operation as well as protect the joints against the excessive heat which would be generated by the continued compression. It is also an advantage in the operation of the plant, since by reducing the temperature in the compressor and adjacent parts, the compressor is filled with gas of a greater density. It is also true that the heat extracted or taken up by the water at this point is a certain portion of the work performed in the condenser and therefore not a waste.

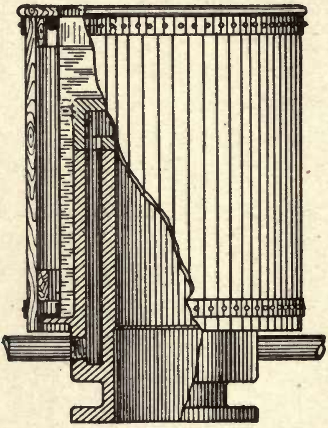


Fig. 15.

In the operation of the plant it is well to have plenty of water flow through the jackets, as the cooler the compressors are kept the better, but in plants in which water is scarce the quantity may be reduced correspondingly until the overflow is upwards of 100° Fahr. In extreme cases of shortage of water the overflow water from the ammonia condenser is sometimes used on the water jackets, that is, the entire amount of available water is delivered to the condenser, and a supply from the catch pan (if it be an atmospheric type) is taken for the water jackets, in which case a greater quantity may be used but at a higher temperature. It is customary to admit the water through the flange forming the bottom of the water jacket and overflow near the top into a stand pipe which is connected at its lower end through the flange to a system of pipes to take it away. To prevent condensation on the outer surface of the jacket, and to present a more pleasing appearance, it is frequently lagged with hardwood strips and bound with finished brass or nickel-plated bands. It is also well to have a washout connection from each jacket.

Lubrication. The vertical type of compressor requires the least amount of lubrication from the fact that all moving parts are in equilibrium. The slight amount of oil used is merely to keep the surfaces from becoming entirely dry. Excessive lubrication is an objection, owing to the insulating effect upon the surfaces of the condensing and evaporating system. Therefore it is well to feed to the compressors as little as is consistent with the operation of the machinery. A proper separating device should be located in the discharge pipe from the compressor to the condenser. To properly admit, or feed the lubricant to the compressors, sight feed lubricators should be provided, by which the amount may be determined and regulated. These may be of the reservoir type, or better still the droppers, fed from a large reservoir through a pipe and which may be filled by a hand pump when necessary (see Fig. 16). Owing to the action of ammonia on animal or vegetable oils, other than these must be used as a lubricant for the compressor. The principal oil for this purpose (and when obtained pure, a very good one) is the West Virginia Natural Lubricating Oil or Mount Farm, which is a dark-colored oil not affected by the action of the ammonia or the low temperature of the evaporator. Of late years the oil refining companies have put on the market a light-colored oil which appears to give good results for the purpose. Care should be used, however, in

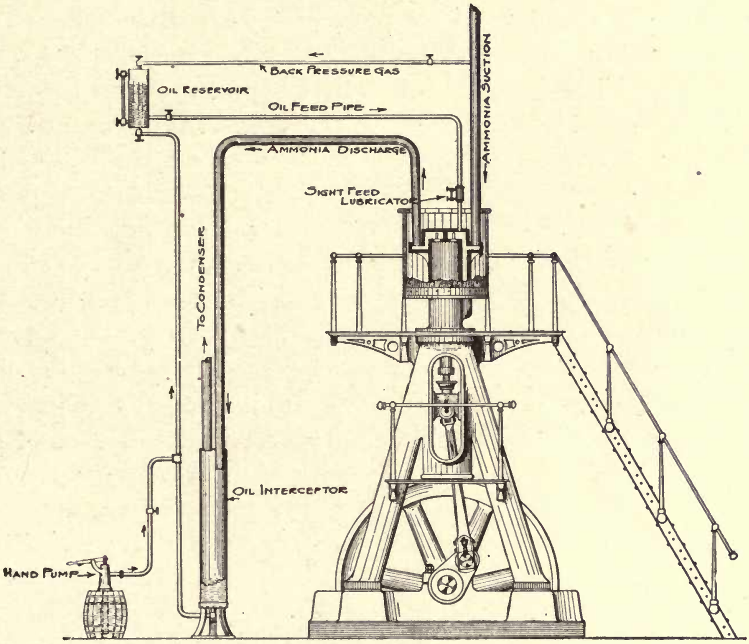


Fig. 16.

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the selection and oil should not be used unless it is of the proper grade, as serious results follow the use of inferior oils. The usual result is the gumming of the compressors and valves or the saponifying under the action of the ammonia through the system.

LOSSES.

Having described the compressor and its parts, let us take up the losses due to the improper working or assembling of the parts of the machine, before proceeding with the description of the rest of the plant. As has been stated in a general way, the economy of the compressor lies in its filling at the nearest possible point to the evaporating pressure and then compressing and discharging at the lowest possible pressure, as much of the entire contents of the cylinder as possible. If the compressor piston does not travel close to the upper end (of a single-acting machine) or the machine has excessive clearance, the compressed gas remaining in the cylinder re-expands on the downward stroke of the piston and gas from the evaporator will not be taken into the compressor until the pressure falls to, or slightly below, this point, and the loss due to this fault is equal to the quantity of gas thus prevented from entering the compressor plus the friction of the machine while compressing the portion of the gas thus expanding.

If we make a full discharge of the gas and there is a leaky outlet valve in the compressor, the escape and re-expansion into the compressor affects not only the intake of the gas at the beginning of the return stroke, but continues to affect the amount of incoming gas during the entire stroke and the capacity of the machine will be correspondingly reduced. If the inlet valve is leaky or a particle of scale or dirt becomes lodged on its seat, as the piston moves upward the portion of the gas which may escape during the period of compression is forced back to the evaporator and a corresponding loss is the result. A piston which does not fit the compressor, faulty piston rings, or a compressor which has become cut or worn to the point of allowing the escape of gas between the cylinder and piston has the same effect as the ill conditioned suction valve. The loss due to leaky or defective cylinders, joints or stuffing boxes, are not included under this head as these more generally effect the loss of the material than the efficiency of the compressor.

To present graphically the losses due to the above causes refer to Fig. 17, which illustrates the usual indicator card taken from an ammonia compressor and the effect upon it of the various losses.

The different mechanisms employed in actuating the compressor piston, such as crossheads, connecting rods, pins, crank shaft and bearings, are of usual engine practice. A detailed description will not be given here. It should be stated that owing to the steady load and the continuous service usually demanded of a refrigerating plant, and the occasional high pressures encountered in the extremely warm weather, the construction should be of the best and the wearing surfaces ample to withstand the hard service. The many types of machines and the methods of connecting the power or engine are of almost endless variety. It is sufficient to state that the general classes of engines are of vertical or horizontal single-cylinder, tandem or cross compound, condensing or non-condensing.

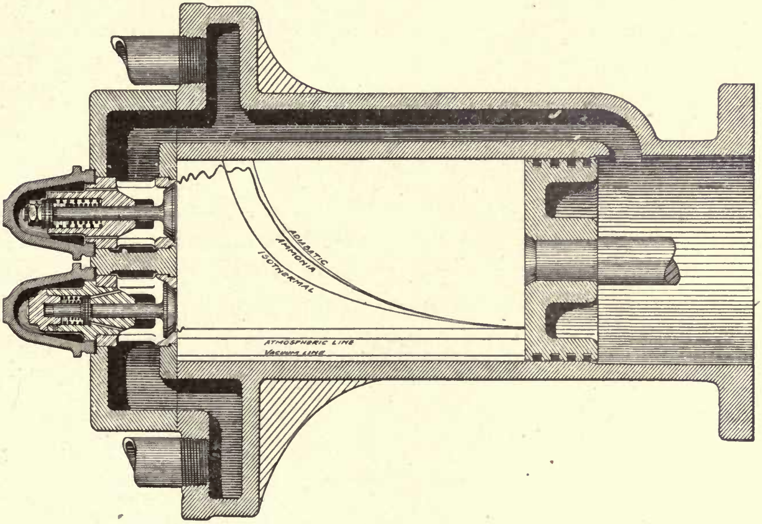


Fig. 17.

The horizontal double-acting compressor embodies all the general principles of the vertical single-acting, but having certain modifications to meet the mechanical differences presented. They may be divided into two classes, those having water jackets and those without. The former usually has a water jacket extending about the body of the cylinder but not over the heads and valves as in the single-acting compressor. Compressors not provided with water jackets are internally cooled either by evaporation of a portion of the ammonia, or the injection of ammonia or cooled oil. The claims of both these last named systems are that instead of the curve of compression being close to the adiabatic it is brought nearly to the isothermal, and that a corresponding economy in horse power required to operate the machine is effected. Owing to the fact that this type of compressor takes in and discharges gas in both directions, it is necessary that inlet and outlet valves be provided in both heads, and that the inner head be provided with a stuffing box also for the piston rod. This renders it impossible to place the valves horizontally, and as a result, the valves are placed at an angle of from 30° to 45° from the center of the compressor, and the inner face of the heads and pistons made on an angle to conform to this; or sometimes the valves are spherical, to avoid clearance which would result from the difference in their surfaces. The weight of the piston and rod being towards the bottom of the cylinder, it is necessary that the piston be of considerable length to provide a greater surface for wear.

The stuffing box must have sufficient depth to successfully retain the gas during the period of compression, and lubrication should take place while the rod is passing through the packing. This is accomplished with a small oil pump actuated from the moving parts of the machine or a pressure system regulated by the pressure in the oil separator. In each case oil passes between the double packing thereby causing the piston rod to pass through a chamber of oil.

The compressor valves and their cages are of the description already given and the same care and caution regarding the construction and operation apply to the valves of this type of machine, but the fact that they are horizontal or nearly so makes their construction somewhat different and necessitates springs of different strength. The valves, cages and springs are covered by a dome bolted in place and its union with the compressor head is provided with a gasket to prevent loss of ammonia. It is well to have at hand duplicates of the compressor valves and springs, as an entire valve can be changed in less time than it takes to repair one out of order. As the machine during this time must remain out of service, it is customary for the builders to supply these in duplicate. After a valve is taken out and replaced, it is well to have the faulty one put in perfect condition, the strength of springs tested, the seat and stem corrected, oiled and put away in readiness to be used again when the occasion requires.

This type of compressor is usually driven from a rotating shaft with the ordinary connecting rod by a crank and crosshead. Adjustment for wear is provided in the piston rod at the crosshead, and the position of the piston may be adjusted between the heads of the compressor by screwing in or out of the crosshead. The clearance of the compressor piston is important; it should be as small as possible and yet not allow the piston to strike the heads. This naturally cannot be reduced to the small degree possible in the single-acting type, from the fact that it must be adjusted to both heads, and the expansion and contraction of the piston and connecting rod and wear is of such an amount as to render a close adjustment impossible. Fig. 18 is a sectional cut of a modern type of double-acting compressor with water jacket; Fig. 4 a section of one not using the water jacket and Fig. 10 an elevation of either in combination with its motive power, a Corliss engine, shaft, fly wheel, etc.

The stuffing-box oil pump is shown in Fig. 16 which illustrates the general method of lubricating the compressor piston, the oil being pumped through the box and returning to a catch pan or basin provided in the bed plate.

THE AMMONIA CONDENSER.

The Ammonia Condenser, or liquefier, as briefly stated in the description of the system, is that portion of the plant in which the gas from the evaporator, having been compressed to a certain point, is cooled by water and thereby deprived of the heat which it took up during evaporation; consequently it is reduced to its initial state, that is, liquid anhydrous ammonia. Let us consider the general principles governing the action before describing the types. On account of the duty having been performed, the ammonia as it leaves the evaporator is a gas of low temperature,

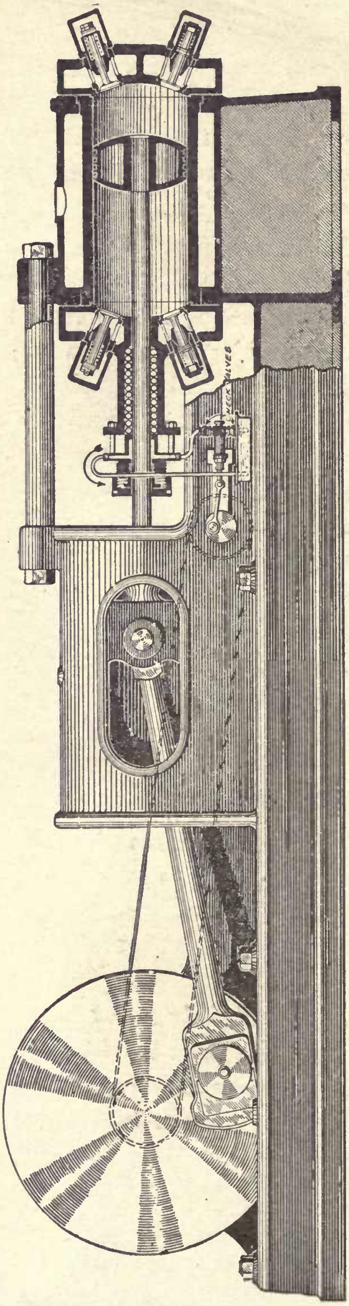
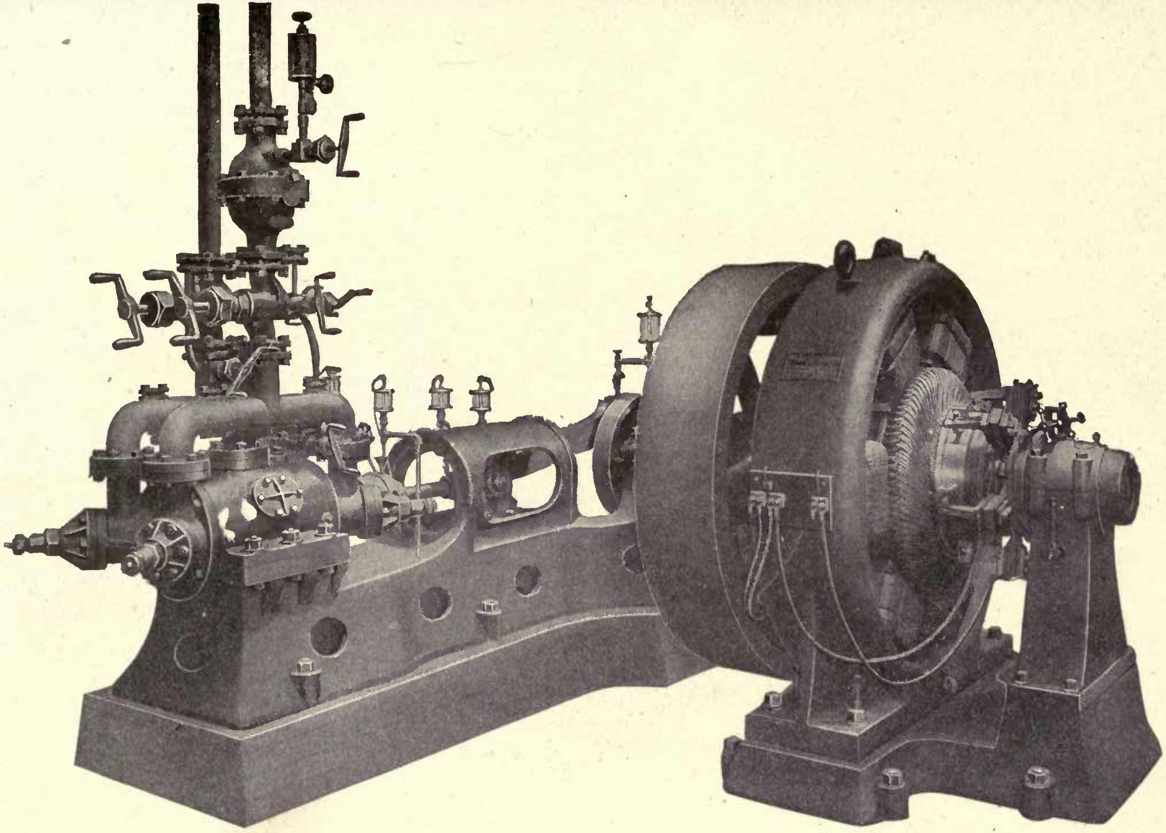


Fig. 18.

usually 5° to 10° below that of the brine, or other body upon which it has been doing duty, yet it is laden with a certain amount of heat, although at a temperature not ordinarily expressed by that term. It is a well-known fact that we cannot obtain a refrigerating agent which can absorb heat from a body colder than itself, and it is therefore necessary to bring the temperature of the ammonia gas to a point at which the flow of heat from the one to the other will take place. This is done by withdrawing part of the heat in the ammonia in the following manner: The cold gas is compressed until its pressure reaches such a point that at ordinary temperatures it will condense to liquid form. As it leaves the compressor it is very hot because of the fact that it still contains nearly all of the heat it had when it left the evaporator in only a small portion of the space occupied before. Thus when it reaches the condenser it is much warmer than the cooling water and will readily give up its heat to the cold water—so much that its latent heat is absorbed by the water and it condenses into anhydrous ammonia.

The temperature of water if pumped from surface streams will average about 60° F and since we



DIRECT-CONNECTED TRIUMPH 10-TON REFRIGERATING MACHINE.

cannot expect to get the ammonia any colder than this it must be compressed until the boiling point corresponding to the pressure obtained is at about 75° F.

In the table, page 78, we find that this temperature corresponds to a pressure of 144.25 pounds per square inch (absolute) or 126.55 pounds per square inch (gauge).

Thus if the gas is compressed until the gauge reads 126.55 and then passed into a condenser where the temperature of the water is less than 75° F the water will absorb the latent heat and we have accomplished our object which was to remove some of the heat contained in the ammonia. In this condition it is drained from the condenser into the ammonia receiver to again repeat the cycle of operation.

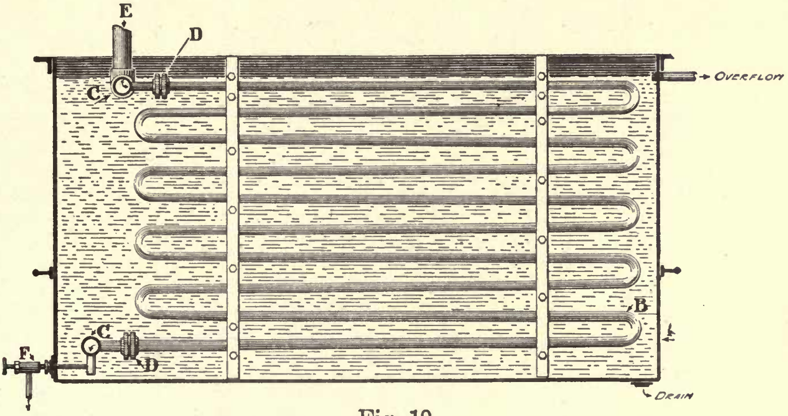


Fig. 19.

The forms of condenser may be divided into three classes; the submerged, atmospheric, and double-pipe. Of each of these classes a number of different types and constructions are in use. To illustrate the general principles, however. it is only necessary to present one of each type.

The Submerged Condenser consists of a round or rectangular tank with a series of spiral or flat coils within joined to headers at top and bottom with proper ammonia unions. In Fig. 19 is shown a sectional elevation of a popular type of submerged condenser. A wrought iron or steel tank A is formed by plates from $\frac{3}{16}$ to $\frac{5}{16}$ inch thick, of the necessary dimensions to contain the coils, and sufficiently braced around the top and sides to prevent bulging when filled with water. A series of welded zigzag pipe coils B are placed in the tank and joined to headers C with ammonia unions D. The ammonia gas enters the top header through the pipe E and an outlet for the liquefied ammonia is provided at F with a proper stop valve. Water is discharged or admitted to the tank at or near the bottom and overflows at outlet

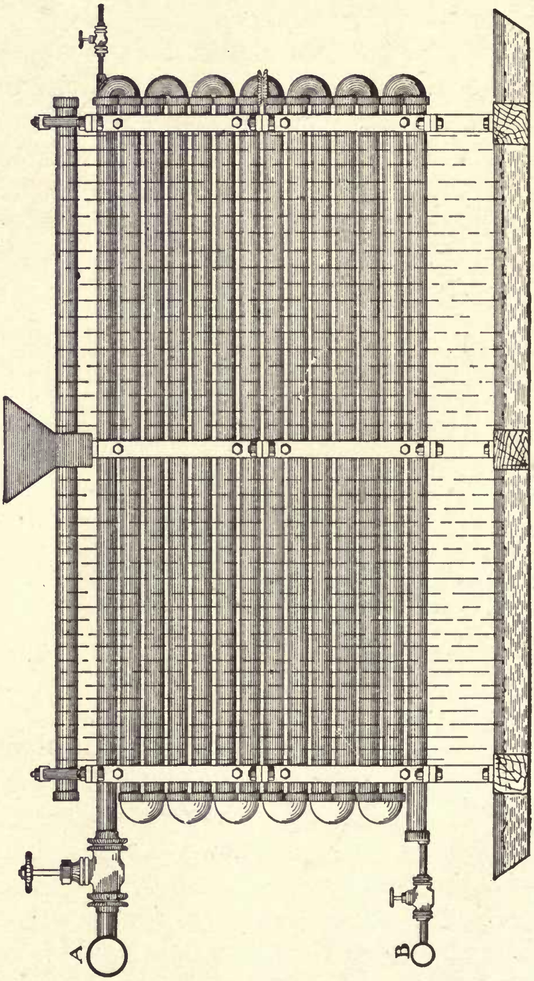


Fig. 20.

M. It will be seen that in this type of condenser a complete reverse flow of the current is effected, the gas entering at the top and the liquid leaving at the bottom, while the water enters at the bottom and leaves at the top, thereby bringing the coldest water in contact with the coolest gas, and the warmer water in contact with the incoming or discharged gas from the compressor, thereby presenting the ideal condition for properly condensing ammonia.

Owing to the necessarily large spaces between the coils and the distance between the bent pipes, the portion of water coming in contact with the surface of the pipes must be small compared with the total amount passing through; it is, therefore, uneconomical as regards amount of water used. With water containing a large amount of floating impurities the deposit on the coils is considerable, and not easily removed owing to the limited space between the coils, and furthermore, the dimensions of the tank necessary to contain the requisite amount of pipe for a plant of considerable size is so great and its weight when equipped with coils and filled with water requires such a strong support that its use is now limited to certain requirements and localities.

A better shape for a condenser of this type is one of considerable height or depth, rather than low and broad. This is owing to the fact that the greater the length of travel of the water and gas in opposite directions, the greater the economy. The number of coils used should be such that the combined internal area of the pipes equals, or exceeds the area of the discharge pipe from the compressor. The circular submerged condenser is similar to the above described except that the tank is circular and the coils bent spirally.

The Atmospheric type of condenser most generally used is made of straight lengths of 2-inch extra-strong, or special pipe, usually 20 feet long, screwed, or screwed and soldered into steel return bends about 3½-inch centers and usually from eighteen to twenty-four pipes high. The coil is supported on cast or wrought iron stands and placed within a catch pan, or on a water-tight floor, having a proper waste water outlet and supplied with one of the several means of supplying the cooling water over their surfaces. Stop valves, manifolds and unions connect with the discharge of the compressor and the liquid ammonia supply to the receiver.

In the manner of making the connections to this type of condenser and the taking away of the liquefied ammonia as well as in the devices for supplying the cooling water, a great variety exists; Fig. 20 represents a side elevation of an ammonia condenser with the discharge or inlet of the gas from the compressor entering at the top A and the liquid ammonia taken off at the bottom B while the water is supplied over the coils flowing down into the

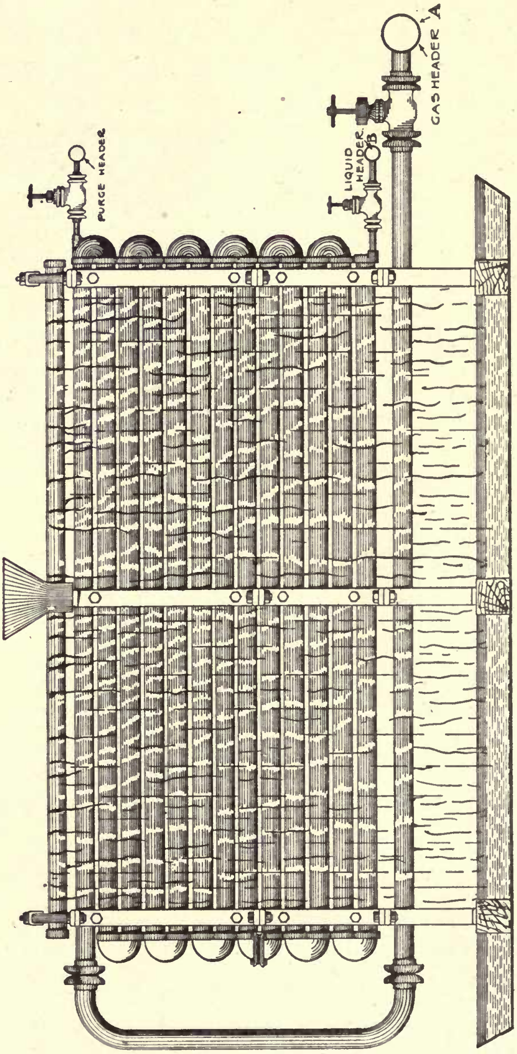


Fig. 21.

catch-pan or water-tight floor where it accumulates and is taken away by any of the usual means. It will be noticed that the flow of the water and gas with this type of condenser is in the same direction, the coldest water coming in contact with the warmest ammonia. The temperature governing or determining the point of condensation will be that of leaving the condenser, or at the bottom pipe in which the liquid ammonia is withdrawn. Owing to this arrangement it is not favorable to a low condensing pressure or economy in the water used. Fig. 21 represents a type in which an attempt is made to eliminate this undesirable feature, and in which it is expected to use the waste from the condenser proper, in taking out the greater part of the sensible heat from the gas leaving the compressor.

The construction of this condenser is identical with that shown in the preceding figure except that its uppermost pipe is continued down and under the pipes forming the condenser proper; it passes backward and forward in order that a large proportion of the heat may be removed by the water from the condenser proper, before the ammonia enters the condenser. A supplemental header is sometimes introduced in connection with this pipe for removing any condensation taking place in it.

A third type of this condenser is shown in Fig. 22. In this type a reverse flow of the gas and water takes place. The gas enters the condenser through a manifold or header A at the bottom and continues its flow upward through the pipes to the top; at several points drain pipes are provided for taking off the condensation into the header B. The condensing water flows downward over the pipes. The form is the most nearly perfect condenser of the class.

The atmospheric type is a favorite, and possesses many features that make it preferred to the submerged. Its weight is a minimum, being only that of pipe and supports and a small amount of water. The sections or banks may be placed a favorable distance apart to facilitate cleaning and repairs, while the atmospheric effect in evaporating a portion of the condensing water during its flow over the condenser, thereby obtaining the advantage of its latent heat as well as the natural raise in its temperature, adds materially to its efficiency.

The various devices for distributing the water over the condenser are numerous:

Fig. 23 represents the simplest and most easily obtained; a simple trough with perforations at the bottom for allowing the water to drip through to the condenser.

Fig. 24 is a modification of the one shown in Fig. 23. This is intended to prevent the clogging of the perforations, by allowing the water to flow into the space at one side of the partition, and then through a series of perforations into the second, and thence through a second set of perforations in the bottom to the pipes in the condenser.

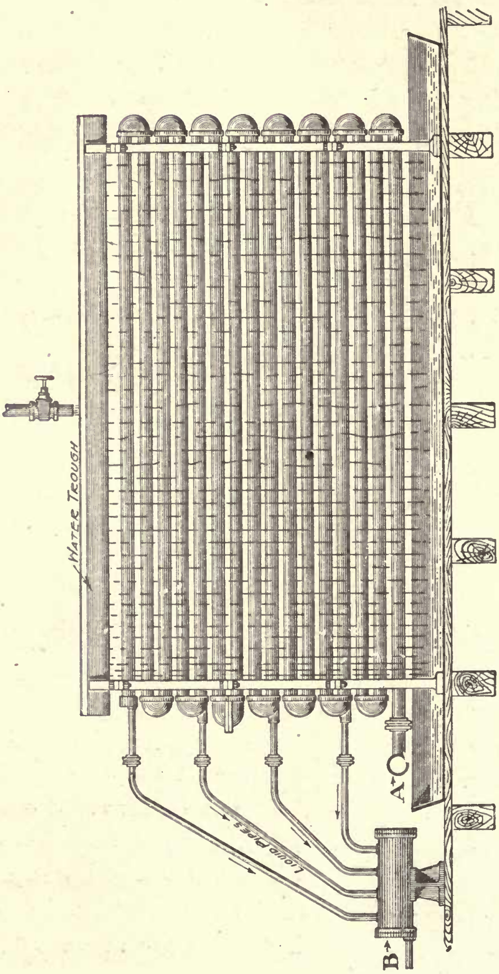


Fig. 22.

Fig. 25 is a type of trough, or water distributor, designed to overcome the objections to a perforated form of trough, and the consequent difficulties due to the clogging or filling of the perforations. As will be readily understood from the illustration, this is also made of galvanized sheet metal with one side enough higher

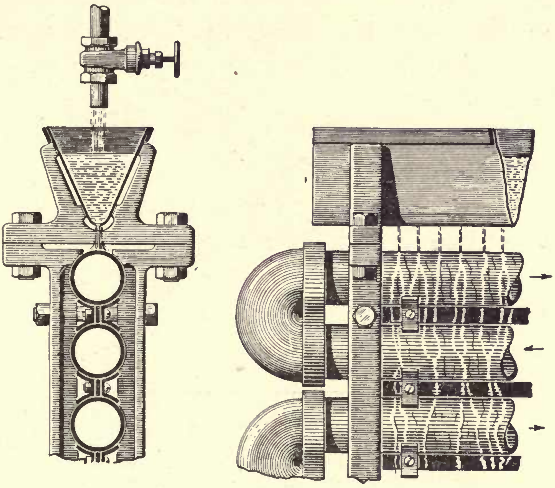


Fig. 23.

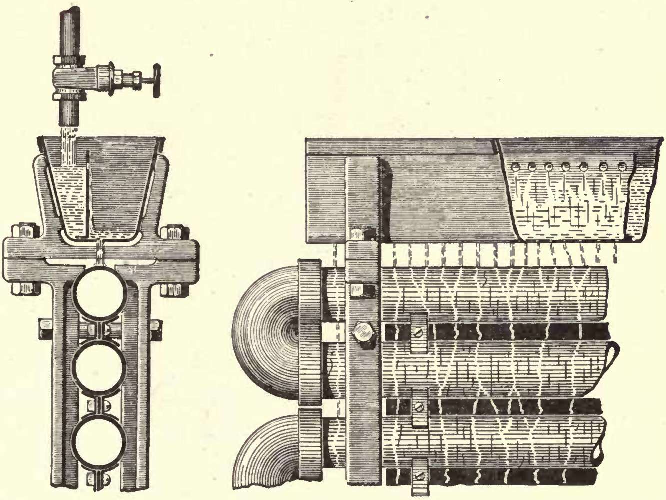


Fig. 24.

than the other to cause the water to overflow through the V-shaped notches or openings along the top of the straight or vertical side of the trough, and down and off the serrated bottom edge to the pipes.

The object of the serrated edges, as will be apparent, is the more even distribution of the water, owing to the fact that while it would be practically impossible to obtain a uniform flow of water over a straight and even edge of a trough, particularly if the amount is limited, it is an easy matter to regulate the flow through the V-shaped openings.

Fig. 26 is termed the "slotted water pipe." It is a pipe slotted between its two ends, from which the water overflows to the series of pipes below. It is good practice to lead the water supply to a cast-iron box at the center of the condenser, into the sides of which is screwed a piece of pipe (usually 2-inch) reaching the ends of the condenser, and having its outer ends capped, which may be removed while a scraper is passed through the slot from the center towards the ends while the water is still flowing, thereby carrying off any deposit within the pipe. This forms a very durable construction, and not liable, as with the galvanized drip trough, to disarrangement or bending out of shape due to various causes. It is impossible, however, to obtain the uniform flow of water over the condenser with this, as with the serrated or perforated troughs, particularly if the supply is limited, from the fact as stated in describing the overflow trough, viz: the impossibility of obtaining a sufficiently thin stream of that length.

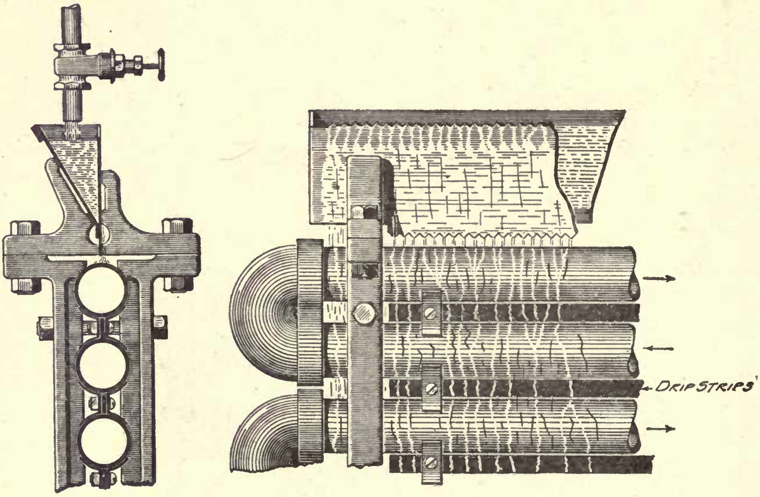


Fig. 25.

The Double-Pipe Condenser is a modern adaptation of an old idea, given up owing to its complex construction and the imperfect facilities available for its manufacture. Also, like the Brine Cooler, it has come into use with great rapidity, and has brought forth many novel ideas of principle and construction. It combines the good features of the atmospheric as well as the submerged; as in the former the weight is small and it is accessible for repairs. It has the downward flow of the ammonia and upward flow of the water, effecting a complete counter flow of the two. minimizing the amount of water required and taking up the heat of condensation with the least possible difference between the ammonia and water.

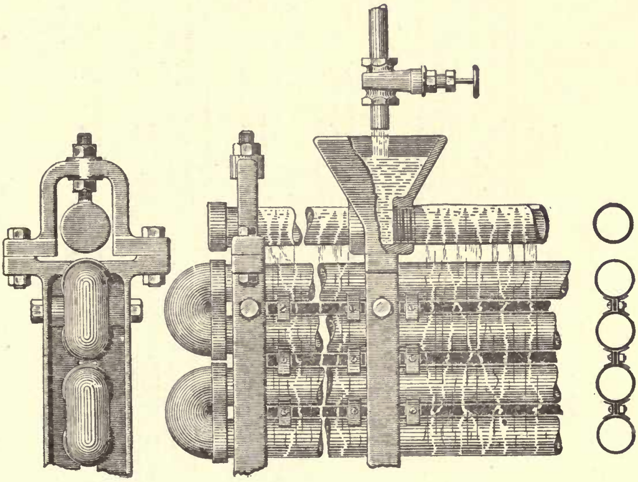


Fig. 26.

The two general forms of construction are a combination of a 1¼-inch pipe within a 2-inch pipe, or a 2-inch pipe within a 3-inch. The water passes upward through the inner pipe, while the gas is discharged downward through the annular space; or, the position of the two may be reversed, the ammonia being within the inside pipe while the water travels upward through the annular space. They are also constructed in series, in which the gas enters a number of pipes of a section at one time, flowing through these to the opposite end to a header or manifold, at which point the number of pipes is reduced, and so on to the

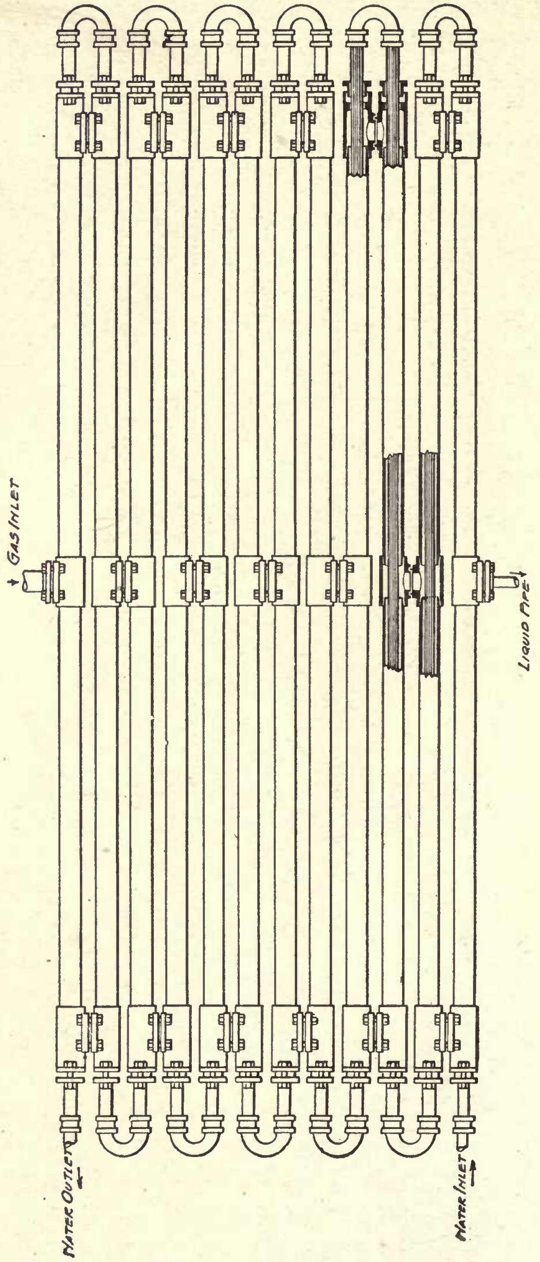


Fig. 27.

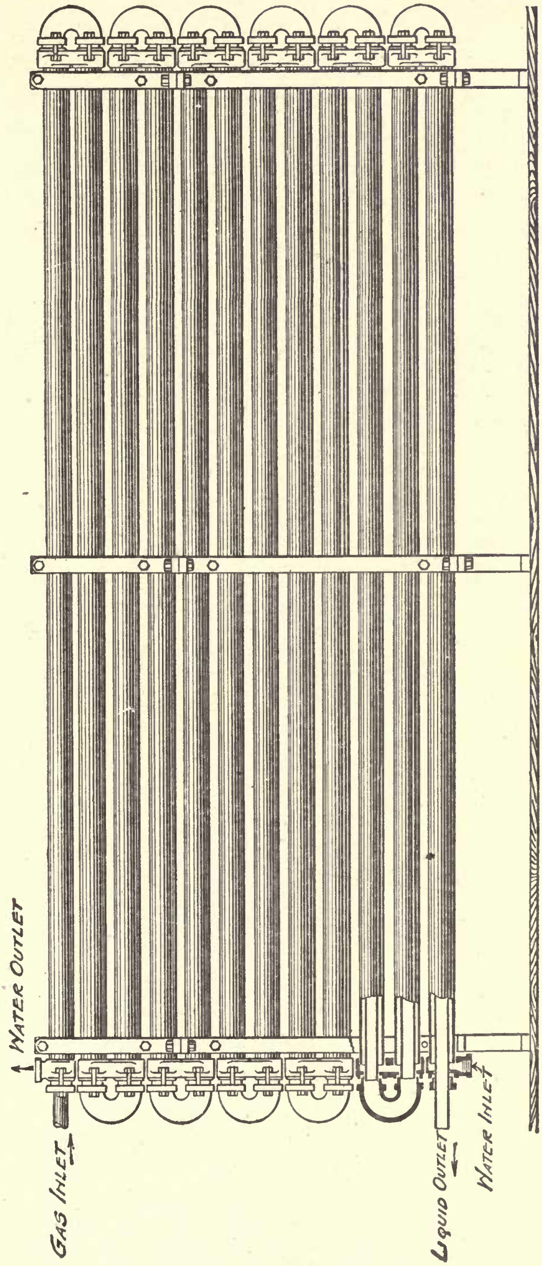


Fig. 28.

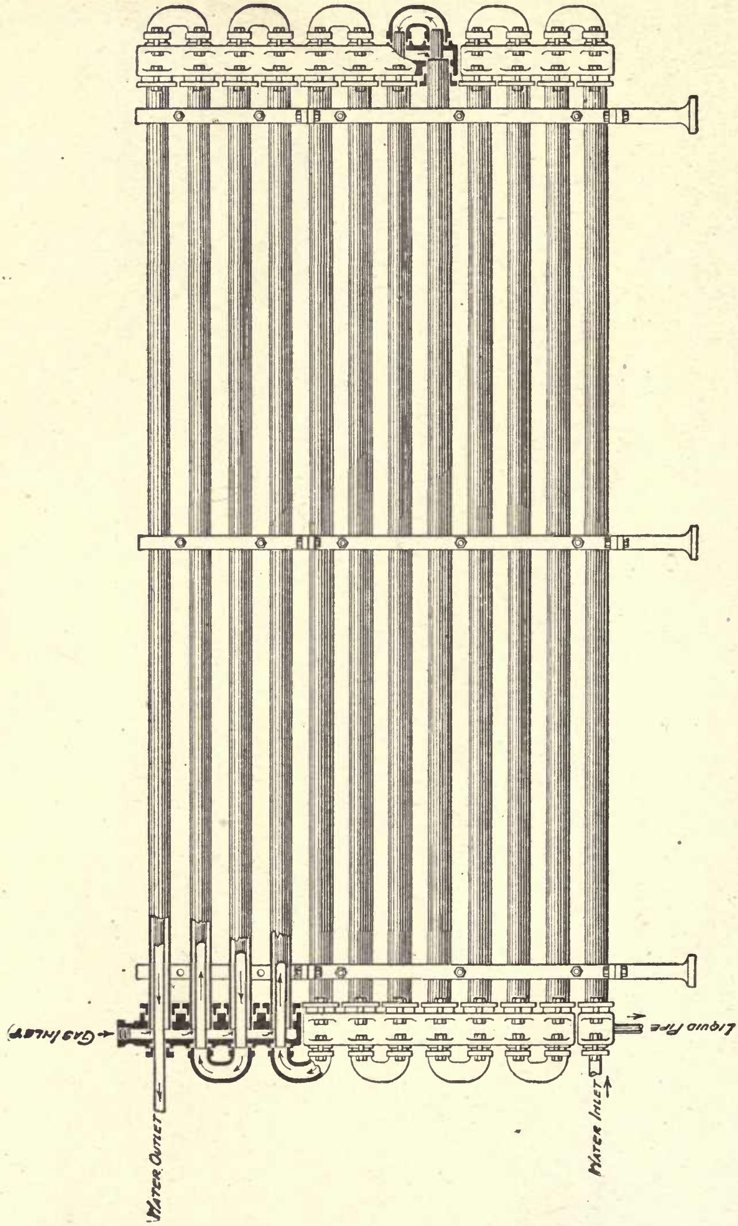


Fig. 29.

bottom with a constantly reduced area. The theory of this construction being that the volume of the gas is constantly reduced as it is being condensed.

Figs. 27, 28 and 29 illustrate a general range of the various types in use.

It is usual in the construction of this type to make each section or bank twelve pipes high by about 17½ feet long; they are rated nominally at ten tons refrigerating capacity each, although for uneven units the construction is made to vary from 10 to 14 pipes in each.

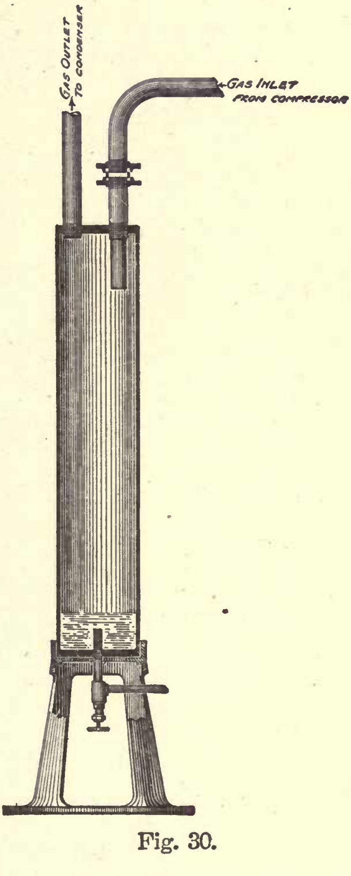


Fig. 30.

The Oil Separator or Interceptor is a device, or form of trap, placed on the line of the discharge between the compressor and the condenser to separate the oil from the ammonia gas. It is to prevent the pipe surface of the condensing and evaporating system from becoming covered with oil which acts as an insulator and prevents rapid transmission of heat through the walls.

The construction admits of quite a variety of principle, from the plain cylindrical shell with an inlet at one side or end and an outlet at the other, to the almost endless variety of baffle plates, spiral conductors and reverse-current devices. The object is similar to that of the steam or exhaust separator, and generally speaking, that which would be effective in one service would be so in the other. Figs. 30, 31 and 32 illustrate three of the most common types in use; from these the student will understand the general principles.

AMMONIA RECEIVER.

The Ammonia Receiver or Storage Tank is a cylindrical shell with heads bolted or screwed on, or welded in each end, and provided with the necessary openings for the inlet and outlet of the ammonia, purge-valve and gauge fittings. They may be vertical or horizontal; the former type is generally used on account of the saving of floor space, while the horizontal is necessary when the condenser is located so low as to make the flow of the liquid ammonia into the vertical type impossible. A convenient location for the receiver in a plant in which the condenser is located above the machine room, is against the wall, or at one side of the room on a bracket or stand at one side of the oil interceptor, the sizes of the two being generally the same. They are then more readily under the control of the engineer than if at some out of the way place.

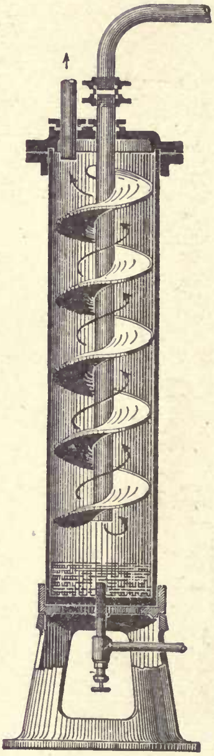


Fig. 31.

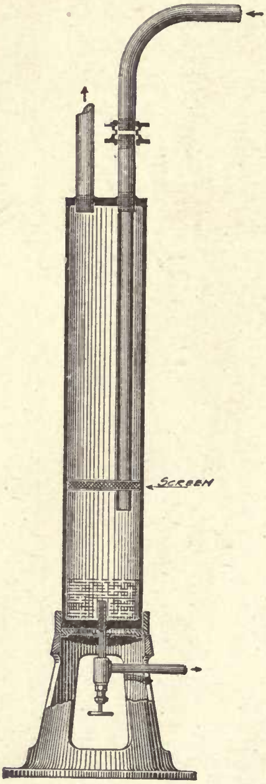


Fig. 32.

Fig. 33 illustrates a receiver of the vertical type with the usual valves and connections for the proper equipment. The liquid ammonia enters at the top and is fed to the evaporator from the side near the bottom, the space below this opening being provided for the accumulation of scale, dirt, or oil, and means are provided for drawing off through the purge valve in the bottom.

PIPES, VALVES AND FITTINGS.

Pipes. Extra strong, or extra heavy pipe (so called) is the generally accepted pipe for connecting the various parts of the refrigerating system. Wrought-iron pipe is generally preferred to steel. Frequently, however, and particularly for the evaporating or low-pressure side of the system, a special weight or grade of pipe is used, also standard or common pipe is sometimes employed for this purpose. Without knowing the particular conditions under which this is to be used, or the relative value of the material, or manner in which the pipe is made, it is always better to use and insist on having the standard extra-strong grade. The threads should be carefully cut, with a good sharp die, making sure that the top and bottom of the threads are sharp and true. With this precaution, and an equally good thread in the fitting, it is not difficult to form a good and lasting joint. Particular care should also be taken that the pipe screws into the fitting the proper distance, and forms a contact the entire length, rather than to screw up against a shoulder without a perfect fit in the thread. This latter often causes leaky joints sometime after the plant has been operated; the temporary joint formed by screwing in too deep against the shoulder or ill-fitting threads very often passes the test and is used for some time after until the combined effect of heat and cold, and action of the ammonia cause it to break out. It is a safe rule that no amount of solder or other doctoring that is not backed up by a good fitting thread to support it can make an ammonia joint. This is particularly true of the discharge or compression side of the plant.

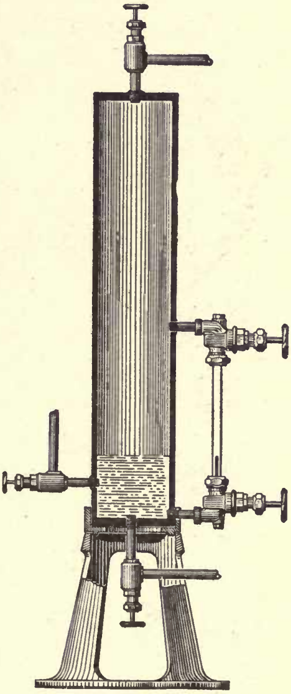


Fig. 33.

The manner of making these joints, may be divided into those having a compressible gasket between the thread on the pipe and the fitting into which it screws and the screwed joint formed by a threaded pipe screwed into a tapped flange or fitting. The latter may be divided into those having a soldered joint, or one in which the union is formed by the threads only, with some of the usual cements to assist in making a tight joint.

The two most prominent types of gasket fittings are shown in Fig. 34 and 35. The former is known in this country as the Boyle Union, and is extensively used. As will be observed, the drawing together of the two glands by the bolts, compresses the gaskets, (usually rubber) against the threaded sides of the pipe, the bottom and sides of the recess in the flanges, and the edges of the ferrule between the two gaskets.

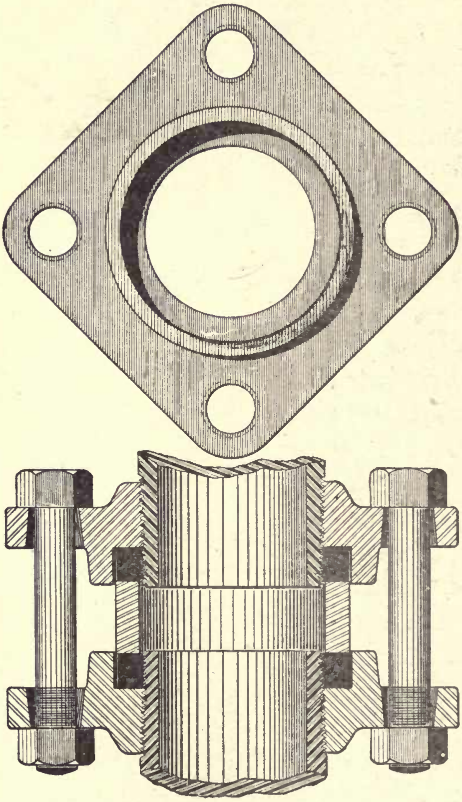
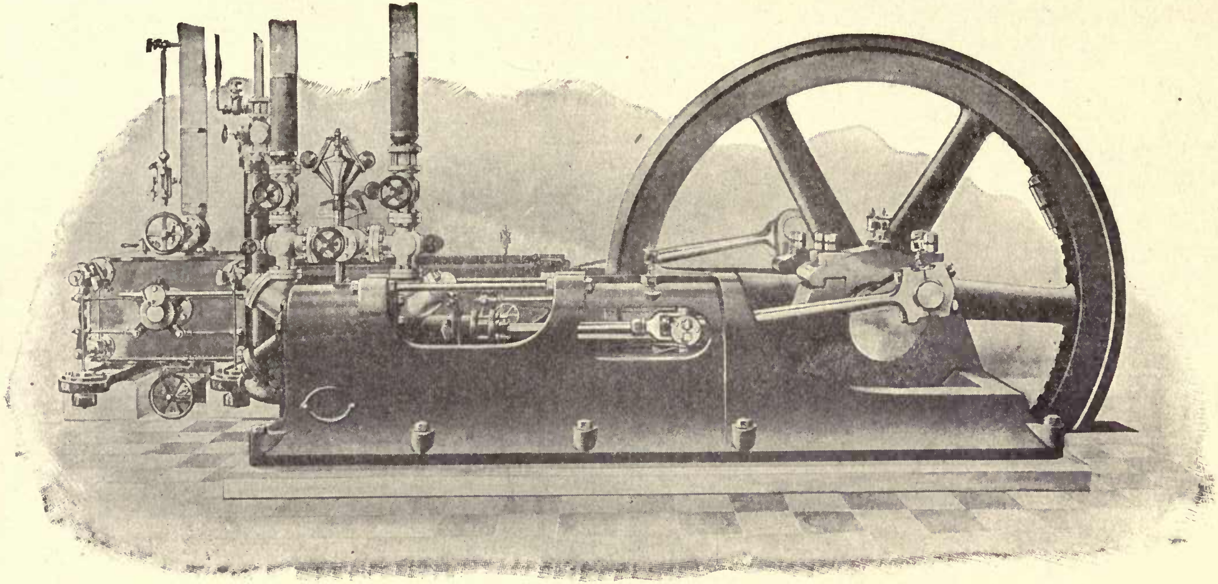


Fig. 34.

Fig. 35 represents a union or joint quite frequently used, although not as commonly as the former. In this the pipe is threaded and screwed into the body of the fitting, but not to form an ammonia-tight joint; leakage is prevented by a packing ring compressed by the gland against the pipe thread and the walls of the recess.

In Fig. 36 (a type of ammonia coupling), the contact between the pipe and fitting is made to withstand the leakage of the gas without the aid of packing or other material other than solder or some of the usual cements; the two flanges are bolted together with a tongue and grooved joint having a soft metal gasket. This makes a permanent and durable fitting.

Other fittings of the class, as ells, tees, and return bends, are usually provided with one of the above methods of connecting with



TANGYE FRAME HORIZONTAL LINDE COMPRESSOR.
Fred W. Wolf Company.

the system, and the different types described may be obtained of the builders of refrigerating machines.

Valves for the ammonia system of a refrigerating plant are of special make and construction, being of steel or semi-steel, with a soft metal seat which may be renewed when worn, and metal gaskets between the bonnets and flanges.

The usual types are Globe, Angle and Gate, subdivided into screwed and flanged. Fig. 37 is a generally adopted type of the flanged globe ammonia valve, while Fig. 38 represents the angle valve of the same construction. This seems to represent the best elements of a durable and efficient valve.

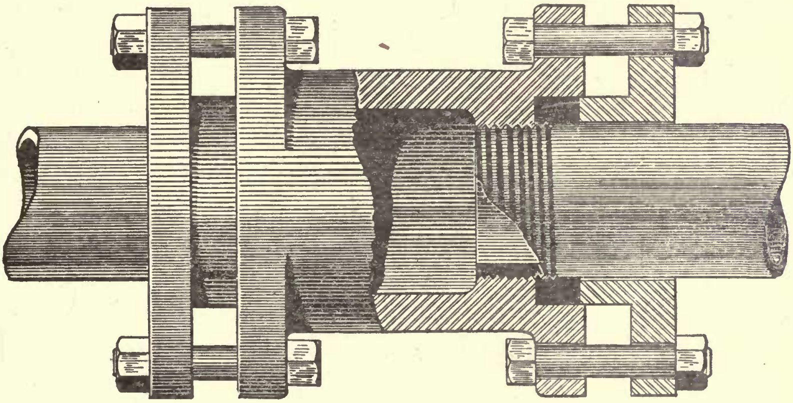


Fig. 35.

For a valve or cock requiring a fine adjustment as is frequently the case in direct-expansion systems, particularly where the length of the evaporating coil or system is short, a V-shaped opening is desirable. Fig. 39 represents a cock for this purpose which will be found to be effective and meet the most exacting requirements.

Pressure Gauges. Two gauges are necessary for an ammonia plant of a single system; one to indicate the discharge or condensing pressure, and one for the evaporator or return gas pressure to the compressors.

Owing to the action of ammonia on brass and copper the gauges for this purpose differ from the ordinary pressure gauge in that it is made with a tube and connections of steel instead of brass, and this construction is the general choice of gauge makers; in other respects the construction is similar. For machines of small capacity instruments with 6-inch dials are common, while for larger plants 8-inch is the generally adopted size. The graduation for the high pressure gauge is usually to 300 pounds pressure, and if a compound gauge is used, it is made to read to a vacuum also. This latter is only needed on certain occasions and frequently omitted from the high-pressure gauge. Owing to the necessity of removing the contents of the system at certain times and usually through the evaporating side of the plant, the gauge for this portion of the system is graduated to read from a vacuum to 120 pounds pressure.

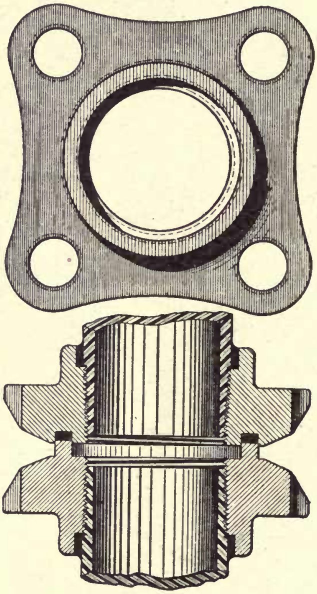


Fig. 36.

In connecting the gauges to the system, it is customary to locate the opening in the discharge and return gas lines near the machine within the engine room, placing a stop valve at some convenient point and carrying a line of $\frac{1}{4}$ or $\frac{1}{2}$ inch extra strong pipe to the gauges, making the joints with the usual ammonia unions. On account of the possibility of leakage of ammonia gas from the gauge tube, it is often considered advisable to fill the gauge pipe with oil (of the kind used for lubricating the ammonia compressor) for a short distance above the gauges, upon which the pressure of the gas will act, causing the gauge to move properly but without allowing the ammonia gas to enter the gauge. This is an application of the same principle as the steam syphon or bent-pipe arrangement in use with steam gauges, for the purpose of keeping the heat and action of steam from the gauge mechanism by the retaining of water in the gauge connection.

Other gauges used about the refrigerating plant are of the ordinary pressure or vacuum types and do not need a special description, as their construction and manner of applying to the different parts of the system are well known to the engineer. It

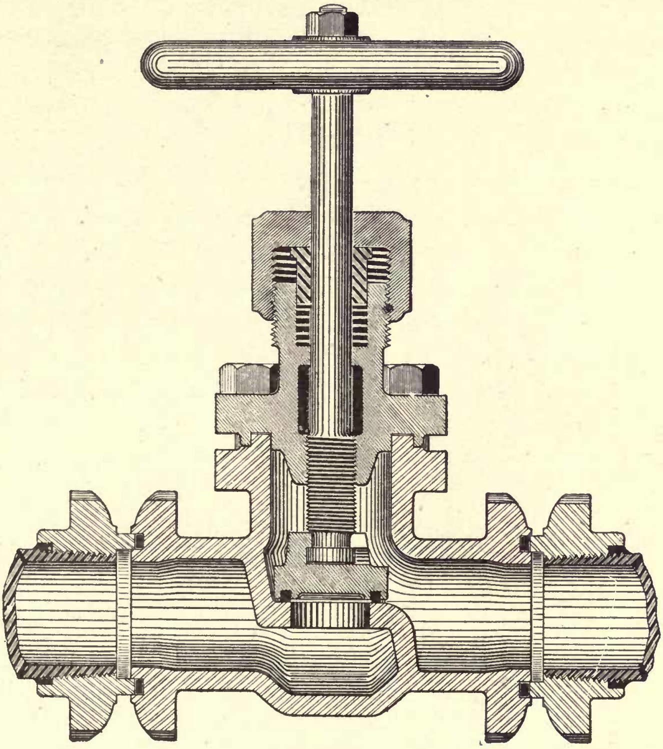


Fig. 37.

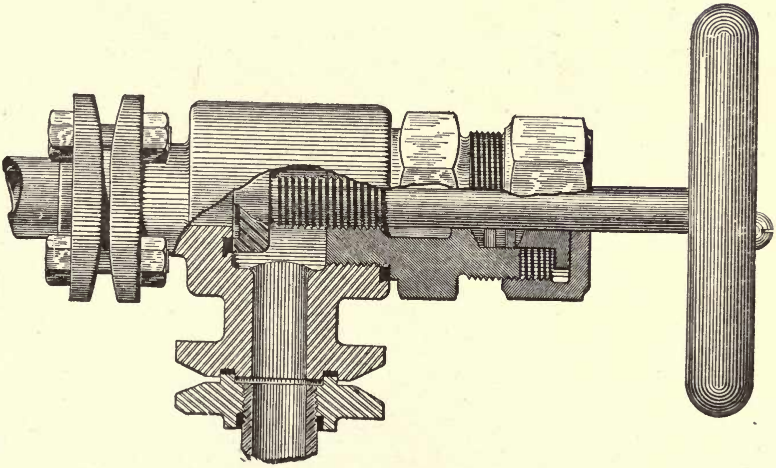


Fig. 38.

may be well, however, to caution the user on the importance of testing the gauges often enough to be sure they are accurate, as serious damages may result from a wrong indication of pressure.

BRINE.

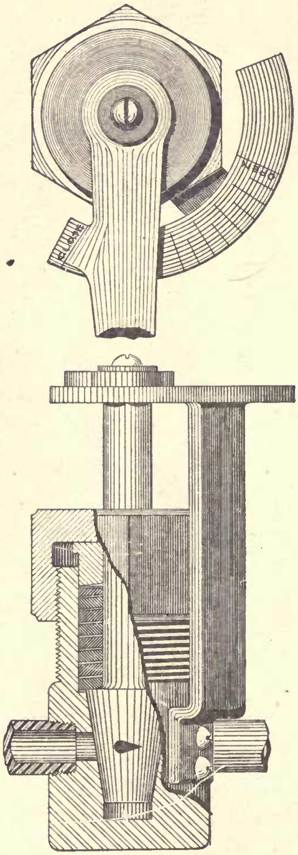


Fig. 39.

Brine is used in refrigeration as a medium for the transmission of heat from the point or object to be refrigerated, to the ammonia or other refrigerant, and accordingly may be found in plants in which the application is indirect.

In the refrigerating practice of today, two kinds of brine are in use, chloride of calcium, and chloride of sodium (common salt). Either one is dissolved in water making a solution of the proper density; it is then pumped from the brine tank or cooler to the objects to be refrigerated, and returned by a system of pipes to be recooled and again circulated through the refrigerating system.

Chloride of calcium brine may be made of such density that its freezing point is—54° Fahr. (54° below zero) while chloride of sodium (salt) brine of maximum density or strength freezes at 0° Fahr. It will, therefore, be seen that for very low temperatures calcium brine should be used. For brine coolers in which the brine passes through the pipes, and the ammonia is evaporated on the outside with a temperature of a few degrees below zero, and the brine not in active circulation, salt brine would be frozen, bursting the pipes and causing a considerable loss. The calcium brine may be made of such density or strength as to make this impossible. It will, therefore, be evident that for use in connection with a brine cooler, the chloride of calcium brine is necessarily the choice It also has no corroding effect on pipes, pumps or other connections, and while the cost is somewhat more than that of salt, the general advantages are decidedly in its favor.

For the brine tank and coil system of refrigeration salt brine may be safely used, and is largely used at the present time. The evaporation of the ammonia, being within the pipes, can only effect the freezing of a small portion on the outer surface, and without damage to the plant. As its temperature may be reduced to zero, or even below (if circulation be maintained) it is effective for practical purposes wherein the temperature required is not below that point. The proper density, or strength of brine, either calcium or salt is determined by the temperature to which it is necessary to be reduced, and the tables on pages 79 and 80 will be found valuable in determining the proper strength for different requirements. It should be remembered, however, that a difference of from 5° to 10° Fahr. exists between the temperature of the brine and that of the evaporating ammonia, and that while the strength of the brine may appear ample for the temperature at which it is carried, the lower temperature of the evaporating ammonia may cause it to solidify within or upon the surface of the evaporator, thus causing it to separate, or freeze, and act as an insulator and prevent the transmission of heat through the surface. It is, therefore, necessary in examining into the strength of the brine, to consider it with reference to the evaporating pressure of the ammonia as well as its own temperature.

In the last column of the tables is given the gauge pressure, corresponding to the freezing point of the brine of different strengths.

The usual and proper instrument for determining the strength of brine is the Beaumè scale, for chloride of calcium brine. A weighted glass tube and bulb (Fig. 40) is graduated 0 to 100, the former being its floating point in water and the latter the floating point in a saturated solution of salt brine. By comparison of the two in the table of calcium brine it will be observed that the ratio of the two scales are as 1 to 4 which makes it possible to obtain one from the other.

In using the scales it is customary to draw a sample of the brine in a glass test tube, raising its temperature to approximately 60° Fahr. and insert the scale; it will then float at the point on its scale corresponding with its strength.

Brine Systems. In the use of the foregoing tables for calcium or salt brine, allowance should be made for the difference in the grades obtained. The quantity required per gallon, or cubic foot of brine, will vary accordingly. The average quantity required however, should nearly correspond with the tables.

In making brine it is well to fit up a box with a perforated false bottom, or, a more readily obtained and equally effective mixer may be made by taking a tight barrel or hogshead, into which is fitted a false bottom four to six inches above the bottom head, and which is bored with one-half inch holes. Over the false bottom lay a piece of coarse canvas or sack to prevent the salt falling through. A water connection is made in the side of the barrel near the bottom, between the bottom head and the false bottom, and a controlling valve placed nearby to regulate the amount of water passing through. An overflow connection is made near the top of the cask, with its end so placed that the brine will flow into the tank, and a wire screen placed across its end inside the cask with a liberal space between it, and the opening, to allow of cleaning. See Fig. 41. The cask or barrel is now filled with the calcium or salt, which dissolves and overflows into the brine tank.

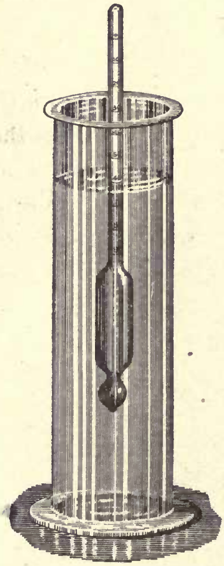


Fig. 40

A test tube and Beaumè scale, or salometer, should be kept at hand, and frequent tests made; the strength may be regulated by admitting the water more or less rapidly. After the first charge it is well to allow the mixer to remain in position for future requirements. A connection should be made from the return brine line from the refrigerating system to the cask, with a controlling valve by the use of which the strength or density of the brine may be increased without adding to the quantity, keeping the cask full of the calcium or salt, and allowing a portion of the return flow of brine to pass through the cask, dissolving the contents and flowing into the tank.

Calcium is usually obtained in sheet-iron drums, holding about 600 pounds each; it is in the shape of a solid cake within the drum. It is advisable to roll these onto the floor or top of tank in which the brine is to be made and pounded with a sledge hammer before removing the iron casing, this process breaking it up into small pieces without its flying about the room. After breaking it up the shell may be taken off and the contents shoveled into the mixer.

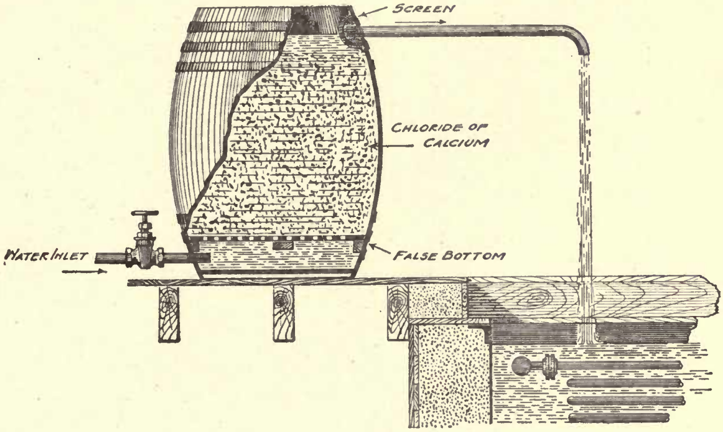


Fig. 41.

It is also sold and shipped in liquid form, in tank cars, generally in a concentrated form (on account of freight charges) and diluted to the proper point upon being put into the plant. Where proper railroad facilities exist, this is probably the most desirable way of obtaining the calcium.

Salt is sold and may be obtained in a number of forms. The usual shape for brine is the bulk, or in sacks of about 200 pounds each. Where it is possible to handle salt in bulk, direct from the car to the tank, this is most generally used on account of the price, being about $1.00 per ton less than if sacked. If it is necessary for it to be carted or stored before using, the sack form is preferable. The coarser grades of salt are used for this purpose, No. 2 Mine being the grade commonly used. The finer salts are higher in price, without a corresponding increase in strength of the brine formed.

The proper density or strength of the brine must be determined for various temperatures. As a rule its freezing point should be equal to, or slightly below, the temperature of the evaporating ammonia, rather than the temperature of the coldest brine, as is common. Referring to the table of salt brine solution, page 80; if we wish to carry a temperature of 10° Fahr. in the outgoing brine, it is necessary that the temperature of the evaporating ammonia be from 5° to 10° degrees below that point, in order that the transfer of heat from the brine to the ammonia will be rapid enough to be effective, which would mean that the ammonia would be evaporating at a temperature of practically 0° Fahr. To prevent the brine freezing against the walls of the evaporator its strength or density should be made to correspond with this, or from 95° to 100° on the salometer. This should be cared for more especially in connection with plants using the brine cooler, in which the brine is within the coil, than in the brine tank system in which the ammonia is inside the pipe and the brine outside; here the only danger or loss would be in efficiency.

In examining into the causes of failure in a plant to perform its usual or rated capacity, it is advisable, unless there is every evidence that the trouble is elsewhere, to make an examination of the brine and determine that its strength and condition is suited to the duty to be performed.

DIRECT EXPANSION.

As its name would imply, this system of refrigeration is one in which the refrigerant is expanded or evaporated in direct contact with the duty to be performed, without an intermediate agent for the transfer of the heat. Its application admits of quite a variety of apparatus to meet the requirements of refrigerating practice, the most general of which is the expansion within a pipe system placed in a room to be refrigerated, or within or between a series of pipes over or within which the substance to be refrigerated is passed.

While the former system admits of a variety of arrangements of the pipes within the room or chamber to be refrigerated, it is confined to the simple principle, however, of the evaporation of the refrigerant within the pipes, by the transfer of heat through the walls of the pipe, thereby reducing the temperature in the room or chamber to the desired point, and for certain purposes is a very satisfactory means of producing the desired results. This is principally true with large rooms in which the temperature and duty to be performed is constant, such as a brewery, packing house, and cold-storage rooms. For rooms requiring an unusually low temperature, as freezers of fish and poultry, direct expansion is desirable, because it is possible to more nearly reach the temperature of the refrigerant direct, than with an intermediate agent, as brine; this is due to the fact that there must necessarily be a difference of from 5° to 10° between the temperatures.

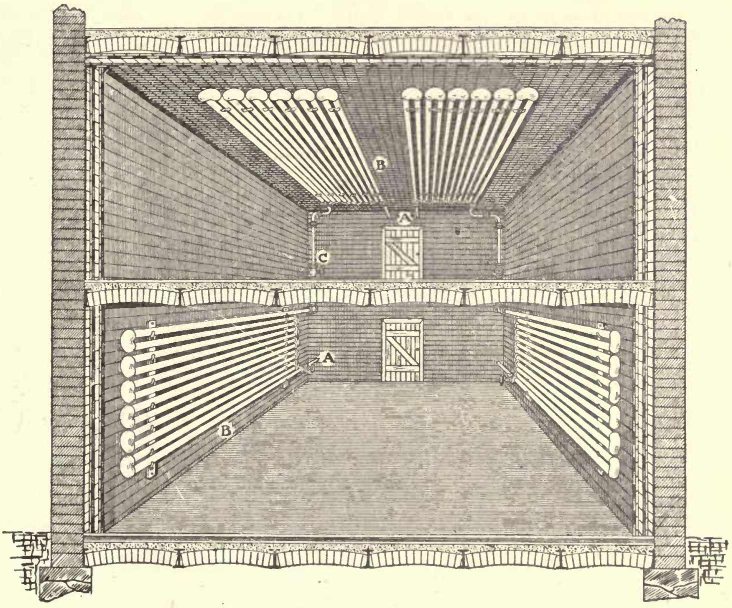


Fig. 42.

Fig. 42 illustrates a direct expansion construction in which the liquid anhydrous ammonia is expanded by the valve or cock A into the coil or system of pipes B and the gas returning to the compressor through the pipe C.

Fig. 43 represents a fish-freezing room on either side of which is arranged a series of pipe shelves, through which the ammonia is evaporated. The fish are laid on tin trays and placed on the pipe shelves until the room is filled. It is then closed, the ammonia turned on and left until the freezing has been accomplished.

It is apparent from the arrangement of the coils being both above and below the trays holding the fish, and close together, that the effect must be very rapid.?

In the cooling of beer or other liquids, two forms of apparatus are used: one (the most common), being a series of a 2-inch pipe with return bends, stands, etc., over which the liquid to be cooled is flowed and within which the ammonia is evaporated, the product being accumulated in an iron pan or other receptacle in which the cooling pipes are placed. In brewery practice it is customary to provide a double series of coils, one above the other, cold water being circulated through the upper section, and the ammonia through the lower, the effect of which is first to remove the heat from the wort as far as possible by the use of water, and the remainder of the cooling being accomplished by the evaporation of the ammonia. This apparatus is called the Baudelot Cooler and is illustrated in Fig. 44.

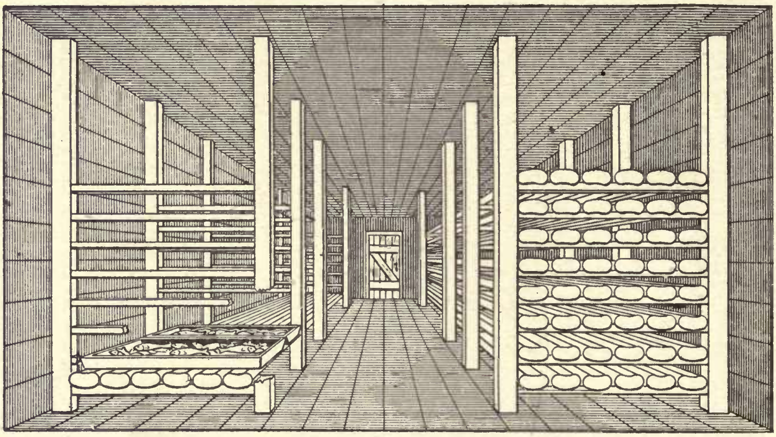


Fig. 43.

Fig. 45 represents a section of a double-pipe cooler for water or other liquids and is similar to the form of double-pipe condenser or cooler already described. It varies only in the construction of the inner tube which is corrugated to prevent bursting by freezing, which becomes possible when used to cool a congealable liquid. In the operation of this type of cooler, when used as an evaporator or direct-expansion cooler, it is usual to reverse the two currents, by feeding or expanding the ammonia into the bottom of the coil the gas issuing from the top, while the liquid to be acted upon enters at the top of the coil and issues from the bottom. This type of cooler is largely used in cooling carbonated ale, as it must be kept from the atmosphere, and for cooling drinking water in circulating systems now installed in hotels, office buildings and department stores.

Purging and Pumping out Connection. A common cause of failure to operate properly and effectively is the introduction of some foreign substance into the system. This will be readily understood and appreciated by engineers and those familiar with the requirements of a steam boiler. Clean surfaces on the shell or tubes are necessary for the maximum evaporation of water, or the transfer of heat through the walls of pipe or other forms of heat-transmitting surface. The most common difficulty encountered in a refrigerating plant is oil, either in its natural condition, or saponified by contact with the ammonia, water or brine. It enters the system in many ways: through leakage, condensation in blowing out the coils or system, foreign gas arising from decomposition of the ammonia through excessive heat and pressure, or the mingling of air which may enter the system through pumping out below atmospheric pressure or the air may have remained in the system from the time of charging, never having been fully removed. It is also probable, though hard to determine with certainty owing to the various conditions surrounding the operation of plants, that impurities are introduced with the ammonia, either as a liquid, gas or air which afterwards becomes impossible to condense.

The oil in a system forms a covering or coating on the evaporating surface which acts as an insulation and prevents the ready transfer of heat through the walls of the evaporator. The presence of water or brine causes an absorption of a portion of the ammonia into the water or brine, forming aqua ammonia which raises the boiling point of the ammonia and causes material loss in the duty. Air or other non-condensable gas in the system, excludes an equal volume of the ammonia gas, thereby reducing the available condensing surface in that proportion.

For the purpose of cleaning the system and removing the different impurities which may appear, purge and blow-off valves and connections are provided. One of these is placed at or near the bottom of the oil interceptor, which is located between the compressors and the condenser; it is used to draw off the oil used as a lubricant in the compressor and precipitated to the bottom. This oil should not be allowed to accumulate to any great extent as it may be carried forward to the condenser by the current of the gas.

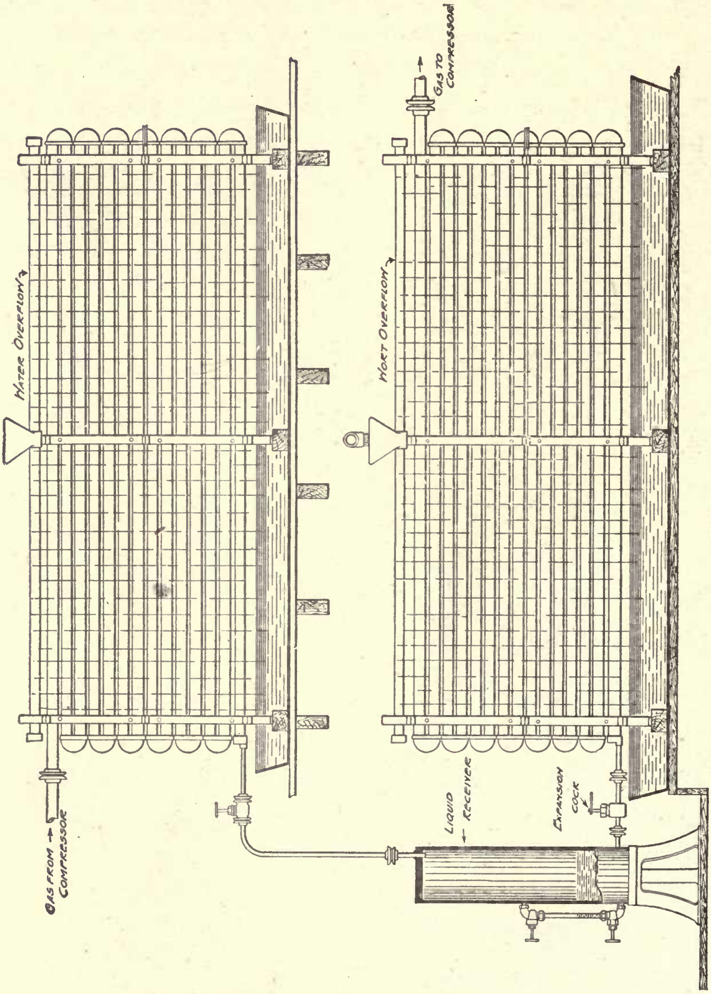


Fig. 44.

If the liquid ammonia receiver be placed in a vertical position it is customary to place a purge valve in the bottom for drawing off oil or other impurities. The supply of liquid to the evaporator being taken off at a short distance above the bottom say 4 to 6 inches.

The next point for the removal of impurities is at the bottom of the brine cooler, or lower manifold of the coil system in a brine-tank refrigerator. These may be tried as often as necessary to determine the state of cleanliness of the system. If the system is charged with any of the common impurities, they should be blown out and the system cleansed at the earliest possible moment, as they cause a decided loss.

Air or foreign gases accumulate in the condenser because the constant pumping out of the evaporating system tends to remove them from that part of the system to the condenser. This point, therefore, is the most natural place for their removal. For this purpose it is customary on the best condensers to place a header or manifold at the top at one end, and connect each of the sections or banks with a valved opening. A valve is also placed at each end of the header, and a connection from one end of this header made to the return gas line between the evaporator and the compressors. By closing the stop valves on the gas inlet and liquid outlet of any one of the sections and opening the purge or pumping-out line into the gas line to the compressors, the section or bank may be emptied of its contents for repairs or examination and then connected up and put into service without shutting down the plant, or a material loss of ammonia. For purging of air or gas, the valve should be closed between this header and the machine, and the valve on the opposite end opened to the atmosphere, the valves on each section opened slightly in turn while the foreign gases are expelled. This process should not be used while the compressor is in operation, as the discharge of the ammonia into the condenser would keep the gas churned to the extent that it would become impossible to remove the foul gases, without removing a considerable portion of the ammonia also.

For this reason it is customary before blowing off the condenser to stop the compressor and allow the water to flow over the condenser until it is thoroughly cooled. Sufficient time should

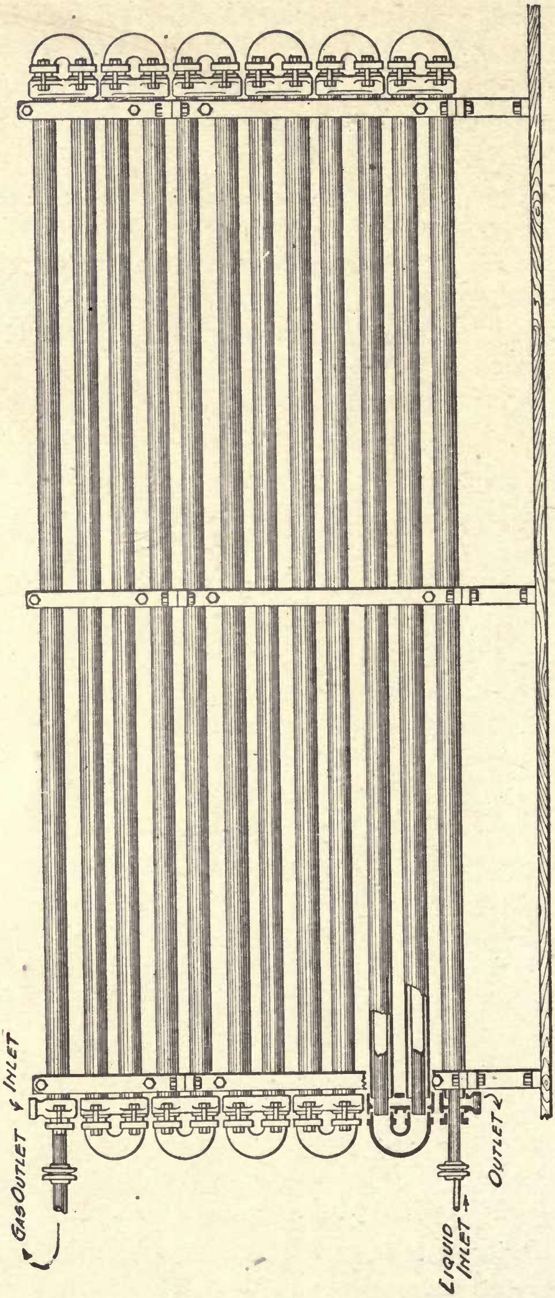


Fig. 45.

elapse for the ammonia to liquefy and settle towards the bottom, while the air and lighter gases rise to the top, at which point they may be blown out through the purge valve to the atmosphere. If doubt exists as to whether ammonia or impurities are being blown out attach a piece of hose to the end of the purge valve and immerse its other end in a pail of water. If it is air, bubbles will rise to the surface, while if it is ammonia, it will be absorbed into the water; the mingling of the ammonia with the water will cause a crackling sound, and the temperature of the water will increase owing to the chemical action.

TESTING AND CHARGING.

Having described the different parts of the refrigerating plant and their relations to one another, let us consider the process of testing and charging, or introducing the ammonia into the system. After the connections are made between the different parts, whether the system is brine or direct expansion, it is necessary to introduce air pressure into it to determine the state of the joints. This may be done in sections or altogether. It is customary, however, to put a higher pressure on the compression side of the plant than on the evaporator owing to the difference in the pressure carried in operation. Adjacent to each compressor is placed a main stop valve, on both the inlet and outlet sides, while on either side of these it is customary to place a by-pass or purge valve.

Before starting the compressor, the main stop valve or valves (if there be two) on the inlet or evaporating side of the compressor, is closed, the small valve between the compressor and the main stop valve opened, and all of the other valves on the system opened except those to the atmosphere. The compressor may then be started slowly, air being taken in through the small by-pass valves and compressed into the entire system. It is well to raise a few pounds pressure on the entire system, before admitting water into the compressor water jackets or other parts of the system, because if a joint were improperly made up, it would be possible for the water to enter the compressors, or coils of the condenser or evaporator, and serious damage or loss of efficiency in the plant occur which it might be impossible to locate afterwards. While if pressure exists within the system when the water is admitted, its entrance into the coils or system is impossible while the pressure exists, and the leak is at once visible, and may be remedied before proceeding farther.

In starting the test it is also well to try the two pressure gauges and see that they agree as to graduation, as it has occurred that owing to a leakage between the discharge pipe and the high pressure gauge, an enormous pressure has been pumped into the system causing it to explode, resulting in loss of life and property. If, however, the pressures are found to be equal on the two gauges it is safe to assume that they are recording properly and their connections are tight. After these preliminaries it is safe to put an air pressure of 300 pounds on the compression side of the plant, care being taken to operate the compressor slowly, not raising the temperature of the compressed air too much, as with the utmost care in making up joints and in selecting material, certain weaknesses may exist, and under such high pressure it is well to proceed with caution.

After the desired pressure has been reached, the entire system should be gone over repeatedly until it is absolutely certain that it is tight. Parts which can be covered with water, such as a submerged form of condenser or brine tank with evaporating coils, should be so covered that the entire surface may be gone over at once and with almost absolute certainty. The slightest leakage will cause air bubbles to ascend to the surface; they may be traced by allowing the water to flow from the tank while the air pressure is still on the coils or system, watching the points where it stops and marking them, to be taken up or repaired when empty. For parts which cannot be covered with water, it is customary to apply with a brush a lather of such consistency that it will not run off too readily; upon coming in contact with a leak, soap bubbles are formed, and by tracing to the starting point the leak may be located. After the compression system has been subjected to a pressure of 300 pounds and found to be tight, the air may be admitted through the liquid ammonia pipe to the evaporating side of the plant, care being taken that the pressure does not rise above the limit of the gauge which as previously stated is usually 120 pounds and the same process of testing as applied to the opposite side of the plant gone over.

Many engineers require the vacuum test as well as the foregoing, and although if the former is gone over thoroughly, there can be little chance of leakage afterwards, it is better to be over-exacting than otherwise in the matter of testing and preparation of the plant, thus preventing the possibility of leaks that may prove disastrous. Open the main stop valves on the inlet line and close the main valves above the compressor on the discharge line, closing the by-pass valves in the suction line, and opening those in the discharge line between the main stop valve and the compressor. Have all the other valves on the system open as before for testing. Starting the compressor draws in the air filling the system through the compressor and discharging it at the small valve left open. Assuming the system to be tight, continuing the operation will finally exhaust the air (or nearly so), when the small valves should be closed and the pressure gauges watched to determine whether or not leakage exists.

Assuming that the system and apparatus is tight in every particular and that it is otherwise ready to be placed in operation, we are now ready to charge the ammonia into the plant.

If the air has been exhausted from the system in testing, this usual step need not be taken before charging, and it is only necessary to put the machine in proper condition to resume the pumping of the gas, and attach a cylinder of ammonia to the charging valve to enable the refrigeration to be commenced. The main stop valves above the compressor which were closed in expelling the air should now be opened and by-pass and other valves to the atmosphere closed. Close the outlet valve from the ammonia receiver and start the machine slowly, at the same time opening the feed valve between the drum of ammonia and evaporator. The anhydrous liquid ammonia will flow into the evaporator through the regular supply pipe, the gas resulting from evaporation being taken up by the compressors and discharged into the condenser and finally settling down into the receiver, when a sufficient quantity has been introduced to form a supply there. Upon closing the valves between the drum from which the supply is being drawn, and opening the outlet valve from the receiver, the process of refrigeration by the compression system is regularly in operation.

OPERATION AND MANAGEMENT OF THE PLANT.

Assuming that the plant has been properly erected, tested, and charged with ammonia of a good quality, and (if a brine system) with brine of proper strength or density, as already explained, it only remains to keep the system or plant in that condition. As all forms of mechanism are liable to disarrangement and deterioration from various causes, repairs and corrections from time to time must be made to keep them in good condition. Let us now consider the most important points requiring attention.

It is absolutely necessary for the good working of any type of plant or apparatus that it be kept clean. As a steam boiler must be clean to obtain the full benefit of the fuel consumed, so must the surfaces of the condenser and evaporator be clean to obtain the proper results from the condensing water and evaporation of the ammonia or other refrigerant.

For satisfactory work the system should be purged of any foreign element present in the pipes, such as air, water, oil, or brine. Foreign matter is the most common among internal causes for loss of efficiency, and the valved openings which have been shown and described should be used for cleaning the system.

Oil is used as a lubricant in nearly if not quite all compressors, and the quantity should be the least amount that will lubricate the surfaces and prevent undue wear. This is considerably less than the average engineer is inclined to think necessary, and consequently a coating forms on the walls of the pipes or other surfaces of the condensing or evaporating systems, and a proportionate decrease in the duty obtained. It is also necessary that the oil be of such a nature that it is not saponified by contact with the ammonia. Such a change would choke or clog the pipes, coating their surfaces with a thick paste which causes a corresponding loss as the amount increases. The purge valve in the bottom of the oil interceptor may be opened slightly about once each week, and the oil discharged from the compressors drawn off into a pail or can, unless a blow-off reservoir is provided. After the gas with which it is charged has escaped, the oil should be practically the same as when fed into the compressors. If, however, the oil is not of the proper quality it will remain thick and pasty, or gummy, showing it to have been affected by the ammonia. Its use should not be continued.

By opening the purge valves, which are usually provided at the bottom manifold or header of the brine tank and the bottom head of the brine cooler, oil or water, if any be in that part of the system, may be drawn off. These valves, however, should not be opened unless there is some pressure in that part of the system, as air would be admitted if the pressure within the apparatus is below that of the atmosphere. Air may enter the system through a variety of causes and its presence is attended with higher condensing pressure and a falling off in the amount of work performed. For the removal of air from the apparatus a purge valve is placed at the highest point in the condenser or discharge pipe from the compressors near the condenser, which may be tried when the presence of air or foreign gases is suspected. This should be done after the compressor has been stopped. When the condenser has fully cooled and the gases separated, a small rubber hose or pipe may be carried into a pail of water and the purge valve or valves slightly opened. If air or other gases exist in the system bubbles will rise to the surface of the water so long as it is escaping, while, if ammonia is being blown off, it will be absorbed in the water and not rise to the surface.

To prevent the possibility of air getting into the system, the evaporating pressure should never be brought below that of the atmospheric, or 0° on the gauge, as at such times, with the least leakage at any point, it is sure to enter. Should it become necessary to reduce the pressure below that point, it is well first to tighten the compressor stuffing boxes and allow the pressure to remain below 0° only the shortest possible time as not only air may enter, but if it be the brine system and a leak exists, brine also will be drawn in.

From the foregoing it is evident that in order to obtain satisfactory results, the interior of the system must be kept clean by purging at the different points provided for this purpose; and it need only be added in this connection, that when the presence of oil or moisture becomes apparent in any quantity, the coils or other parts should be disconnected and blown out with steam until thoroughly clean and afterwards with air to make certain that condensation from the steam does not remain, after which the parts may again be connected and tested ready for operation.

If the plant be a brine system it is necessary that the brine be maintained at a proper strength or density to obtain satisfactory results, for if it becomes weakened it freezes on the surfaces of the pipes or evaporator, acting as an insulator and preventing the rapid transmission of heat through the walls.

Frequently the engineers or owners in looking about for the cause of a falling off in the capacity of a plant, overlook the fact that the strength of the brine is the sole difficulty, and the addition of salt or chloride of calcium is a remedy. Referring to the tables of brine solutions, there should be no difficulty in determining the proper strength of the brine for the different temperatures at which the plant may be operating; but as already stated, this should be made to correspond to the temperature of the evaporating ammonia rather than the temperature at which the brine may be handled.

It is of great importance to know at all times whether or not the gas taken into the compressors is fully discharged into the condenser, as the slightest loss at this point is certain to make itself felt in the operation of the plant. The compressor or valves seldom need be taken apart to determine their operation. The engineer should be able to discern the slightest change in temperature from the normal, when the compressors are working at their best, by placing the hand on the inlet and outlet pipes or the lower part of the compressors. Should the inlet pipe to one compressor be warmer than that to the other (of a pair), or the frost on the pipe from the evaporator reach nearer one compressor than the other, it is then certain that the one with the higher temperature, or from which the frost is farthest, is not working properly or doing as much duty as the other, and it is equally certain that some condition exists which prevents the complete filling and discharge of its contents; possibly it has more clearance or leaky valves.

The most common difficulties experienced with ammonia condensers are those of keeping the external surfaces clean and free from deposits, and preventing the accumulation of air or foreign gases within. Deposits on the surface are usually of two kinds, one which remains soft and may be washed off with a brush or wire scraper such as is used for cleaning castings in a foundry, the other a hard deposit which must be loosened with a hammer or scraper. It is hardly necessary to explain in detail the methods employed in cleaning the condenser as this is a matter that each engineer will be able to accomplish in his own way. It should not, however, be overlooked, and with a condensing pressure higher than ordinary, this should be the first point to be examined after the water supply.

Air, or foreign gases due to decomposition of the ammonia or other causes find their way into the condenser and make themselves manifest generally in a higher condensing pressure, or a falling off in the duty to be obtained from the plant. They should be blown off through the purge valve at the top of the condenser in the manner already described.

It is possible, through leakage of the coils or other parts of the apparatus, that the ammonia may become mixed with brine or water, thereby retarding its evaporation and interfering with the proper or usual operation of the plant. If this is suspected, a sample may be drawn off into a test glass through the charging valve or purge valve of the brine tank or ammonia receiver, and allowed to evaporate, in which case the water or brine will remain in the glass and the relative amount be determined. Through careful evaporation, and continued purging of the evaporator at intervals, this may in time be eliminated, and care should be taken to prevent future recurrence.

Loss of ammonia should be constantly guarded against. It is watchfulness which determines between a wasteful and an economical plant in this particular, and the engineer who allows the slightest smell of ammonia to exist about the plant is certain to be confronted with excessive ammonia bills; while he who is constantly on the alert and never rests until his plant is as free from the smell of ammonia as an ordinary engine room, will be referred to as the one who ran such and such a plant without addition of more ammonia for so many years.

The escape of ammonia into the atmosphere is readily detected; but where a leakage occurs in a submerged condenser, brine tank or brine cooler it is necessary to examine the surrounding liquid to determine whether or not it exists. For this purpose various agents are employed, and may be obtained of druggists or from the manufacturers of ammonia. Red Litmus paper when dipped into water or brine contaminated with ammonia will turn blue. Nessler's solution causes the affected water to turn yellow and brown, while Phenolphthalen causes a bright pink color with the slightest amount of ammonia present.

The stopping of a leakage of ammonia in the brine tank or cooler may be possible while the plant is in operation, by shutting off the coil in which it occurs, or, if the point is accessible a clamp and gasket may be put in place temporarily.

PROPORTION BETWEEN THE PARTS OF A REFRIGERATING PLANT.

There is necessarily a certain ratio or proportion between the several parts of a refrigerating plant, as there is between the boiler, engine, and parts of a steam or power plant, in order to obtain the most economical results. It is first necessary that the evaporator be provided with heat-transmitting surface sufficient to conduct 284,000 B. T. U. from the brine to the ammonia, for each ton of refrigeration to be performed. Without going into a theoretical calculation of this amount, we shall state in both lineal feet of pipe and square feet of pipe surface the commercial sizes and amounts ordinarily in use.

The coil surface in a brine-tank system of refrigeration, should contain approximately 50 square feet of external pipe surface, to each ton in refrigerating capacity of the plant, when it is to be operated at a temperature of 15° Fahr. This is an ample allowance and will be found under general working conditions to give readily the required capacity. While tests have been made in which 40 square feet of pipe surface has been found sufficient for one ton of refrigeration, it will be safer to use the former amount, owing to the varied conditions under which a plant may be operated. This would amount in round figures to 150 linear feet of 1-inch pipe, 115 feet of $1\frac{1}{4}$-inch, 100 feet of $1\frac{1}{2}$-inch, or 80 feet of 2-inch pipe.

The brine tank should contain from 40 to 60 cubic feet (depending on the amount of storage capacity desired) for each ton in capacity of the plant. The brine cooler should contain 12 square feet of external pipe surface for each ton, from which, in comparison with the amount required for the brine-tank system, the statements regarding the relative efficiency of the two methods of cooling brine may be more readily understood. This amount of surface would practically correspond to 35 linear feet of 1-inch pipe, 28 feet of 1¼-inch, 25 feet of 1½-inch or 19 feet of 2-inch pipe. The shell of the cooler is made sufficiently large to contain only the number of coils necessary, there being no advantage in a larger shell.

The submerged type of ammonia condenser should contain approximately 35 square feet of external surface which nearly corresponds to 100 linear feet of 1-inch pipe, 80 feet of 1¼-inch, 70 feet of 1½-inch and 56 feet of 2-inch pipe.

The atmospheric type of condenser should contain 30 square feet of external pipe surface which corresponds to 87 linear feet of 1-inch pipe, 69 feet of 1¼-inch, 60 feet of 1½-inch and 48 feet of 2-inch pipe.

The double-pipe type of condenser, as usually rated, contains 7 square feet of external pipe surface for the water circulating pipe and about 10 square feet of internal surface of the outer pipe and corresponds to approximately 20 linear feet each of 1¼-inch and 2-inch sizes for each ton of refrigerating capacity.

The above quantities are based on a water supply of average temperature (60°) and quantity. In cases of a limited supply or higher temperature than ordinary, a greater amount should be used.

The ammonia compressor should be of such dimensions that it will take away the gas from the brine cooler, evaporating coils, or system, as rapidly as formed by the evaporation of the liquid ammonia, and unless the temperature at which the plant is to be operated be known, it is impossible to determine the volume of gas to be handled and the necessary sizes of the compressor.

As stated before, the unit of a refrigerating plant is usually expressed in tons of refrigeration equal to 284,000 B. T. U. Up to the present time, however, a standard temperature at which this duty shall be performed has never been established, and therefore the rating of a machine, evaporator, or condenser by tonnage is a merely nominal one and misleading to the purchaser, a range of as great as 50 per cent very often existing in the tenders for certain contracts. Upon the basis, however, of the average temperature required of the refrigerating apparatus that of 15° Fahr. is probably the mean; and at this temperature in the outgoing brine, it is necessary to take away from the evaporator nearly 7,000 cubic inches of gas per minute for each ton of refrigeration developed in twenty-four hours. This may be considered as a fair basis for the rating of the displacement of the compressor or compressors of the plant, unless a specific temperature is stated at which the plant is to operate. At 0° Fahr. it is necessary to calculate on approximately 9,000 cubic inches, while at 28° Fahr. about 5,000 will be the required amount.

For example, if we have two single acting compressors 12 inches diameter by 24 inches stroke operating at 70 revolutions per minute, we would have 113.09 (inches, area of 12-inch circle) × 24 (inches stroke) × 2 (number of compressors) × 70 (revolutions) ÷ 7,000 (cubic inches displacement required) = 54.28 (tons refrigeration per 24 hours of operation), while if the same machine is to be operated at or near a temperature of zero and we divide the product by 9,000 we have a capacity of 42.22 tons only in the same length of time. The above quantities are given as approximate only, but they have been deduced from the average results obtained from years of practice and will be found reliable under average conditions. It is to be hoped, however, that a standard will soon be adopted which will rate machines or plants by cubic inches displacement at a certain number of revolutions or a stated piston speed, and the cooling of a certain number of gallons of brine per minute through a certain range of temperature.

THERMOMETER SCALES.

Fahr.	Cent.	Reau.	Fahr.	Cent.	Reau.	Fahr.	Cent.	Reau.
212	100	80	120	48.9	39.1	30	— 1.1	— 0.9
210	98.9	79.1	118	47.8	38.2	28	— 2.2	— 1.8
208	97.8	78.2	116	46.7	37.3	26	— 3.3	— 2.7
206	96.7	77.3	114	45.6	36.4	24	— 4.4	— 3.6
204	95.6	76.4	112	44.4	35.6	22	— 5 6	— 4.4
202	94.4	75.6	110	43.3	34.7	20	— 6 7	— 5.3
200	93.3	74.7	108	42.2	33.8	18	— 7.8	— 6.2
198	92.2	73.8	106	41.1	32.9	16	— 8.9	— 7.1
196	91.1	72.9	104	40	32	14	—10	— 8
194	90	72	102	38.9	31.1	12	—11.1	— 8 9
192	88.9	71.1	100	37.8	30.2	10	—12.2	— 9.8
190	87.8	70.2	98	36.7	29.3	8	—13.3	—10.7
188	86.7	69.3	96	35.6	28.4	6	—44.4	—11.6
186	85.6	68.4	94	34.4	27.6	4	—15.6	—12.4
184	84.4	67.6	92	33.3	26.7	2	—16 7	—13.3
182	83.3	66.7	90	32.2	25.8	0	—17.8	—14 2
180	82.2	65.8	88	31.1	24.9	— 2	—18.9	—15.1
178	81.1	64.9	86	30	24	— 4	—20	—16
176	80	64	84	28.9	23.1	— 6	—21.1	—16.9
174	78.9	63.1	82	27.8	22.2	— 8	—22.2	—17.8
172	77.8	62.2	80	26 7	21.3	—10	—23.3	—18.7
170	76.7	61.3	78	25.6	20.4	—12	—24.4	—19.6
168	75.6	60.4	76	24.4	19.6	—14	—25.6	—20.4
166	74.4	59.6	74	23.3	18.7	—16	—26.7	—21.3
164	73.3	58.7	72	22.2	17.8	—18	—27.8	—22.2
162	72.2	57.8	70	21.1	16.9	—20	—28.9	—23.1
160	71.1	56.9	68	20	16	—22	—30	—24
158	70	56	66	18.9	15.1	—24	—31.1	—24.9
156	68.9	55.1	64	17.8	14.2	—26	—32.2	—25.8
154	67.8	54.2	62	16.7	13.3	—28	—33.3	—26.7
152	66.7	53.3	60	15.6	12.4	—30	—34.4	—27.6
150	65.6	52.4	58	14.4	11.6	—32	—35.6	—28.4
148	64.4	51.6	56	13.3	10.7	—34	—36.7	—29.3
146	63.3	50.7	54	12.2	9.8	—36	—37.8	—30.2
144	62.2	49.8	52	11.1	8.9	—38	—38.9	—31.1
142	61.1	48.9	50	10	8	—40	—40	—32
140	60	48	48	8.9	7.1	—42	—41 1	—32.9
138	58.9	47.1	46	7.8	6.2	—44	—42.2	—33.8
136	57.8	46.2	44	6.7	5.3	—46	—43.3	—34 7
134	56.7	45.3	42	5.6	4.4	—48	—44.4	—35.6
132	55.6	44.4	40	4.4	3.6	—50	—45.6	—36.4
130	54.4	43.6	38	3.3	2.7	—52	—46.7	—37 3
128	53.3	42.7	36	2.2	1.8	—54	—47.8	—38.2
126	52.2	41.8	34	1.1	0.9	—56	—48.9	—39.1
124	51.1	40.9	32	0	0	—58	—50	—40
122	50	40						

TEMPERATURE, PRESSURE, LATENT HEAT AND WEIGHT OF AMMONIA, OR PROPERTIES OF SATURATED AMMONIA.

Temp. F.	Pressure		Latent Heat	Volume in Cu. Ft. of 1 Lb. Vapor	Volume in Cu. Ft. of 1 Lb. Liquid	Weight of 1 Cu. Ft. Vapor
	Absolute	Gauge				
—40	10.69	—4.01	579.67	24.38	.0234	.0411
—35	12.31	—2.39	576.69	21.32	.0236	.0471
—30	14.13	— .57	573.69	18.69	.0237	.0535
—25	16.17	1.47	570.68	16.44	.0238	.0609
—20	18.45	3.75	567.67	14 48	.024	.069
—15	20.99	6.29	564.64	12.81	.0242	.0775
—10	23.77	9.07	561 61	11.36	.0243	.088
— 5	27.57	12.87	558.56	9.89	.0244	.1011
0	30.37	15.67	555.5	9.14	.0246	.1094
+ 5	34.17	19.47	552.43	8.04	.0247	.1243
10	38.55	23.85	549.35	7.2	.0249	.1381
15	42.93	28.23	546.26	6.46	.025	.1547
20	47.95	33.25	543 15	5.82	.0252	.1721
25	53.43	38.73	540.03	5.24	.0253	.1908
30	59.41	44.71	536.92	4.73	.0254	.2111
35	65.93	51.23	533.78	4.28	.0256	.2336
40	73.	58.3	530.63	3.88	.0257	.2577
45	80.66	65.96	527.47	3 53	.026	.2832
50	88.96	74.26	524.3	3.21	.02601	.3115
55	97.63	82.93	521.12	2.93	.02603	.3412
60	107.6	92.9	517.93	2.67	.0265	.3745
65	118.03	103.33	515.33	2.45	.0266	.4081
70	129.21	114.51	511.52	2 24	.0268	.4664
75	144.25	126 55	508.29	2.05	.027	.4978
80	154.11	139.41	504 66	1.89	.0272	.5291
85	167.86	153.16	501.81	1.74	.0273	.5747
90	182.8	168.1	498.11	1.61	.0274	.6211
95	198.37	183.67	495.29	1.48	.0277	.6756
100	215.14	200.44	491.5	1.36	.0279	.7353
105	232.98	218.28	488.72	1.29	.0281	.7862
110	251.97	237.27	485.42	1.2	.0283	.8451
115	272.14	257.44	482.41	1.12	.0285	.9042
120	293.49	278.79	478 79	1.04	.0287	.9738
125	316.16	301.46	475.45	.97	.0289	1.172
130	340.42	325.72	472.11	.9	.0291	1.2218
135	365.16	350.46	468.75	.84	.0293	1.3212
140	392.22	377.52	465.39	.79	.0295	1.4108
145	420.49	405.79	462.01	.74	.0297	1.4904
150	450.2	435.5	458.62	.69	.0299	1.5896

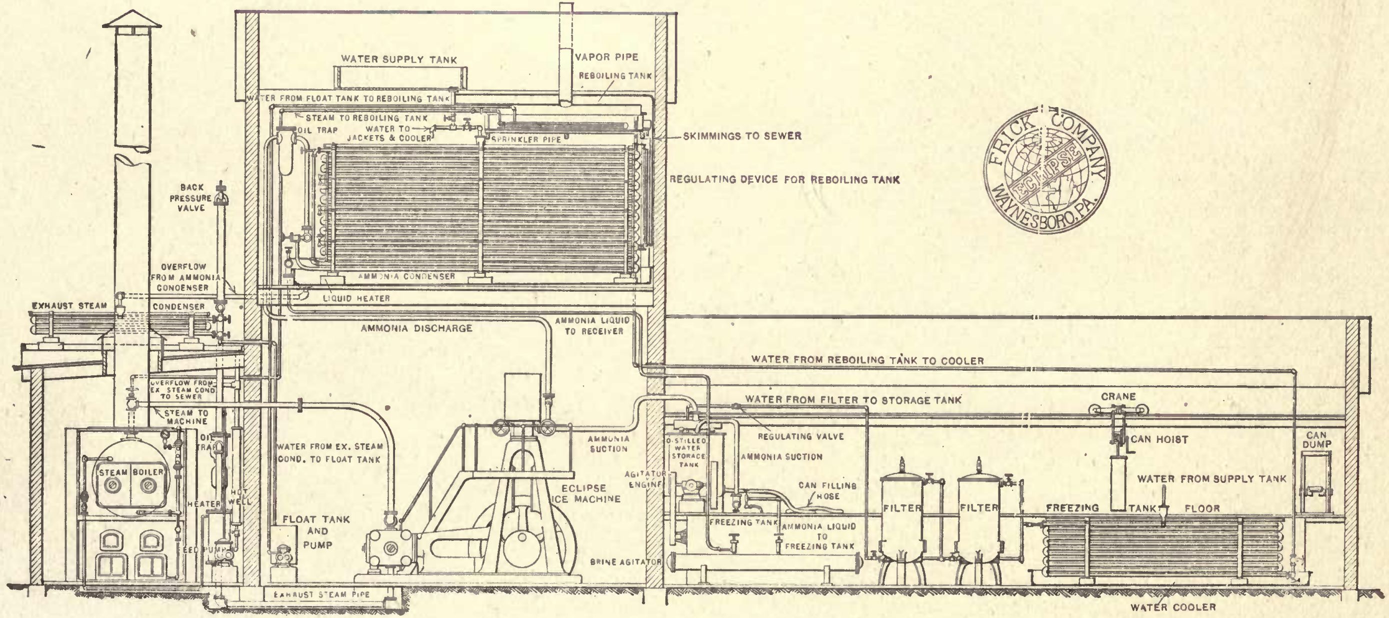
TABLE OF CALCIUM BRINE SOLUTION.

Deg. Baumé 60° F.	Deg. Salometer. 60° F.	Per Cent Calcium by Weight	Lbs. per Cu. Ft. Sol.	Lbs. per Gallon	Specific Gravity	Specific Heat	Freezing Point F.	Amm. Gauge Pressure
0	0	0	0	0	1	1	32	47.31
1	4	.943	1.25	⅙	1.007	.996	31.1	46.14
2	8	1.886	2.5	⅓	1.014	.988	30.33	45.14
3	12	2.829	3.75	½	1.021	.98	29.48	44.06
4	16	3.772	5	⅔	1.028	.972	28.58	43
5	20	4.715	6.25	⅚	1.036	.964	27.82	42.08
6	24	5.658	7.5	1	1.043	.955	27.05	41.17
7	28	6.601	8.75	1⅙	1.051	.946	26.28	40.25
8	32	7.544	10	1⅓	1.058	.936	25.52	39.35
9	36	8.487	11 25	1½	1.066	.925	24.26	37.9
10	40	9.43	12.5	1⅔	1.074	.911	22.8	36.3
11	44	10.373	13.75	1⅚	1.082	.896	21.3	34.67
12	48	11.316	15	2	1.09	.89	19.7	32.93
13	52	12.259	16.25	2⅙	1.098	.884	18.1	31.33
14	56	13.202	17.5	2⅓	1.107	.878	16.61	29.63
15	60	14.145	18.75	2½	1.115	.872	15.14	28.35
16	64	15.088	20	2⅔	1.124	.866	13.67	27.04
17	68	16.031	21.25	2⅚	1.133	.86	12.2	25.76
18	72	16.974	22.5	3	1.142	.854	10	23.85
19	76	17.917	23.75	3⅓	1.151	.849	7.5	21.8
20	80	18.86	25	3⅓	1.16	.844	4.6	19.43
21	84	19.803	26.25	3½	1.169	.839	1.7	17.06
22	88	20.746	27.5	3⅔	1.179	.834	— 1.4	14.7
23	92	21.689	28.75	3⅚	1.188	.825	— 4.9	12.2
24	96	22.632	30	4	1.198	.817	— 8.6	9.96
25	100	23.575	31.25	4⅙	1.208	.808	—11.6	8.19
26		24.518	32.5	4⅓	1.218	.799	—17.1	5.22
27		25.461	33.75	4½	1.229	.79	—21.8	2.94
28		26.404	35	4⅔	1.239	.778	—27.	.65
29		27.347	36.25	4⅚	1.25	.769	—32.6	1" Vac
30		28.29	37.5	5	1.261	.757	—39.2	8.5" "
31		29.233	38.75	5⅙	1.272		—46.3	12
32		30.176	40	5⅓	1.283		—54.4	15
33		31.119	41.25	5½	1.295		—52.5	10
34		32.062	42.5	5⅔	1.306		—39.2	4
35		33	43.75	5⅚	1.318		—25.2	1.5

minimum
temp

TABLE OF CHLORIDE OF SODIUM (SALT) BRINE.

Degrees on Salom.	Percentage Salt by Weight	Pounds Salt per Cu. Ft.	Pounds Salt per Gallon	Specific Gravity	Specific Heat	Freezing Point F.	Ammonia Gauge Pressure
0	0	0	0	1	1	32	47.32
5	1.25	.785	.105	1.009	.99	30.3	45.1
10	2.5	1.586	.212	1.0181	.98	28.6	43.03
15	3.75	2.401	.321	1.0271	.97	26.9	41
20	5	3.239	.433	1.0362	.96	25.2	38.96
25	6.25	4.099	.548	1.0455	.943	23.6	37.19
30	7.5	4.967	.664	1.0547	.926	22	35.44
35	8.75	5.834	.78	1.064	.909	20.4	33.69
40	10	6.709	.897	1.0733	.892	18.7	31.93
45	11.25	7.622	1.019	1.0828	.883	17.1	30.38
50	12.5	8.542	1.142	1.0923	.874	15.5	28.73
55	13.75	9.462	1.265	1.1018	.864	13.9	27.24
60	15	10.389	1.389	1.1114	.855	12.2	25.76
65	16.25	11.384	1.522	1.1213	.848	10.7	24.46
70	17.5	12.387	1.656	1.1312	.842	9.2	23.16
75	18.75	13.396	1.791	1.1411	.835	7.7	21.82
80	20	14.421	1.928	1.1511	.829	6.1	20.43
85	21.25	15.461	2.067	1.1614	.818	4.6	19.16
90	22.5	16.508	2.207	1.1717	.806	3.1	18.2
95	23.75	17.555	2.347	1.182	.795	1.6	16.88
100	25	18.61	2.488	1.1923	.783	0	15.67



COMPLETE ICE FACTORY.
Frick Company.

REFRIGERATION

PART II

REFRIGERATION BY CARBONIC ANHYDRIDE GAS.

In general design and requirements, the refrigerating machine using carbonic anhydride gas is substantially like the machine using ether, ammonia, or carbonic dioxide gases in that it liquefies the gas by the removal of the latent heat in condensers and tanks. Where it differs materially is in the pressures required to accomplish the liquefaction of the gas.

The following table shows the pressure required for liquefaction at different temperatures from an approximate normal condition of 80 degrees to a point where the gas remains a liquid under the atmospheric pressure of 14.7 pounds from the absolute.

TEMPERATURE OF GAS LIQUEFIED.

Temperature Fahrenheit.	Pressure Pounds per sq. in.	Temperature Fahrenheit.	Pressure Pounds per sq. in.
80	1000.6	-60	134.2
70	889.3	-70	113.2
60	771.7	-80	96.2
50	689.4	-90	81.0
40	588.0	-100	70.1
30	507.1	-110	57.9
20	433.6	-120	47.4
10	367.1	-130	38.4
0	311.6	-140	30.0
-10	260.1	-150	21.3
-20	217.5	-160	15.2
-30	182.8	-170	7.1
-40	162.8	-179.6	0.0
-50	156.8		

In the operation of refrigerating machines where the gas is rapidly passing through the condensers, it has been established that the temperature of the gas liquefied is from 8 to 12 degrees above that of the water used for condensing. If the condensing water is 60 degrees, though during the summer days of August

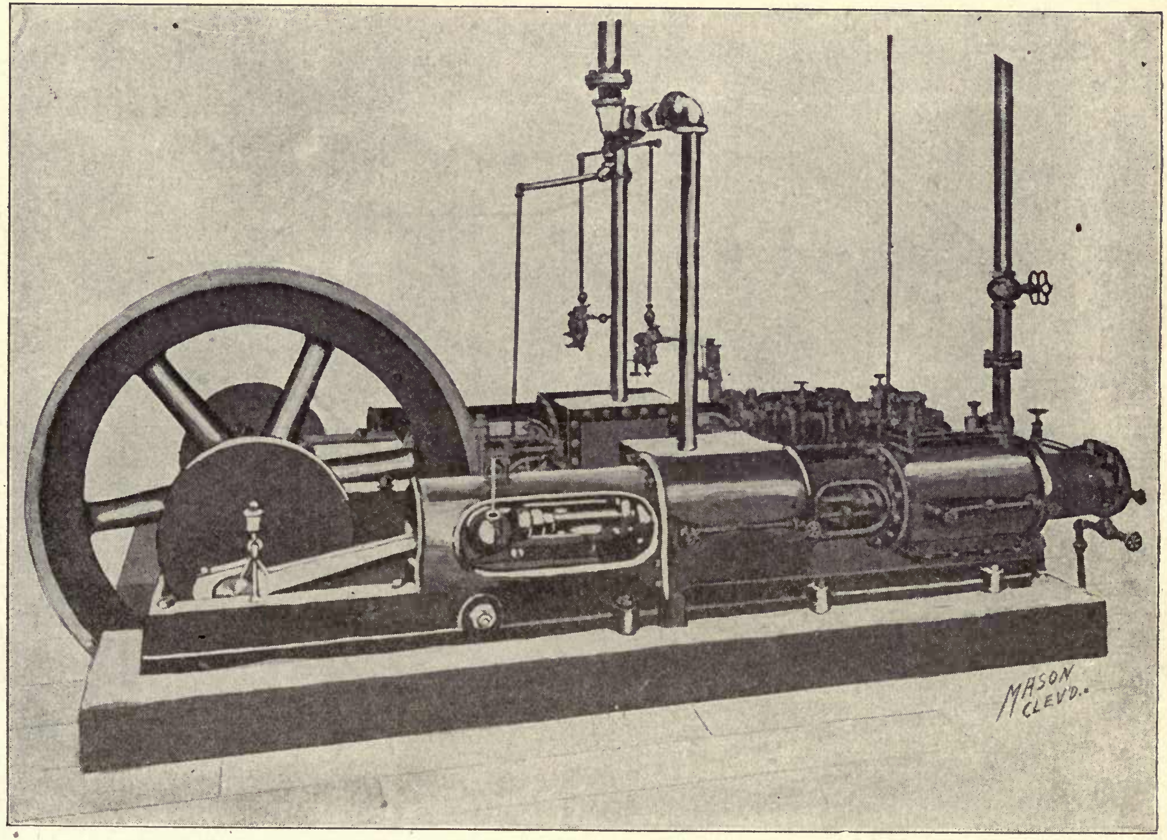


FIG. 46.

or September a temperature of 65 to 76 degrees is more common where city service water is in use, a pressure of at least 1,000 pounds per square inch is required for the working conditions.

With this pressure, compressing cylinders and piping must be very strong to withstand the pressure, and the diameter of the gas cylinder must be small compared with that of the steam cylinder. As carbonic anhydride gas does not attack copper or kindred metals they can be used with safety for the working parts of the machine.

Although as dangerous as any of the other gases, as it excludes the presence of oxygen, the gas is not noticed by smell as is the case with ammonia. In a vapor form, the specific gravity is greater than that of the atmosphere, and the gas escaping in small quantities is not easily detected as it immediately sinks in the cellars, sewers, or loose earth. As life cannot be sustained without the presence of oxygen, any gas that excludes it is dangerous. The presence of ammonia is so pronounced that it is easily detected when but a small amount is in the atmosphere, while the presence of carbonic anhydride gas is difficult to detect even up to the moment of exhaustion of life.

In the use of carbonic anhydride gas it is necessary that the most careful attention be paid to the joints and stuffing boxes. The compressors are invariably of the single-acting type, as it is almost impossible to maintain tight stuffing boxes under the intense pressure necessary for liquefaction

Compressors are quite extensively made for the liquefaction of carbonic acid anhydride gas, by industries supplying the same in small carboys of steel for recharging soda water or beer, or any beverage which requires the addition of carbonic acid gas for enlivenment. In the better class of these compressors, the cylinder for compressing the gas is compounded as shown in Fig. 46. By this design the first set of cylinders deliver the gas to a receiver at a pressure between 400 and 600 pounds per square inch. Here the gas is cooled; from this cylinder the suction of the final pump is taken, which leaves the gas at 1,000 pounds pressure. There is an advantage in machines of this build (compound cylinders), as there is a less amount of engine friction than in single-acting cylinders.

Fig. 47 shows a single-acting horizontal compressing cylinder direct connected to a throttling steam engine "D" valve pattern,

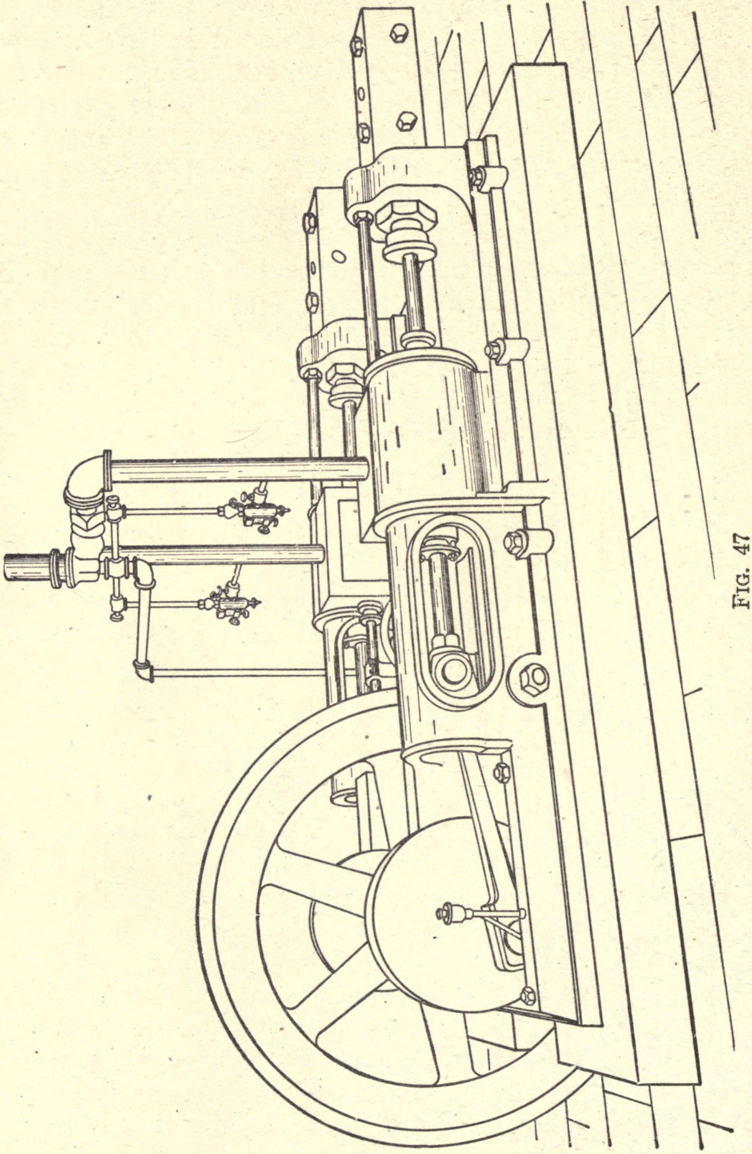


Fig. 47

DIRECT-CONNECTED HORIZONTAL REFRIGERATING COMPRESSOR

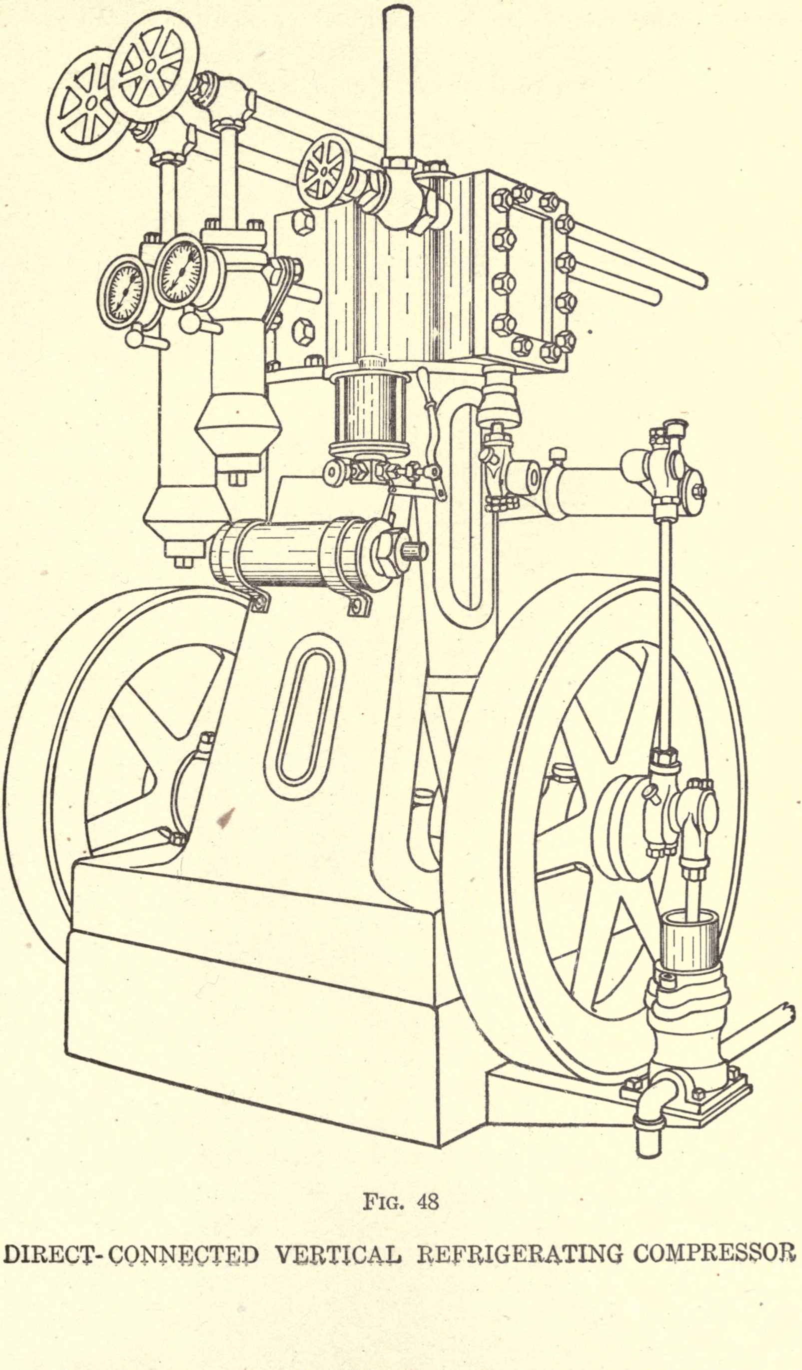


FIG. 48

DIRECT-CONNECTED VERTICAL REFRIGERATING COMPRESSOR double cylinder operating on a single shaft. The tail rod of the steam cylinder extends into and forms the piston rod of the compressor.

Fig. 48 shows a vertical steam engine connected to a single-

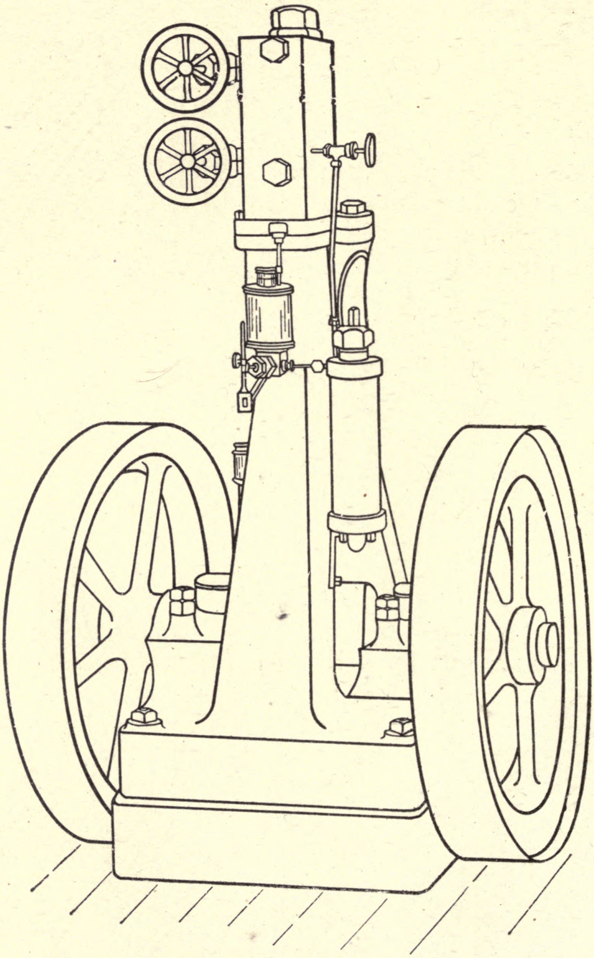


FIG. 49
BELT-DRIVEN REFRIGERATING COMPRESSOR

acting compressor; the compressor being bolted to the side of the steam cylinder with a double center-crank engine and over-hung fly wheel.

Fig. 49 shows a single-acting vertical compressor, connected to a shaft and belt, wheels over hanging. This design is for a belt-driven plant.

The cycle of operation of the gas is as follows: the gas passes from the compressor into a cylinder in which the oil from the lubricator of the cylinder is separated from the gas. From this tank the gas passes to the condensing coils where the latent heat is taken from it and the gas as it becomes a liquid flows to a receiving tank, being carried there by gravity.

From this liquid tank, the gas is conducted through piping to the freezing coils, where it is liberated from the condensing pressure to the vaporizing pressure, usually 30 to 50 pounds per square inch. A far greater back pressure can be carried than with ammonia when accomplishing the same work. This is due to the much lower vaporizing temperature, (boiling point) of the carbonic anhydride gas in a liquefied form when passing from a liquid to a vapor by the taking up of latent heat.

Carbonic Anhydride gas when liquefied to be used as a refrigerant may be applied through a brine tank, cooling the brine which afterwards may be circulated in cooling coils in refrigerator boxes or rooms. This system is known as the *indirect.* The process of sending the gas direct through the piping suspended in the refrigerating rooms is known as the direct application of refrigerating fluid.

REFRIGERATION BY COMPRESSED AIR.

To obtain refrigeration by compressing and expanding air, we resort to the effort of compression, and while air is compressed conduct off the heat which has multiplied in proportion to the amount of compression. We can convert the heat held by the air into power; then the air containing but little heat is used for refrigerating purposes.

That this may be more clearly understood let us consider the following: By taking air at atmospheric pressure at sea level, usually 14.7 pounds per square inch (this varies as the pressure increases or diminishes as shown by the mercury column in a barometer) and compressing it to 150 pounds per square inch, ten volumes of air have been compressed into the space occupied by one volume at atmospheric pressure. The heat which was contained in the ten volumes has been forced into the one volume.

The temperature is increased because the total amount of heat is now in the one volume. The increase of heat is in proportion to the compression. This is the important factor which makes possible refrigeration by mechanical means.

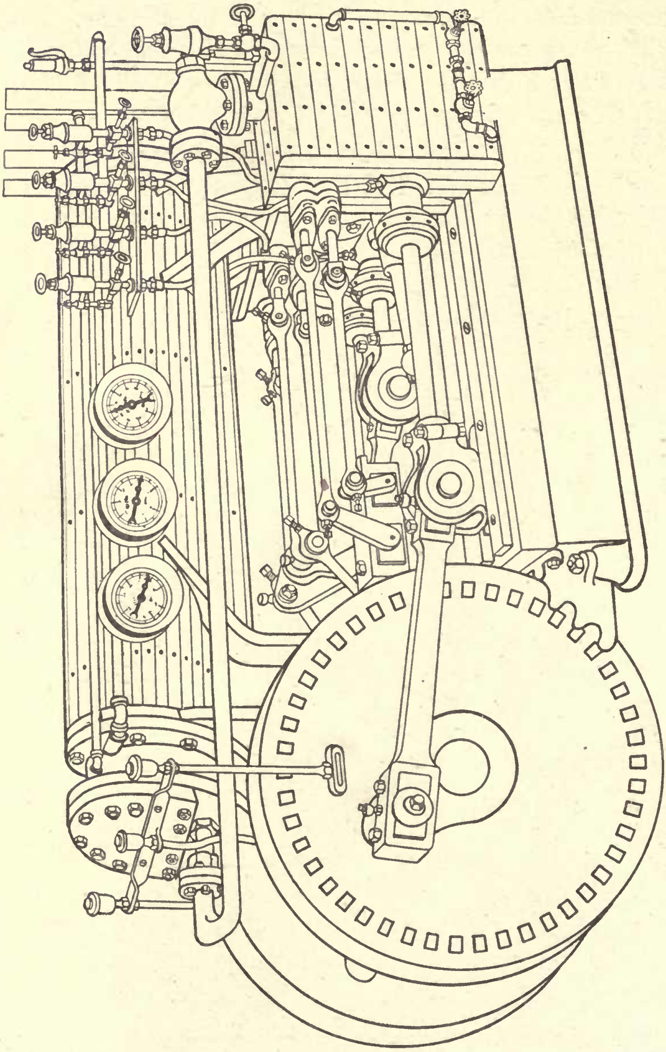
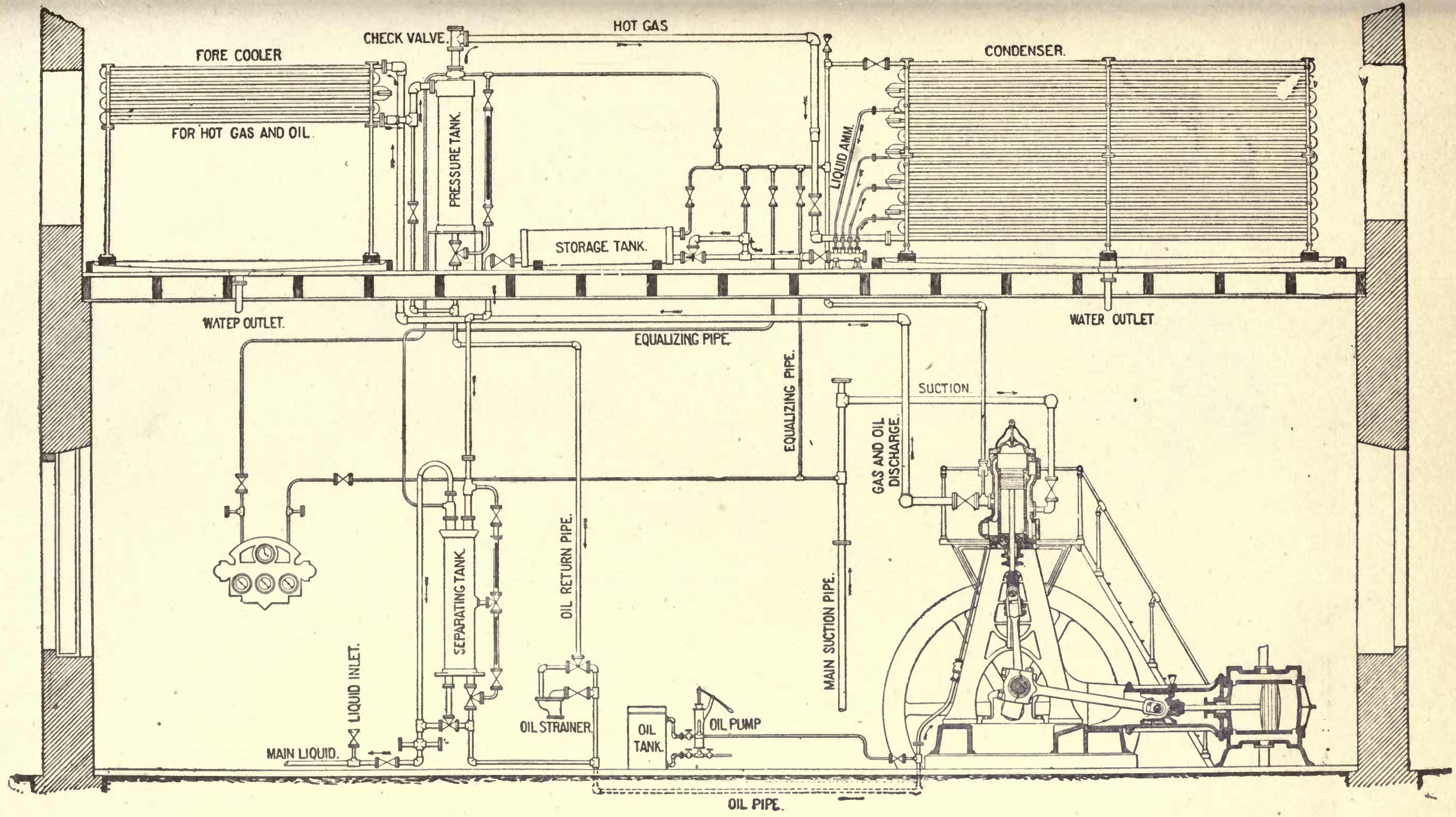


FIG. 50

THE ALLEN DENSE AIR ICE MACHINE

From the compressor, the air is discharged into piping which is surrounded by water; the heat is thus carried off and the temperature of the air is reduced to that of the surrounding water.



De La Vergne Refrigerating Plant.

Should the air be liberated at this time there would be but a slight reduction in temperature, probably from 20 to 30 degrees Fahrenheit.

Expansion of Air. From the cooling coils, the air passes to an expanding cylinder which is not unlike a steam engine cylinder. The air at the pressure of 150 pounds expands and drives a piston which is connected to the driving shaft of the machine and aids in the compression of air. The amount of work accomplished by this cylinder is in proportion to the heat the air contains, and this heat is used up or converted into power. The air is delivered into the cooling pipes for ice-making or refrigeration at a temperature of from 40 to 65 degrees below zero, the final condition depending upon the efficiency of the machinery.

The machinery represented by the accompanying drawings and descriptions is in use in the United States Navy and has been adopted as standard.

First. Assembled parts of the machine. This can best be understood by reference to Fig. 50. The machine is known as the Allen Dense Air Ice Machine.

In Fig. 51 we have three cylinders with slide valves, not unlike a steam engine, A in fact representing a steam cylinder, driving the air compressor B. This cylinder is operated by a single D valve and controlled by a throttling governor or by any governor adapted to conditions at sea. Power from the steam cylinder is conducted by connecting rod and disc crank, to which is attached a driving shaft H with a crank in the center of the shaft which drives the air compressor. On the opposite side of the shaft is a disc crank from which the expanding cylinder is attached which in turn aids the steam cylinder in its work. F is a plunger piston pump for circulating sea water around the coils in the cooling tank C. G is a priming pump for air.

In the *location of cylinder cranks,* the crank driving the air compressor leads the steam cylinder about 30 degrees. This is the practice followed by the best engine and air or gas compressor builders, where they are direct connected. The object of the lead is to apply the greatest pressure attainable to the piston of the air compressor at the time it is completing its stroke, when the angle of the crank pin nears the position exerting the greatest effort on the crank and previous to the time of the closing of the cut-off on the steam cylinders. By this method a much lighter fly wheel

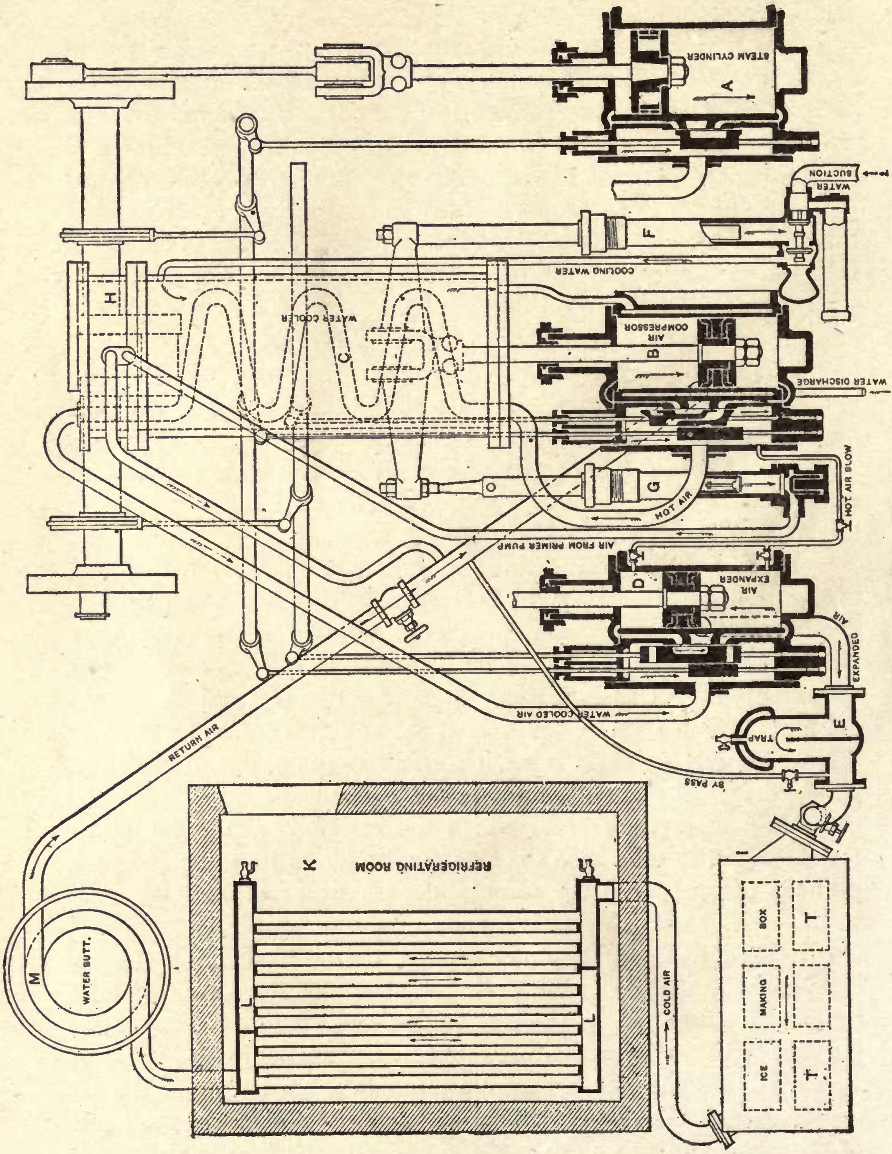

STEAM CYLINDER
A
WATER SUCTION
F
COOLING WATER
WATER COOLER
H
C
AIR COMPRESSOR
B
WATER DISCHARGE
HOT AIR BLOW
G
HOT AIR
AIR FROM PRIMER PUMP
AIR EXPANDER
D
AIR EXPANDED
E
TRAP
BY PASS
WATER COOLED AIR
RETURN AIR
REFRIGERATING ROOM
K
L
L
M
WATER BUTT
COLD AIR
ICE MAKING BOX
T
T

FIG. 51

can be used, for the power developed by the engine is applied directly through the shaft and not transmitted to the fly wheel to be given off when the compression of the air cylinder is taking the maximum power and the steam crank is nearly completing its stroke.

Air Compressor "B." In considering the action of this specially designed air compressor, we find that the suction is taken through the opening in the bottom of the valve chest, the opening being located in the same way as the exhaust on a slide valve engine. The discharge is through the face of the valve chest, the location again being similar to the steam supply to a slide-valve engine. The valves are of the slide design. It is a question with engineers whether or not this design is superior to the poppet valve as used by ammonia and kindred gas compressors. The advantages of using the slide valves are: first, they are comparatively noiseless; second, they are not constantly hammering their seats or faces in closing, and third, there is no unbalanced pressure of the valve seat to be overcome by the engine, or to cause the rapid destruction of the metal forming a poppet valve.

Note: For a description of unbalanced valve operation see page 93.

In the operation of the valves we find two rocker shafts, each of which is operated by an eccentric from the main shaft. The rocker shaft nearest to the main shaft operates the valve admitting steam to the engine A; this is a plain D valve. The shaft also operates the rider valve on both air compressor and expander cylinder.

The second rocker shaft operates the main valve of the compressor and the expander cylinder. From the crosshead of the air compressor an arm extending horizontally operates the charging air pump and also the water circulating pump. Water from the water cooler is continuously flowing around the jacket of the air compressing cylinder. The action of the expanding chamber is the same as though steam were used to move the piston, the energy given by this expansion of air aids in driving the air compressor, thereby adding to the economy of the operation. This is not, however, the primary cause for this construction. By using the air, which is at high pressure, to obtain power, the heat that it contains is consumed or converted into power and at 60 pounds per square inch, which is the back pressure carried, there is ob-

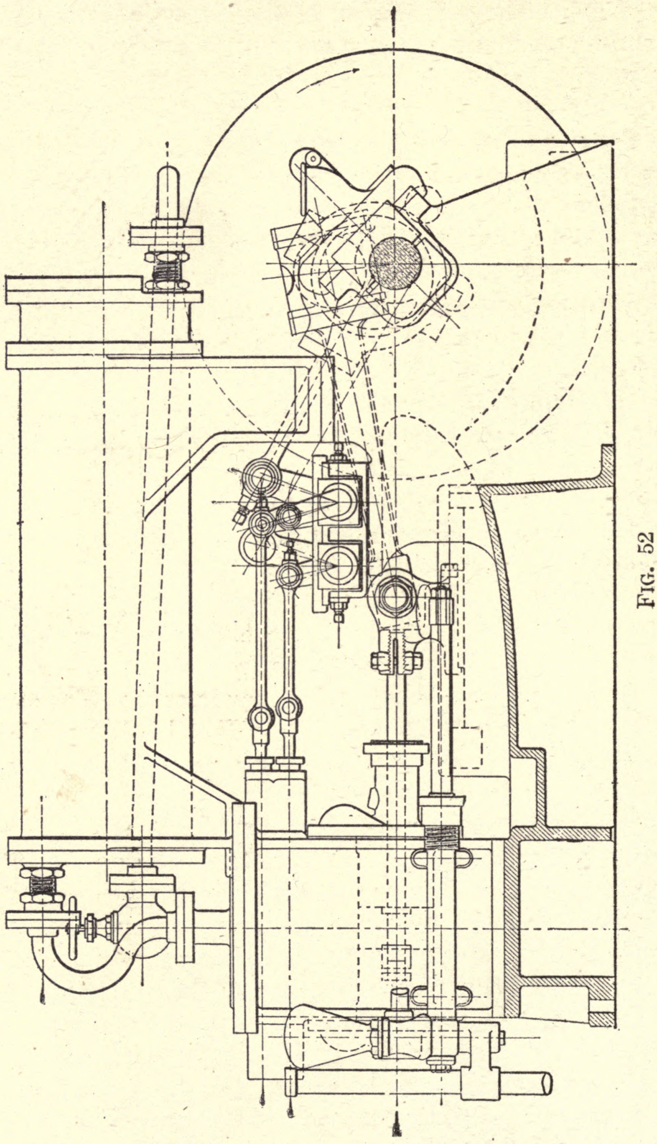


FIG. 52

tained a temperature of from 70 to 90 degrees below zero. This can be obtained with a working initial pressure of 260 pounds per square inch. In no instance is the latent heat of the air affected except to a slight degree, equaling in ratio the ability of the air to carry latent heat due to the different specific temperatures during the compression and expansion.

Relief of Valves. Should the pressure in the expanding cylinder become greater than the pressure in the discharge chamber, due to the distortion of rods or slipping of eccentrics, the valves would spring back from their seats and relieve the pressure. Upon the receding of the piston the valve would close.

Unbalanced Valve Pressure. In considering this question, let us take a poppet valve for our illustration; this is shown in Fig. 53.

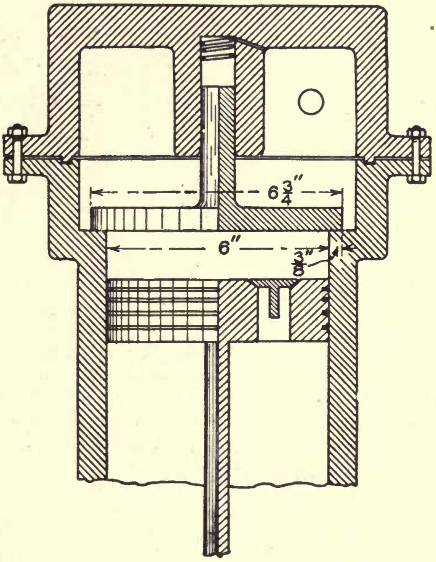


FIG. 53

The design calls for a 6-inch compressing cylinder with a valve seat of ⅜ inch face giving a bearing surface on top of the valve 6¾ inches in diameter. The area of the cylinder equals 28.274 square inches, while the area of the top of the valves including the seat is 33.183 square inches. Let us consider a working pressure of 150 pounds per square inch. To open this valve there must be exerted a pressure of 150 × 33.183 = 4977.45 pounds. The power exerted on the under side of the valve, when the pressures are equal to that of the discharge chamber, is 28.274 × 150 = 4241.1 pounds, or in order to open the valve there must be added 4977.45—4241.1 = 636.35 pounds. In other words, to force the valve from its seat there must be exerted 28.53 pounds per square inch in excess, or a total pressure above the valve of 150+28.53=178.53 pounds per square inch on the entire compressing piston. This power is overcome by placing springs or compressing chambers on top of the valve, the latter by far the most satisfactory.

The loss caused by this defect in design of poppet valve equals 19.02 per cent of the entire requirements for compression of gases.

Oil and Water Traps. In the main discharge line from the air-expanding cylinder to the ice-making tank, is placed a separator E, for intercepting water or oil that may be in the system. The water is carried in at any time when fresh air is taken to replenish the air in use in the cycle of operation. These air-blows or vents are used upon starting up a refrigerating plant. The vents in the cooling chamber C, can be blown off at any time but this usually occurs at the starting of the plant.

The very low temperature of the air congeals any water or oil that may remain in the system; this freezing taking place in the piping or oil traps. This insures dry air to work with. The jacket around the bottom of the trap is to receive steam when it is desired to remove the oil or water, the latter collecting and remaining in the separator as snow. These traps hang vertically so that the operation of gathering the water and oil is one of gravity. In the plan (Fig. 51) they are shown as being horizontal. This is never done in practice but shows more clearly the arrangement of different parts.

Ice Making Tank. The air is ejected from the expanding cylinder, and after passing the trap enters a series of pipes divided up into manifolds and coils to cause the air to travel many times from one end to the other, to form a long coil. It is not necessary that this should be a continuous coil, as there are no liquids to vaporize. The air takes up specific heat only and conveys it back to the compressing cylinder for removal in the cooler in the expanding cylinder.

Surrounding the air coils in the ice tank is a solution of brine made from Chloride of Calcium. The ice moulds used are formed of cans made of galvanized iron the same as those used for ice making plants. The condition of the air in passing from the ice-making tank is governed by the quantity of ice withdrawn. This should not be sufficient to raise the temperature of the air above zero Fahr. This increases the amount of heat taken from the tank from 60 degrees below zero to zero, or about two British thermal units for each cubic foot of air passing through the cycle.

Refrigerator Box. The air from the ice-making tank passes into the refrigerator box coils, entering at a temperature of zero. These coils are made with a manifold at each end with divisions in the manifolds to direct the flow of air, causing a circulation back and forth of three times the length of the box. By this method of distributing the circulation, a small pipe system can be used for the piping, while the headers are of an area equaling the discharge from the expanding cylinder. The required area for the circulating pipes is made up of several of the smaller pipes. This is not a vital or even a necessary point. A large pipe could be erected, giving the entire area of the exhaust cylinder opening. This would increase the friction of the passage of air over the design as illustrated in the plan.

Water "Butt" or Cooler. From the refrigerator box, the air passes through a coil of pipe in a tank filled with water. The object being the cooling of the water for the use of the men. This is the last operation of the air and it is desired to have the air at as high a temperature as is consistent with the work.

The application of compressed air was first made successful in ocean steamships carrying meat to Europe. The engines were so large that no auxiliary boiler could furnish sufficient steam; so that to cool the refrigerator box it required the starting of one of the ship's main boilers. The air was exhausted from the box at atmospheric pressure, and from the expanding cylinder it was discharged directly into the refrigerator box. The result was that the oil used for lubrication became very strong in the air and left a taste in the meat. The moisture in the atmosphere was turned to snow as it came in contact with the cool air; this snow in turn becoming melted when striking the sides or floor of the refrigerator or coming in contact with the merchandise in shipment. This has been remedied by enclosing the air in piping and having a continuous cycle of the cooling fluid in operation.

In no instance does the liquefaction of air enter into the problem of refrigerating with air.

In the work of construction, iron pipe may be used, with any of the pipe cements for joints common to first class piping.

The following instructions for starting and operating the Allen Dense Air Ice Machines are used by the United States Navy.

On starting the machine, have the blow valves of the expander and the pet-cocks of the various traps open until no more grease or water discharges.

The two 1½-inch or 2-inch valves of the main pipes must be open and the 1-inch by-pass pipe closed; also the ½-inch hot-air valves from the compressor to the expander cylinder must be closed.

Be sure that the circulating water is in motion.

The full pressure is 60 to 65 lbs. low pressure, and 210 to 225 lbs. high pressure.

During the running, open the pet-cocks of the water-trap which takes the water out of the air from the primer pump, frequently enough that it will never be more than half filled. If the water should be allowed to enter the main pipes, it is liable to freeze and clog at the valves.

By keeping all stuffing boxes well lubricated by the lubricator cups, the pressures are easily maintained with but little screwing up of the packing.

If the low-air pressure is not maintained, the fault is almost always due to leaks at the stuffing boxes. Under all circumstances it is due to some leak into the atmosphere, as we have never yet found the primer pump valves at fault.

The packing of valve stems and piston rods consists of a few inner rings of Katzenstein's soft metal packing, then a hollow greasing ring, then soft fibrous packing (Garlock packing).

The sight feed lubricators of the compressor and expander should only use a light pure mineral machine oil, from which the paraffine has been removed by freezing—usually three drops per minute in the compressor and one or two in the expander.

The pistons of the compressor and expander cylinders are packed with cup leathers, which commonly last about one or two months of steady work. When these leathers give out, the high pressure decreases in relation to the low pressure, and the apparatus shows a loss of cold. A leak at any other point of high pressure into low pressure will have the same effect.

These packing leathers are made of thick kip leather, or of white oak-tanned leather of somewhat less than ⅛-inch thickness. They are cut ⅝ inch larger in diameter than the cylinders. The leathers must be kept soaked with castor oil and must be well soaked in that before using; and a tin box containing spare leathers and castor oil must be kept on hand.

Once, or sometimes twice, a day, it is necessary to clean the machine by heating it up and blowing out all the oil and ice deposits. This is done as follows:

The 1-inch valve of the by-pass is opened. Then the two $1\frac{1}{2}$ or 2-inch valves in the main pipes are closed; then the two $\frac{1}{2}$-inch valves in the hot air pipe from the compressor chest to the expander are opened, and the $1\frac{1}{4}$-inch valve of expander inlet is closed partly; then the live steam is let into the jacket of the oil-trap slowly, keeping the outlet from the steam jacket open enough to drain the condensed steam.

Run in this manner for about one-half hour, during this time frequently blow out the bottom valve of the oil-trap, also the blow-off from the expander, until everything appears clean. Then shut off the steam and drain connections of the jacket of the trap and the hot air pipe from the compressor to the expander. Then open the two $1\frac{1}{2}$-inch valves in main pipes. Then close the 1-inch by-pass pipe and all pet-cocks and run as usual.

Whenever opportunity offers to blow out the manifolds of the meat-room and the ice-making box (that is, whenever they are thawed), this should be done.

If it is suspected that a considerable quantity of oil and water have got into the pipe system and are clogging the areas and coating the surfaces, the pipes can be cleaned by running hot air through them as is done during the daily cleaning of the machine. The oil and water are then drawn off at the bottom of the ice-making box and the manifolds of refrigerating coils.

The clearance of the two air pistons and of the primer plunger is only $\frac{1}{8}$ inch; therefore not much change of piston rods and connecting rods is permissible, and when the piston nuts are unscrewed to change the piston leathers, the rod should be watched that it does not unscrew from the crosshead.

Whenever it is noticed that the brine freezes, more chloride of calcium should be added and should be well stirred into the brine.

ABSORPTION SYSTEM.

By the rapid vaporization of water in the desert of Arabia, due to the intensely dry atmosphere, the first ice, other than that formed by the natural process of winter freezing, was made. For cooling large quantities of water, this process is in use to-day on a more clearly defined and greatly enlarged plan known as the

Water Cooling Tower. This method is being extensively used for cooling for condensing ammonia gas or for condensing the exhaust steam from an engine.

Carré's First Ice Plant. From the use of this system of vaporization, Carré, a French scientist, constructed the first device for cooling by mechanical means and producing ice, and all devices for absorption refrigeration owe their results to the work so ably accomplished by him.

A definition of the terms used in the two systems in connection with refrigerating machinery is as follows:

Absorption Refrigeration. In the absorption, as in the compression system, it is necessary to maintain pressure upon the ammonia gas when freed from water in order that it may become liquefied, and during its period of liquefaction give up the latent heat.

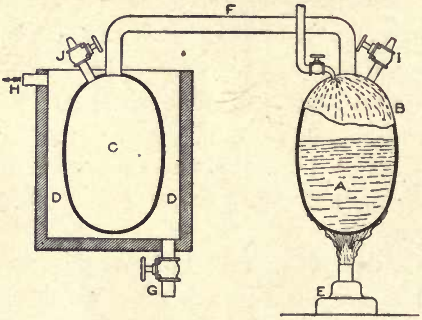


Fig. 54.

The Carré original machine consisted of two strong iron jars connected together with an iron pipe as shown in Fig. 54. In the jar A, or ammonia still, was placed a quantity of highly charged aqua ammonia. A spirit lamp E was placed under the jar. An air cock was placed at I, and when the jar became heated, the air cock was opened until the air was exhausted. The pressure increased in both jars and connection A, B, C. Jar C was placed in a tank and surrounded by cold water D. The supply of this water was constantly changing so that at all times the water remained cold or at its original temperature, which we may assume at 60 degrees Fahr. The heat from the lamp caused the ammonia to vaporize and a pressure was obtained sufficient to liquefy the gas in the jar C. This pressure was about 120 pounds per square inch. The intense pressure made by the ammonia gas was sufficient to raise the boiling pressure of the water to 230 degrees Fahr., thereby preventing the vaporization of the water. This temperature was ample to drive out a large amount of gas.

After the process was complete, which was determined by the length of time that the heat was exposed to jar A, the lamp was removed. The water was drawn off from around jar C and the tank filled with whatever substance it was desired to freeze. A water pipe allowed water to flow over the jar A and cool its contents, the result being that the pressure was removed from both jars A and C, and the liquid anhydrous gas began to vaporize in jar C, the gas returned to jar A, and was taken up in the water from which it had been expelled. By the passage of the anhydrous ammonia from a liquid into a gas, the heat which was taken up and caused the vaporization, being held latent by the gas, was taken from the surrounding liquid in tank D.

This produced a low temperature, the boiling point of liquid anhydrous ammonia being at atmospheric pressure 47 degrees below zero Fahr. The ratio of the temperature and pressure determines the temperature at which the gas boils in passing from a liquid to a gaseous condition.

Reabsorbing. As the expanded gases return to the jar A and come in contact with the water, they are absorbed by the water and in this process of absorption, the heat, which is taken up latent by vaporization in the freezing jar C, is given off. The heat thus given off in the jar A is carried away by the water flowing from connection H.

It was by this simple device that Carré established the principles of refrigeration. We should remember that it was in 1858 when this work was done and that the methods of working iron were then very crude. Carré's success was due to his patience and endurance.

In Fig. 55 is shown a double plant absorption machine, including an ice making tank, each machine having a capacity of 12½ tons, or a 25-ton ice-making output for every twenty-four hours of constant operation. The plants are connected together so that they can be interchangeable in their working parts.

The following is a brief description: An ammonia still A is built of iron pipe 12 inches in diameter with heavy flanged heads, which are of wrought iron, screwed on to the pipe and soldered where the pipe and metal of the head joins. The object of a flanged head is to admit of coils in the interior. A strong solution of aqua ammonia is placed in the still and heated by a steam spiral coil placed in the interior of the still. In operation, the aqua ammonia still is kept about one-third filled with aqua ammonia. In naming the parts of the apparatus, each designer or builder selects names to suit his fancy. While the part used for applying heat to the aqua ammonia is necessary to all designs of absorption

Eddie has read this book

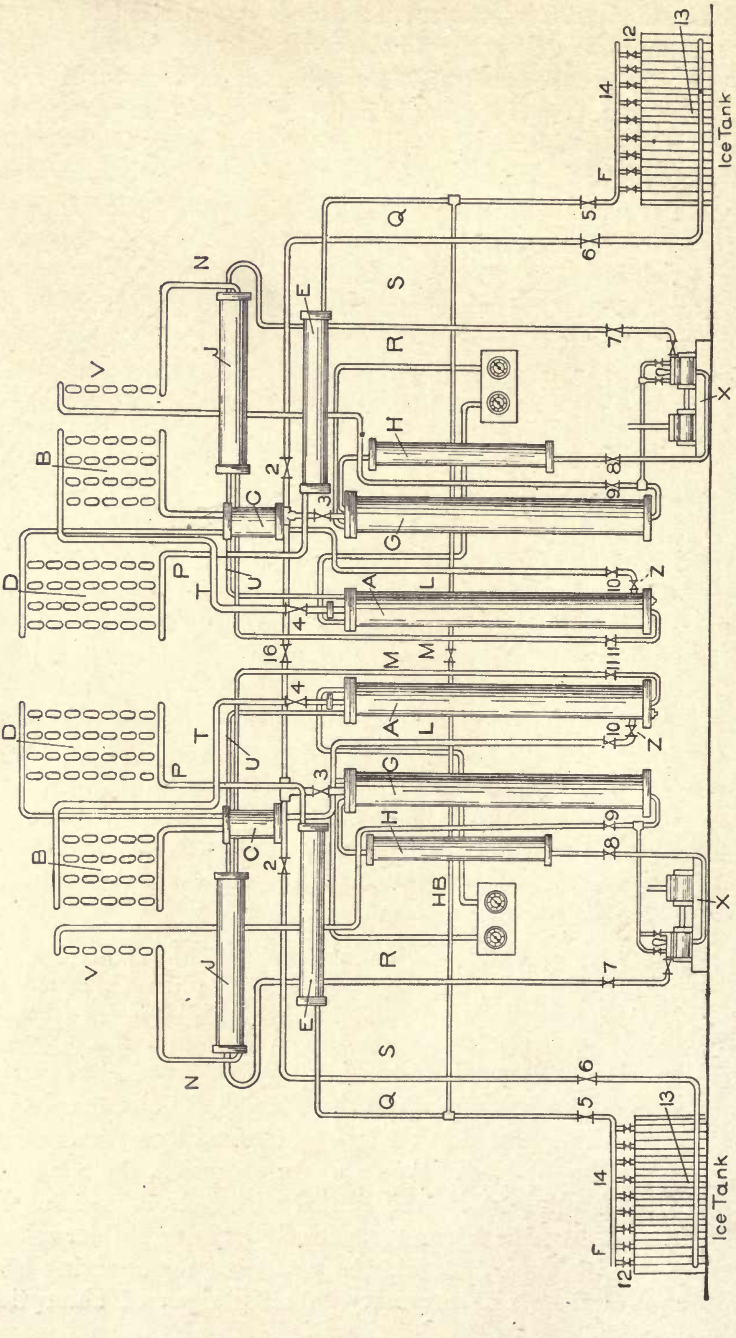


Fig. 55.

machinery, we find it bearing the following names: "ammonia boiler," "ammonia still," "ammonia pressure generator."

The steam connection is not shown in the drawing. The ammonia gas is driven off by heat and passes up through the connection T into the dehydrating coil B. As the ammonia gas passes from the still, it carries with it a small quantity of water in a foaming condition which is separated from the gas in the dehydrating coil. This coil is enclosed in a tank and filled with water which is maintained at a temperature of approximately 150 degrees Fahr. At this temperature the water condenses, but allows the ammonia to remain a gas. The pressure in the still corresponds to the temperature being maintained in the condenser for liquefaction. Here the same ratio is obtained as in the compression machines, usually from 110 to 180 pounds per square inch. It is usually considered necessary to maintain 150 pounds per square inch for liquefaction. This requires condensing water at approximately 60 degrees.

From the dehydrating coil the gas and water pass to a separate tank C, which is a plain cylinder. The action is to separate the gas from the water, the gas passing from the top of the separating tank C to the condenser coil D, while the water which has been séparated from the gas by the action of the dehydrating coil drops by gravity through pipe L and valves 10 back to the still.

The law of gravity holds good in all cases and under all circumstances where pressures are the same. Therefore, in all parts of the ammonia generating plant this law of falling of liquids by gravity is made use of and care must be taken in designing plants that liquids will come to their proper places by gravity.

The ammonia gas is now separated from water and passes to the condenser for liquefying.

Ammonia Condensers. The condenser coils D may be enclosed in a tank and surrounded with water, or they may be left open to the atmosphere and the water allowed to drip over them. In the ammonia condenser, the heat held latent by the ammonia gas is given off and a liquefaction takes place, the liquid ammonia having the appearance of clear water. The ammonia drops into a liquid storage tank E, through connection P.

Freezing or Ice Making Tank. The ammonia is now liquefied and ready for use under a pressure normally of 150 pounds per square inch.

Note: Do not confuse liquid ammonia with anhydrous ammonia.

From the liquid tank E, the liquid ammonia flows through the connecting pipe Q, being held in check by the main liquid valve 5. The object of this main liquid valve is to simplify the working of the plant. The nine valves 12, are the expanding valves, each connected to the coil of pipe in the freezing tank. Each coil has a separate return with a stop valve, entering connection 13. The tank is shown with insulation but the coils are not shown. This freezing tank is designed to hold 240 cans or ice moulds, each having the capacity of 200 pounds of ice, when the freezing is complete. The tank is eight cans wide and thirty cans long, or a tank 9 feet wide by 60 feet long and 36 inches deep, inside measure. These tanks may be built either of iron or wood as the designer wishes. The coils run the entire length of the tank, between the cans and outside of them.

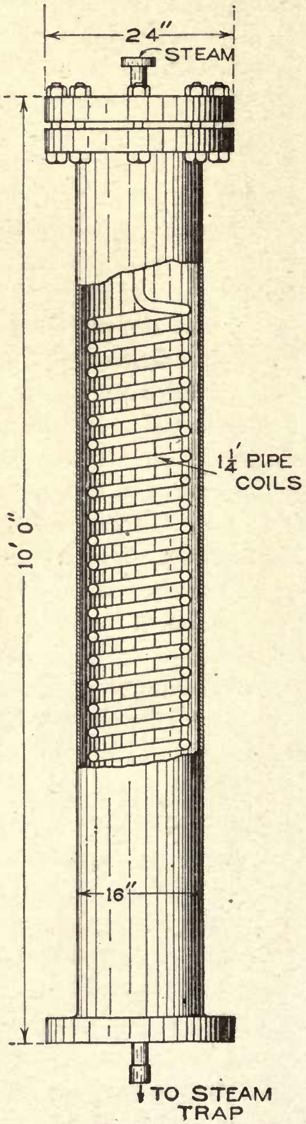


Fig. 56.

Freezing. In operating, the main liquid valve 5 is opened and the gas flows to the nine expanding valves 12, which are opened to permit a flow of gas through an opening varying from $\frac{1}{100}$ to $\frac{1}{8}$ of a square inch.

Low Pressure Side of the Apparatus. At this point the gas is allowed to pass from the pressure under which it is condensed to the vaporizing pressure, usually from 150 to 15 pounds per square inch.

Note: In all cases where pressures are referred to, the zero point is the atmosphere and not absolute zero.

The liquefied ammonia entering the freezing coils under pressure of 15 pounds per square inch immediately begins to vaporize and in so doing takes the specific heat from the water. The heat passes through the iron pipes, is taken up and returned to the absorber G through connection S. The boiling point of liquid ammonia at 15 pounds pressure approximates 26 degrees below zero Fahr. The action of the ammonia in boiling is identical to water boiling at 212 degrees in the atmosphere, with which every one is familiar.

Absorber. The vaporized gas flows into the top of the absorber where it meets the water from which the gas has been driven.

Circuit of Weak Water. Returning now to the ammonia still; during the period of distillation, the water, freed from the gas by heat and called by different names such as "mother liquid," "weak water," etc., is allowed to flow from the bottom of the still through connection, M, and passing through "heat exchanger" or "equalizer" J, flows on to weak water cooler V, entering the cooling coil at the bottom. It is preferable to have this coil enclosed in a tank so as to get the advantage of "Baudlett" system of cooling or the bringing of the hot water to the hot gas and cold water to the cold gas. From this cooler, the weak liquid returns to the absorber G, through valve 9. The water is carried to the top where it falls down over a spiral coil of water pipes. The water and gas here intermingle and the water absorbing the gas is allowed to flow into reservoir H. A strong solution of aqua ammonia is taken by the pump through connection 8 and returned to the still through connection 7, there to be re-distilled and the cycle of operation again to be performed.

Pressure Gages. There are two pressure gages: one being a high-pressure and the other a low-pressure instrument. The high-pressure gage reads from zero to 300 pounds or more, the low-pressure being a combination gage reading from 30 inches vacuum to 150 pounds pressure per square inch, the zero point being at atmosphere and not absolute. These gages are connected as follows; the high pressure gage to the head of the ammonia still A, the low pressure gage to the head of the absorbing tank G. Stop valves must be placed in the gage lines between absorber and still-tank heads to permit the removal of the gages for cleaning or repairs. In locating gages, a position about 12 inches higher than the eyes should be chosen. At this point they are easily seen and accessible for cleaning.

A steam gage is required on the steam line entering the still, also a reducing valve on the steam line to control the pressure of steam. The steam gage is connected between the reducing valve and the ammonia still steam coil.

A steam trap is placed on the discharge of the steam coil coming from the still, and so connected as to keep the still coils free from water at all times.

Glass Gages. It is common with many builders of refrigerating and ice-making plants to place on their systems glass gages, in order to determine the amount of liquid in the different parts by actual observation. Many accidents of a severe nature have been the result of breaking these glass tubes.

Automatic Gage Cocks. There have been many devices to close the gage cocks automatically in case of breaking the glass; one device being the placing of long lever handles on the plug cocks and closing them by a rope over a pulley at a safe distance. These glasses are often made 36 inches in length, and from that down to a few inches.

Enclosed Glass Gages. It is often the practice to enclose these glass tubes within a pipe split for a quarter of an inch on opposite sides and the space between the glass and the tube filled with plaster of paris; or, to make the tubes quite thin and drill holes through them, the drill passing straight from side to side and at right angles to the pipe, the object being that when the glass bursts the pipe covering keeps the glass from flying and injuring the attendant.

Glass Gages in Operation. It is a fact that most gages after they have been in use about six months become filled with a dirty substance, and become inoperative, their reading being misleading to the attendant. To the successful operation of any refrigerating plant, either compression or absorption, the presence of glass gages is an unnecessary adjunct, and the attendant soon becomes so familiar with his plant that he can operate it without reference to glass gages.

In installing and first charging a plant, these gages are a convenience but not a necessity. In order to charge a plant without gages, the engineer must know positively the amount of liquid necessary to fill the different parts of his apparatus. Often thermometers are inserted to determine the temperatures of the liquids at the different parts. This may be very important to determine the positive condition where a test is made for laboratory purposes.

In the parts of the apparatus shown in Fig. 55, glass gages could be located on ammonia still A about 30 inches from the bottom of the tank; a glass about 24 inches long should be used. The water collecting at this point should fill the tank to a height of about 45 inches from the bottom, which would bring it to the center of the glass. A thermometer could also be inserted in the still 6 inches from the bottom, this to be an angle thermometer and a "thimble" inserted to come in contact with the liquid. In this thimble the bulb of the thermometer should be placed. This thermometer should read from 80 to 300 degrees Fahrenheit.

Absorbing Tank Glass Gages and Thermometer. Glass gages and thermometer may be placed on this tank in the same way as those described for the distilling tank A. On liquid receiving tank E glass gages may be placed, the connection being made in the head or from the upper and lower sides of the tank. This glass is to indicate the quantity of liquefied ammonia in the tank.

Operating Without Glass Gages. The object of a refrigerating or ice-making plant is to do the work for which it is designed, and when an absorption plant is operating and the output is not equal to the amount that it has turned out when operating at its best, either it is short in some requirements necessary to make it work successfully, or there is present a condition that is foreign to the best working condition. No glass gages can determine these conditions for the attendant. Only familiarity with his plant will instruct him what to do. Passing his hand on the weak water pipe as it leaves the still and also on the return for the water entering the absorber, will tell him the conditions necessary for successful operation.

Gas Foreign to Ammonia. One of the most serious obstacles to the successful operation of absorption ice-making machinery is the generating with the ammonia still of a superabundance of free hydrogen gas, ammonia gas being composed of three parts nitrogen gas.

There is present in the still, water which forms the method of transit of the ammonia for part of its journey. This water is formed of two parts of hydrogen to one part of oxygen. The iron piping forming the heating coils has a large capacity for taking oxygen and holding it in the shape of iron scales or rust. The action of the ammonia tends to free this rust or oxygen scale from the piping on which it has formed and as a result a large deposit of scale forms in the ammonia still. The worst feature is that the affiliation of the oxygen and iron has liberated a large amount of free hydrogen gas which finally rises to the highest point in the system, usually in the condensers, and remains there where the conditions are not right for it to liquefy, because there is not enough nitrogen gas to combine with it and form new ammonia. It is necessary to get this hydrogen gas out of the system. This is done by having a valve at a convenient place and occasionally blowing it off. In a refrigerating plant in operation in 1904, which was built to do refrigeration equal to the melting of 12 tons of ice for every twenty-four hours of operation, the actual result upon a careful observation, where the conditions permitted a knowledge of the facts, was 2.6 tons. Part of the defect probably might have been due to a depreciated charge of ammonia gas.

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