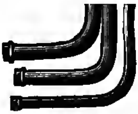
The Absorption Refrigerating Machine



THE ABSORPTION REFRIGERATING MACHINE

A COMPLETE, PRACTICAL ELEMENTARY TREATISE ON THE ABSORPTION SYSTEM OF REFRIGERATION, AND ITS BROAD GENERAL PRINCIPLES OF OPERATION

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PREFACE

The author is of the opinion that the past literature relating to the absorption system of refrigeration is quite too fragmentary and technical to be easily pieced together or properly understood except by those who, through their own practical experience, are already well versed on the subject.

While many have a good general knowledge of the compression refrigerating system, but few seem to have such a knowledge of the absorption system, due probably to the fact that simple, practical literature on the subject was not available.

The author acknowledges the great value of much excellent work along this line by his brother engineers, and hopes that this addition to absorption machine literature may be of value to such engineers as well as to those not so well versed on the subject. It is wrong to attempt to understand the absorption system without first laying a proper foundation for such understanding. With the few broad, simple, underlying principles of the absorption system well in mind one should then easily understand the absorption refrigerating apparatus.

In this work the general principles of refrigeration are first given in a simple, practical, popular way, and it is then shown how the absorption machine is a heat compression machine, as compared with the mechanical compression machine of the compression apparatus. By not starting in with a complete diagram of the assembled parts of an absorption system, as is usually done, but instead by taking up each part and its functions, step by step, and then assembling them in like manner, illustrating and explaining each step by original drawings and descriptions, as it is done in this work, it should be quite easy to obtain a firm grasp of the construction and operation of the complete absorption system in its several modified forms.

All the principal parts of the various makes of absorption machines are impartially shown and described without reference by name to any particular make of machine.

Practical operating instructions derived from the author's long experience and from his many exhaustive tests are given which should in many cases enable owners or operators of absorption machines to greatly increase the capacity and economy of their plants.

It is believed that a careful study of this work will enable anyone, whether he be a layman or an engineer, to become well versed on the construction and operation of absorption refrigerating machines.

The author invited all the well known builders of absorption machines, in the United States, to furnish illustrations and brief original descriptions of their machines. Such matter as has been so contributed forms part of the appendix to this work and has not been altered or edited by the author.

GARDNER T. VOORHEES.

TABLE OF CONTENTS

CHAPTER I.

General Principles Underlying the Process of Mechanical Refrigeration—Raising or Lowering the Boiling Point of a Fluid-Heat Interchange—Latent Heat of Vaporization—Specific Heat—Absolute Pressure and Gauge Pressure—The Simple Volatile Liquid Refrigerating Machine.

CHAPTER II.

The Simple Compression Machine and the Simple Absorption Machine—The Intermittent Absorption Machine—Historical Facts Regarding the Discovery of Principles that Led to the Invention of the Absorption Refrigerating Machine—Faraday's Tube—Modified Forms of the Simple Absorption Refrigerating Apparatus—Diagrams Illustrating the Operation of an Intermittent Machine.

CHAPTER III.

Simple Continuous Absorption Refrigerating Machine Without Liquor Pump—Simple Continuous Machine with Liquor Pump and (Aqua) Regulating Valve.

CHAPTER IV.

Weak Liquor Cooler—Cooling Weak Aqua Before it Enters Absorber—Operation and Advantage of Cooler.

CHAPTER V.

The Exchanger—Ratio of Weights of Strong Liquor to Weak Liquor and Anhydrous Ammonia—Unequal Heating or Cooling Range of Strong and Weak Liquor—The Real Value of an Exchanger.

CHAPTER VI.

The Analyzer—Ammonia Data—Water Vapor in Gas from Generator—Water in Condenser and Refrigerator—Purging for Refrigerators.

CHAPTER VII.

The Rectifier—Drip Liquor—Best Temperature for Drip Liquor—Best Temperature for Gas from Rectifier to Condenser—Automatic Aqua Regulating Valve—Complete Wet Absorber Cycle.

CHAPTER VIII.

Further Details for Complete (Wet Absorption) System—Pressure Gauges, Gauge Glasses, Purge Valves, Charging Valves, Draw-off Connections, Hydrometers, Proper Strength of Strong and Weak Liquors, Thermometers, Water Supply Refrigerators, Brine Coolers, Weak Liquor Coolers, Condensers, Rectifiers, Exchangers, etc.

CHAPTER IX.

Generators and Absorbers—Liquid Surface in Generators—Length of Steam Coils—Boilovers of Generators—Beat Temperature of Strong Liquor from Absorber.

CHAPTER X.

Complete Dry Absorber Cycle—Steam Reducing Valve—Condensed Steam Receiver.

CHAPTER XI.

General Construction and Parts of the American Absorption Machine—Lower Temperatures Obtainable by Aid of Absorber—Operation of the Plant.

CHAPTER XII.

How Refrigerating Machines Work—Description of the Carbondale Machine, Including the Tubular System, and the Atmospheric System—Type to Use—Advantages.

CHAPTER XIII.

Columbus Absorption Machine—Description of Principal Parts—Generator—Ammonia Condenser—Cooler—Absorber—Ammonia Pump—Exchange—Steam Condenser—Fore Cooler and Distilled Water Storage Tank.

CHAPTER XIV.

Description of Polar Absorption Machine—Various Parts of Machine—General Construction—Operation—Efficiency—Installation.

CHAPTER XV.

Description of Vogt Absorption Machine—Construction of Generator, Rectifier, Separator, Condenser, Weak Liquor Cooler, Exchanger, Aqua Ammonia Pump, Absorber and Brine Cooler—Operation of Machine.

CHAPTER XVI.

Description of the York Absorption Machine—Shell and Coil Generators—Multitubular Generator—Analyzer—Dehydrator—Condenser—Absorber — Exchanger—Weak Aqua Cooler — Aqua Pump—Brine Coolers—The Several Types of Each Apparatus Outlined.

CHAPTER XVII.

Voorhees Multiple Effect Receiver—Prevention of Evaporation at the Expansion Valve—Tables Showing Gains Made.

CHAPTER XVIII.

Voorhees' Multiple Effect Absorption System, Used with Voorhees Multiple Effect Receiver.

CHAPTER XIX.

TABLES—Comparison of Fahrenheit and Centigrade Thermometer Scales—Comparison of Centigrade, Fahrenheit and Reaumur Scales—Properties of Saturated Ammonia—Properties of Ammonia Liquor—Solubility of Ammonia in Water at Different Temperatures and Pressures—Solubility of Ammonia in Water at Different Temperatures—Solubility of Ammonia in Water at Different Temperatures, Rosco—Strength of Ammonia Liquor—Comparison of Degrees Beau mé with Specific Gravity.

THE ABSORPTION REFRIGERATING MACHINE

CHAPTER I.

General Principles Underlying the Process of Mechanical Refrigeration—Raising or Lowering the Boiling Point of a Fluid—Heat Interchange—Latent Heat of Vaporization—Specific Heat—Absolute Pressure and Gauge Pressure—The Simple Volatile Liquid Refrigerating Machine.

Over fifty years ago, in the year 1858, Ferdinand Carré of France invented the absorption refrigerating machine. Not the absorption machine as we know it today, but its broad principle. Before many years had passed Carré had so improved and perfected his machine that it was then but little different in general principles and operation from some of the well known absorption machines of today. The broad principle upon which the absorption machine depends for its operation is that water absorbs ammonia gas at a low temperature and pressure and releases this ammonia gas again at a high temperature and pressure.

The fundamental principle of all volatile liquid refrigerating machines, to which class the absorption machine belongs, lies in the physical law that when the pressure of a liquid is increased, the temperature of its boiling point is raised, and when the pressure of a liquid is reduced the temperature of its boiling point is lowered.

A familiar example of this is that a longer time than usual is required to cook an egg in boiling water on the top of a high mountain, as in the air on the mountain top the atmospheric pressure is less than at the sea level, and so the water on the mountain top does not have as high a boiling point as its sea level boiling point of 212° F.

The boiling point of a substance or the temperature at which a liquid boils to a vapor, and the condensing point of a substance or the temperature at which a vapor is condensed to a liquid, are identical.

If a substance is exposed in its liquid state to a temperature greater than that of its boiling point, its temperature will increase until its boiling point is reached; then its temperature remains constant and the liquid boils or evaporates into a vapor at that temperature.

If the substance is exposed in its gaseous state to a temperature below that of its condensing point it will be cooled from the gaseous state to that of a vapor and the vapor will be condensed at a constant temperature to a liquid at that temperature.

A vapor is the gaseous state of a substance at the temperature of its condensing point, and a gas is a superheated vapor or a vapor at a temperature greater than that of its condensing point.

In the broad principle of raising or lowering the boiling or condensing point of a substance by raising or lowering its pressure we have the basic principle of all volatile liquid refrigerating machines, and all that any of these machines accomplishes is to raise the heat head of the refrigerating fluid so that it is higher than the heat head of an available supply of condensing water.

Heat, like water or electricity, will not flow up hill without the aid of outside energy. Therefore we must first use energy to make the heat flow up hill as, say from 10° to 90°, and when we have the heat on a hill a little higher than that on which the condensing water is, the heat will, of its own accord, flow down hill to the lower level of the condensing water. In simpler terms, we have from the second law of Thermodynamics that heat will not, unaided, flow from a cold to a hot body. Heat and cold are only relative terms, for while one body may be cold to another body it may be hot to a third body. For example, a piece of ice is cold to a hot stove, but hot to anhydrous ammonia at atmospheric pressure. One should not speak of taking the *cold* out of a body, as it is more proper to say taking the *heat* out of a body.

To discharge heat into condensing water the heat must be discharged from a temperature or heat head higher or greater than the heat head or temperature of the hottest condensing water. For example, if we have condensing water at a temperature of 70° to the condenser and 80° from the condenser, we must discharge heat into the condensing water, as from the ammonia to be condensed from a temperature greater than 80°, as say 90°, which 90° is the condensing temperature of the ammonia and gives a condensing pressure corresponding thereto as per the ammonia table.

It is easier to fully grasp this simple principle by firmly instilling into one's mind that ammonia or any other volatile liquid will act, in most respects, as will water under parallel conditions as to its boiling and condensing point and otherwise. Just as we are sure that water will not of itself flow backwards or up over a dam in a river, we may be sure that heat will not of itself flow backwards up over a dam from a cold temperature to a hot temperature any more than will electricity of itself at one voltage flow backwards up over a dam to a place of higher voltage.

So if we have a substance from which to extract heat, as say from water to be frozen, we must provide a lower plane of temperature than the freezing temperature of the water, to dump its heat into. As water freezes at 32° F. we can only freeze it by exposing it to a temperature below 32° F., and it is to obtain this low temperature plane that the use of a volatile liquid is required, which, at available pressures, has a low temperature boiling point.

Another broad principle and we have nearly all that must be known to understand the operation of either the compression or the absorption machine. That principle relates to the latent heat of vaporization. When a liquid substance changes its form to a vapor or a vapor substance changes its form to a liquid, there must be put into the substance or taken from it a certain fixed quantity of heat called the latent heat of vaporization or condensation. Heat is measured like so many quarts of water, only in figuring heat our measure is the British thermal unit—hereinafter called B. T. U. This heat measure, or heat unit, is the measure of the quantity of heat that is required to heat one pound of water through one degree Fahrenheit, as from 60° to 61°.

In heating one pound of water from 50° to 60° we put ten measures, or ten B. T. U., into the water and in cooling the one pound of water from 60° to 50° we take out ten measures of heat, or ten B. T. U., from the water. The heat that must be added to a pound of liquid to turn it into vapor or the heat that must be taken from a pound of vapor to turn it into a liquid is called the latent heat of vaporization or condensation, and is at a given pressure the same quantity whether the liquid is turned into a vapor or the vapor turned into a liquid except, of course, the latent heat is added to the substance to turn it into a vapor and taken from it to get it back into a liquid again at the same pressure.

We have already seen that it takes one heat unit added or subtracted to heat or cool one pound of water through one degree Fahrenheit of temperature. Likewise, approximately, 100 heat units must be added to one pound of water to heat it through a range of 100°, or 100 heat units subtracted from the water to cool it through a range of 100° of temperature. This quantity of heat, the quantity to heat or cool a pound of a substance through a range of one degree Fahrenheit, is called the specific heat of the substance.

The specific heat of water is one, that is, one B. T. U. is required to heat one pound of water through one degree Fahrenheit. Other substances have different specific heats, which are usually less than that of water, but all specific heats of all substances are referred to the specific heat of water, the specific heat of water being the standard measure for all other specific heats. If we know the specific heat of a substance to be 0.5 we know that to heat or cool one pound of that substance through 1° F. requires 0.5 B. T. U. or just half as much heat as if it were water.

Having it firmly fixed in mind what a heat unit, or B. T. U., is, we are in a better position to comprehend what a vast quantity of heat goes to make up the latent heat of vaporization or condensation. Remembering that the specific heat of water is one B. T. U., then at atmospheric pressure the latent heat of vaporization or condensation of one pound of water, that is the number of B. T. U. that must be added to one pound of water to evaporate it into steam, or the number of B. T. U. that must be subtracted from a pound of steam to condense it to a pound of water, is approximately 1,000 B. T. U. In other words, as much heat must be added to change one pound of water at its boiling point of 212° into one pound of steam at 212° as would be required to heat one pound of water through a range of 1,000 degrees of temperature, or 1,000 pounds of water through one degree of temperature. Likewise 1,000 B. T. U. must be taken from one pound of steam at 212° and at atmospheric pressure to condense it to one pound of water at 212°.

This quantity of heat (the latent heat of vaporization or condensation) is a fixed quantity for any substance at a given pressure, and it is greater in value for lower pressures than for higher pressures, as can be seen from an examination of the steam and ammonia tables.

Substances other than water have other values of latent heat or vaporization and condensation, usually less than that of water. At atmospheric pressure anhydrous ammonia has a latent heat of vaporization or condensation of approximately 555 B. T. U. So that if one pound of steam were condensed to water by evaporating anhydrous ammonia, nearly two pounds of anhydrous ammonia would be evaporated thereby. From the above we see that our great agent for doing refrigeration is the latent heat of vaporization.

The refrigerant liquid, as anhydrous ammonia, is simply a carrier of heat. A cart is backed up under a chute and is filled with dirt; the dirt is carried away by the cart and dumped and the cart is brought back and gets another load of dirt. Likewise a pound of ammonia has a load of heat dumped into it from the substance being cooled, as from water being frozen or from any substance being cooled, whether a dead body in a morgue or a pint of cream being frozen into ice cream. The ammonia carries the load of heat and dumps it into the condensing water and then the ammonia returns for another load of heat. The horse, through its energy, pulled the cart of dirt up hill to the dump, and also through its energy brought back the empty cart for another load of dirt. Energy in the refrigerating machine pulled or pushed the ammonia with its load of heat to the condensing water dump and returned the ammonia for another load of heat.

Another broad principle is that any gas occupies space almost inversely proportional to its absolute pressure. Absolute pressure is the pressure above a perfect vacuum, which is gauge pressure in pounds per square inch plus the weight of the atmosphere or 14.7

pounds per square inch. Unless otherwise noted all pressures hereafter given are gauge pressures in pounds per square inch. For example, a given weight of gas at thirty pounds absolute pressure, equal approximately to fifteen pounds gauge pressure, occupies one-half the space that it would at the same temperature at approximately fifteen pounds absolute pressure, or zero pounds gauge pressure.

Also a given weight of a gas occupies space almost directly proportional to its absolute temperature. Absolute temperature being the temperature taken from absolute zero or the thermometer temperature plus 461° F. For example, a given weight of gas at 0° F., 461° absolute temperature, occupies only one-half as much space at the same pressure as it would at 461° F. or 922° absolute temperature. Vapor or gas may be likened to a sponge or a piece of rubber. The sponge or piece of rubber occupies less space if it is squeezed than if it is not squeezed, so likewise does a gas or a vapor. The hot air balloon is a good example of the lighter weight of a given volume of hot air as compared with its surrounding body of colder air.

The elementary volatile liquid refrigerating machine can be divided into three elements: First, the refrigerator wherein the volatile liquid boils and evaporates and takes up the latent heat of vaporization from a substance to be cooled, by having the volatile liquid's vapor loaded up with heat from the substance to be cooled and so cooling that substance; second, the compressor which takes in the vapor from the refrigerator at the refrigerator pressure and compresses it to the condenser pressure and discharges it into the condenser, through the medium of energy expended in so doing; third, the condenser wherein the compressed vapor parts with its load of heat by dumping it into the condensing water, thereby heating the condensing water and becoming liquefied.

From what has gone before one should readily imagine the refrigerator as being an ammonia boiler in which the volatile liquid, as anhydrous ammonia, takes up its heat load as it is boiled from a liquid into a vapor by the heat given to it and so taken from the substance being cooled. The condenser liquefies the vapor after it has been compressed by a compressor located in a pipe circuit between the refrigerator and the condenser. Here, in the condenser, the ammonia vapor dumps its load of heat into the condensing water thereby heating the condensing water and the resultant liquefied vapor or liquid ammonia is then passed on to the refrigerator again to pick up another load of heat.

The compressor is nearly as simple in action as the refrigerator and condenser. If a hollow rubber ball with a hole in it is squeezed it will be compressed and the air that was in it will be expelled and when the ball is relieved of the pressure air will flow into it and this new charge of air in the ball would then be compressed and discharged through the hole by giving the ball another squeeze. If the ball were squeezed and if the hole in the ball were connected to the vapor outlet of the refrigerator and the pressure on the ball then removed, the ammonia vapor from the refrigerator would flow into and fill the ball. Now if the ball were removed and the hole in it connected to the gas inlet to the condenser and the ball squeezed again, the ammonia vapor in the ball would be compressed and discharged into the condenser. We now have, in general, the broad principles of operation of a volatile liquid refrigerating machine.

CHAPTER II.

The Simple Compression Machine and the Simple Absorption Machine—The Intermittent Absorption Machine—Historical Facts Regarding The Discovery of Principles that Led to the Invention of the Absorption Refrigerating Machine—Faraday's Tube—Modified Forms of the Simple Absorption Refrigerating Apparatus—Diagrams Illustrating the Operation of an Intermittent Machine.

In Fig. 1 a diagram of a simple mechanical compression machine is shown. Liquid anhydrous ammonia at 90° F., and 170 pounds pressure per square inch flows from the condenser past the expansion valve into the refrigerator, where its pressure is reduced to fifteen pounds gauge and its temperature to 0° F. Brine from a spray pipe flows over the outer surface of the refrigerator and is reduced in temperature from 20° to 10°. This 20° and 10° brine is in effect the fire that boils the ammonia liquid and changes it, through adding to it the latent heat of vaporization, to a vapor in the refrigerator. The heat flows downhill from the hotter 20-degree and 10-degree brine to the colder 0-degree ammonia. The ammonia vapor is so formed by being loaded up with the latent heat of vaporization, this heat being that which is removed from the brine in cooling it from 20° to 10°. The ammonia vapor formed in the refrigerator now flows from the refrigerator to the compressor through the suction pipe, as indicated by the arrows, past the suction valve, and as the piston retreats from the vapor inlet the vapor follows it and fills the cylinder. Next the piston reverses its motion and through the mechanical energy given to the piston, from any desired source, as from a steam engine, it compresses the vapor in the cylinder and so closes the suction valve and gradually increases the pressure of the vapor (now gas because it is hotter than a vapor due to the heat of compression, to be discussed at length later) until the pressure of the gas in the cylinder has reached the condenser pressure of 170 pounds, at which point the pressure in the cylinder opens the discharge valve and the piston forces the compressed gas out of the cylinder, past the discharge valve, and through the discharge pipe, as shown by the arrows, into the condenser.

The condenser is provided with a spray pipe that allows water to flow over the outer surface of the condenser; this condensing water is heated from 70° to 80° in first cooling the gas from the condenser to 90°, its condensing point at 170 pounds pressure, and then condensing the 90-degree ammonia vapor to ammonia liquid at 90° and 170 pounds pressure. Here, in the condenser, the load of heat taken up by the ammonia vapor in the refrigerator, plus the heat due to its compression, is dumped into the condensing water, thereby heating the condensing water, or raising its temperature from 70° to 80°. The ammonia in the condenser now being reduced to a liquid through the extraction from the vapor of the latent heat of condensation again flows past the expansion valve to the refrigerator and the cycle is repeated.

By this time the reader is doubtless thinking that this book should be called the compression refrigerating machine and not the aborption refrigerating machine, and in this he is nearly correct, for generally and broadly speaking, *the absorption machine is a compression machine,* only the compression of the vapor between the refrigerator and the condenser in the absorption machine is accomplished in a different manner from that already described.

The compression machine just described is a mechanical compression machine, the compression of the vapor between the refrigerator and the condenser being accomplished through the direct expenditure of *mechanical energy* applied through the piston. The absorption machine is a heat compression machine whereby the vapor from the refrigerator is taken in and compressed and discharged into the condenser through the direct expenditure of *heat energy,* as such, applied through the equivalent of the piston.

It may be well to look into the relative values of mechanical energy and heat energy. The measure of mechanical energy is the foot-pound, that is one pound raised one foot in one minute. And 33,000 foot pounds per minute is a horse power, that is, 33,000 pounds raised one foot in one minute or one pound raised 33,000 feet in one minute, or 330 pounds raised 100 feet in one minute is one horse power.

One heat unit, or one B. T. U., equals 778 foot pounds and this figure, 778 foot pounds, is called the mechanical equivalent of heat. So one horse power in heat units is equal to 33,000 foot pounds divided by 778 foot pounds, which equals 42+ B. T. U. In other words, if one pound of water be heated through 42°+ or two pounds through 21°+ or forty-two pounds through 1°+ in one minute, the heat energy used in so doing is 42+ B. T. U., which equals 33,000 foot pounds of mechanical energy per minute, which equals one horse power.

Referring again to Fig. 1, and paying particular attention to the mechanical compressor, it will be noticed that the movement of the piston can be divided into two separate actions, first, the suction stroke of the piston and, second, the compression stroke of the piston.

Everything in the simple absorption machine is like that in the simple compression machine except the compressor, which in the absorption machine I have called the heat compressor and in the compression machine, the mechanical compressor. The equivalent of the suction stroke of the compression machine is the absorber of the absorption machine and the equivalent of the compression stroke of the compression machine is the still, or generator of the absorption machine.

We have already seen that heat will expand the volume of a body. The mercurial thermometer is a familiar example, the mercury expands by heating and contracts by cooling. It is easy to imagine that if a body were confined and heated, as it could not then increase its volume, it would therefore increase its pressure. If a given volume of gas is heated its pressure is increased. In the mechanical compressor when external mechanical energy is applied to the piston to compress the gas, this mechanical energy heats the gas in compressing it. Conversely, if the cylinder full of gas had been heated by heat directly applied in place of being compressed by mechanical energy it would have been compressed by heat energy. So if the piston of Fig. 1 were removed and the cylinder first cooled and then heated, the gas in the cylinder would alternately be drawn in from the refrigerator and discharged into the condenser.

Water has a great attraction for ammonia gas and will absorb a great quantity of it at a low pressure and temperature and then give it out again at a high temperature and pressure. If we consider that water is made up of a great number of little balls of liquid, we can also imagine that these little balls of water have voids or spaces between them just as lead bullets in a barrel would have.

If we had a barrel full of lead bullets the voids or spaces between the bullets would be filled with air, and if we heated the barrel of bullets we would also heat the air in the voids or spaces and would so compress and expel some of the air from these voids or spaces between the bullets. We can imagine that water and ammonia, commonly called aqua ammonia, will act somewhat in the same way; that if aqua ammonia is cooled it will take in more ammonia gas to fill the little spaces between the little water balls, and if heated, part of the ammonia gas in these voids or spaces between the water balls will be compressed and expelled from the aqua ammonia just as the air between the lead bullets was compressed and partly expelled when we heated the lead bullets.

The simple heat compression machine or absorption machine is shown in Fig. 2. Here we see that the condenser, refrigerator, expansion, suction and discharge valves and pipes leading to and from the compressor, are the same as in the simple mechanical compressor of Fig. 1. And the action and operation in Fig. 2 is exactly like that in Fig. 1, except as to the method of operation of the compressor.

In Fig. 2 liquid ammonia flows from the condenser at 90° and 170 pounds past the expansion valve into the refrigerator, where its pressure is reduced to fifteen pounds and its temperature to zero degrees. And the liquid ammonia changes to a vapor in the refrigerator in taking in the latent heat of vaporization to cool the brine from 20° to 10° and this vapor flows from the refrigerator through the suction pipe, as indicated by the arrows, past the suction valve to the heat compressor. Here the heat compressor is like the mechanical compressor, except that the piston is removed and a coil of pipe substituted therefor. The piston was the direct means for mechanical compression and the coil of pipe is the direct means for heat compression. Referring to Fig. 2 it will be seen that the space surrounding the pipe coil in the vessel, like the cylinder of Fig. 1, is filled with say twenty-five per cent aqua ammonia, that is, a solution of ammonia gas in water that is twenty-five per cent by weight of ammonia and seventy-five per cent by weight of water.

The ammonia vapor from the refrigerator flows past the suction valve, as indicated by the arrows, through the pipe leading from the refrigerator to the heat compressor and then forces itself into the twenty-five per cent aqua ammonia, called weak liquor, through the little holes in the bottom of the heat compressor. This action occurs because the twenty-five per cent weak liquor at its temperature of 110° F. and pressure of fifteen pounds, has a capacity for holding more than twenty-five per cent of ammonia, and so absorbs the gas. The ammonia vapor bubbles up through the weak liquor and is absorbed by it, but in so doing it generates what is called "the latent heat of absorption," which heat, if not removed from the weak liquor, would shortly heat the weak liquor and raise its temperature so it could not absorb any more ammonia vapor. To take care of this heat of absorption, cooling water is circulated through the coil. This cooling water, so circulated, enters the coil at say 80° and leaves it at 90° in taking up the heat of absorption. The heat flows down hill from 110° weak liquor to the 80° or 90° cooling water. The weak liquor now continues to absorb ammonia vapor from the refrigerator until it has taken all it will hold at fifteen pounds pressure and 110°, which is thirty-five per cent, so that the weak liquor has now increased its load of ammonia from twenty-five per cent to thirty-five per cent; the latter, or thirty-five per cent liquor, is called the strong liquor.

Here we see that this absorption action through the cooling effect of the coil in the heat compressor is exactly like the suction stroke of the mechanical compressor through its piston.

When the aqua ammonia has absorbed all the ammonia it can at the refrigerator or absorber pressure of fifteen pounds and a temperature of 110°, it is, as before stated, strong liquor. At this point the cooling water is shut off from the coil in the heat compressor and steam at say forty pounds pressure and 286° is passed into the coil. This steam condenses in the coil by letting its latent heat of condensation flow to the 110° strong liquor. This heat raises the temperature of the strong liquor and so also increases its pressure so that the suction valve closes and the pressure in the heat compressor gradually rises from fifteen pounds to 170 pounds. When 170 pounds pressure has been reached in the heat compressor the discharge valve is forced open by this pressure and the ammonia gas, and some water vapor (to be discussed at length later) is distilled from the strong liquor by having the heat of disassociation added to the gas so formed, and this ammonia gas at 170 pounds pressure then flows past the discharge valve through the discharge pipe, as indicated by the arrows, into the condenser, where it is cooled to a vapor at 90° and 170 pounds pressure, and is condensed into a liquid at 90° and 170 pounds pressure by giving up its heat of condensation to the condensing water.

The condensing water flowing over the outer surface of the condenser from the spray pipe takes up this heat of condensation in being heated from 70° to 80°, as before explained, and the liquid ammonia from the condenser now flows past the expansion valve to the refrigerator to repeat the above cycle.

In the meantime the temperature of the aqua ammonia in the heat compressor has risen from 110° to 255°. At this temperature the aqua ammonia has distilled off ammonia gas so as to have reduced its strength from thirty-five per cent to twenty-five per cent. Or it has changed from a strong liquor to a weak liquor. Here it is apparent that the coil with steam in it has acted like the piston of the mechanical compressor and has compressed the gas through heat energy from fifteen pounds to 170 pounds and at the same time reduced the strength of the aqua ammonia from thirty-five per cent to twenty-five per cent. Now the steam is shut off from the coil and the cooling water is again circulated through the coil, so that the weak liquor is again cooled down to 110° and as this cooling of the weak liquor progresses, the discharge valve closes and as the pressure in the heat compressor gradually falls from 170 pounds to fifteen pounds pressure, the suction valve opens again and more ammonia vapor from the refrigerator flows into and is absorbed by the weak liquor, until it is strong liquor again and the heat compression process is repeated.

This heat compressor, Fig. 2, the author has called the absorber-generator. Here again it is observed that the absorber action is equal in effect to the suction stroke of the mechanical compressor and the generator action is equal in effect to the compression stroke of the mechanical compressor. The absorption machine just described is what is known as the intermittent machine. In the continuous absorption machine the absorber-generator is divided into two units called the absorber and the generator and a new element called the liquor pump is added.

Before turning our attention from the intermittent absorption machine to the continuous absorption machine, a further study of the intermittent machine in its simplest form and in some of its modified forms and a brief historical mention of its early conception will be of interest. Although Ferdinand Carré invented the absorption machine in 1859, I desire, without attempting to detract from the great credit due to Carré, to touch on a few historical facts that would seem to show that Carré was more the adapter of principles already discovered than the originator of such principles. "On the 5th of March, 1823, Dr. John A. Paris, who was the biographer of Sir Humphrey Davy, had occasion to call on Sir Humphrey and after having concluded his call he looked up Sir Humphrey's assistant, Michael Faraday, in his laboratory at the Royal Physical Society in London.

"Faraday was experimenting with hydrate of chlorine, which was being heated in closed glass tubes. Dr. Paris noted some drops of dark oily looking substance in one of the tubes and called Faraday's attention to it and criticised him for not using cleaner tubes. Faraday admitted the fault and taking a file broke the fuse point of the tube, with the result that there was a slight explosion and the drops of oily matter vanished from the tube. Both Faraday and Dr. Paris were much puzzled and mystified, as neither could explain the explosion or the disappearance of the oily looking drops. The next morning Dr. Paris received the following letter:

"Dear Sir:
"The oil you noticed yesterday turns out to be liquid chlorine. Yours faithfully,
"Michael Faraday."

That letter startled the world with the newly discovered fact that gases could be liquefied. Thus Faraday laid the cornerstone of one of the most useful principles of modern science and the great principle upon which the liquefiable gas refrigerating machines of today depend for their operation.

Faraday further discovered that chloride of silver would absorb ammonia and that upon being heated in one end of a closed bent glass tube, the other end of which was immersed in salt and ice, liquefied ammonia would be condensed from the ammonia vapor in the cooled end of the tube. He further discovered that upon removal of the ammonia end of the tube from the ice and salt, and upon cooling the chloride of silver end of the tube, the liquid ammonia would boil in one end of the tube and its vapor would be reabsorbed in the chloride of silver end of the tube. Also, that the end of the tube in which the ammonia boiled was intensely cold and colder by far than the temperature of the ice and salt mixture. This was the first experimental liquefiable gas refrigerating machine and was the forerunner of and involved the great broad principles of the well known absorption and compression machines of today.

In Figs. 3 and 4 are shown modified forms of Faraday's tube as an absorption machine. In each figure is shown a bent tube and each end of the tube is shown provided with a spray pipe that can spray a heating or cooling fluid on the end of the tube under it.

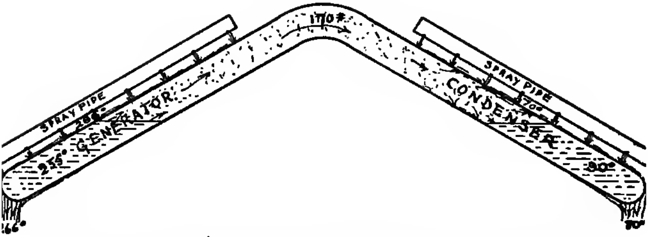

FIG. 3.—FARADAY'S TUBE AS GENERATOR AND CONDENSER.

In Fig. 3, the left-hand end of the tube is filled with strong aqua ammonia, say thirty-five per cent by weight of ammonia and sixty-five per cent of water. The spray pipe sprays hot chloride of calcium brine, at say 286°, onto this end of the tube. The thirty-five per cent ammonia in the tube will be heated and ammonia vapor will be distilled over into the other end, as shown by the arrows. The heating fluid is thus cooled from 286° to, say, 266° F. in evaporating the ammonia to vapor at, say, 255° F. The right-hand end of the tube has 70° water sprayed over it from its spray pipe and this water cools and condenses the ammonia vapor to liquid ammonia at, say, 90° and 170 pounds pressure. The condensing water is heated to

80° F. in so doing. This process goes on until the thirty-five per cent aqua in the left-hand end of the tube is reduced to twenty-five per cent aqua, then the operation is changed as shown in Fig. 4. Now a spray pipe sprays 20-degree brine over the right-hand end of the tube of Fig. 4 and this brine is cooled to 10° F. by evaporating the ammonia at 0° F. and fifteen pounds pressure. The ammonia vapor so formed passes as shown by the arrows into the left-hand end of the tube and is absorbed by the weak liquor therein. The heat of absorption so generated is taken out by cooling water sprayed over the left-hand end of the tube, which water is heated from 80° to 90° in so doing. This process continues until the aqua ammonia in the

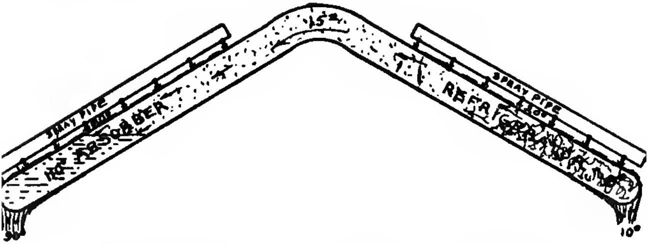

FIG. 4.—FARADAY'S TUBE AS ABSORBER AND REFRIGERATOR.

left-hand end of the tube is strengthened from twenty-five per cent to thirty-five per cent, and then the process as described and shown in Figs. 3 and 4 are alternately repeated.

It is evident that the left-hand end of the tube in Fig. 3 was a generator and the right-hand end a condenser, and that the left-hand end of the tube in Fig. 4 was an absorber and the right-hand end a refrigerator. This tube, as shown in Figs. 3 and 4, is the simplest form of absorption refrigerating machine (the intermittent form.)

Now to adapt this simplest form to the form of apparatus shown in Fig. 2, see Fig. 5, which is divided into two parts, 5A and 5B. The apparatus of 5A is the same as 5B, except that it is used for a different purpose.

The operation of 5B is almost exactly like that of Fig. 3, and of 5A is almost exactly like that of Fig. 4, and both Figs. 5A and 5B are quite similar to Fig. 2.

In Fig. 5B the generator is first filled with thirty-five per cent aqua, then steam is passed through the coil and distills off the ammonia vapor into the condenser, as shown by the arrows, wherein it is condensed at, say, 90° and 170 pounds pressure by the cooling action of the condensing water from the spray pipe, the condensing water being heated in so doing from 70° to 80°. When the strength of the aqua in the generator has been reduced to twenty-five per cent, the action as shown in Fig. 5A takes place.

Brine at 20° F. is sprayed on the refrigerator, which was the condenser of Fig. 5B, and is cooled to 10° F. by evaporating the ammonia in the refrigerator to a vapor at, say, 0° F. and fifteen pounds pressure. The vapor so formed flows as indicated by the arrows from the refrigerator and up through the little holes in the bottom of the absorber (which was the generator of Fig. 5B) and up into the aqua and is absorbed therein. The heat of absorption caused thereby is taken out by the cooling water passed through the coil, which water is heated from 80° to 90° in so doing. When the strength of the aqua in the absorber has been increased to thirty-five per cent the process of Fig. 5B is repeated.

It is evident that the generator in Fig. 5B is the same apparatus as the absorber of Fig. 5A and that the refrigerator of Fig. 5A is the same apparatus as the condenser of Fig. 5B. In other words, the low pressure apparatus, or the refrigerator and absorber of Fig. 5A is just the same as the high pressure apparatus or condenser and generator of Fig. 5B. The only difference between these two figures is in the method of operating. The low pressure apparatus of Fig. 5A takes in heat in the refrigerator and gives it out in the absorber, while the high pressure apparatus in Fig. 5B takes in heat in the generator and gives it out in the condenser. The heat taken in in the low pressure apparatus does useful work in doing refrigeration, and the heat taken in in the high pressure apparatus does useful work in getting the ammonia in a proper condition to again do useful refrigeration in the low pressure apparatus. The process of refrigeration is still intermittent and it must be stopped long enough to enable the distilling process to get the ammonia into proper condition to again do refrigeration.

CHAPTER III.

Simple Continuous Absorption Refrigerating Machine Without Liquor Pump—Simple Continuous Machine With Liquor Pump and (Aqua) Regulating Valve.

If we combine Figs. 5A and 5B with certain modifications of the pipes, and connect the condenser to the refrigerator with a pipe provided with an expansion valve, as shown in Fig. 6, we have advanced a step toward the modern absorption machine.

There is also seen a close resemblance in Fig. 6 to Fig. 2, the difference being that in Fig. 6 there are two heat compressors or absorber-generators, in place of the single one of Fig. 2. The operation of the apparatus shown in Fig. 6, the simplest form of continuous absorption machine, is as follows: Anhydrous ammonia at 90° F. and 170 pounds pressure flows from the condenser into the refrigerator, past the expansion valve, as indicated by the arrows, where its pressure is reduced to fifteen pounds. The liquid ammonia in the refrigerator is evaporated at 0° and fifteen pounds pressure to a vapor by the heat taken up from the brine flowing over the refrigerator and so cooling the brine from 20° to 10°. The vapor so formed in the refrigerator flows, as indicated by the arrows (full line arrows), into the left-hand absorber-generator, which now acts as an absorber. The vapor is absorbed in this absorber at fifteen pounds pressure and its heat of absorption is taken up by the cooling water in the coil, the cooling water being heated from 80° to 90°. At the start 25 per cent aqua ammonia is in the left-hand absorber-generator, or absorber, and it gradually strengthens up to 35 per cent as it continues to absorb ammonia vapor from the refrigerator.

In the meantime, however, the right-hand absorber-generator, or generator, started up with 35 per cent aqua ammonia in it and steam passing through its heating coil is condensed and so disassociates the aqua ammonia in it. The ammonia vapor so formed flows from this right-hand absorber-generator, or generator, as indicated by the arrows (full line arrows), to the condenser wherein it is condensed to a liquid at 90° and 170 pounds pressure by the action of the condensing water flowing over the condenser, which heats the condensing water from 70° to 80°. This process continues in the right-hand absorber-generator, or generator, until the aqua therein is reduced from 35 per cent to 25 per cent aqua.

Next the right-hand absorber-generator has cooling water in place of steam circulated through its coil and it becomes an absorber, and the left-hand absorber-generator has steam in place of cooling water circulated in its coil and it so becomes a generator, and the process just described is again repeated, the check valves preventing the backward flow of gas, and the dotted arrows showing the flow of gas during this second part of the process.

This second part of the process is continued until the strong aqua in the absorber-generator, now used as a generator, is reduced to weak liquor again, and until the weak aqua in the absorber-generator, now used as an absorber, is built up to strong aqua again, at which point the action of the absorber-generator is again reversed and the first part of the process again repeated.

Here it is apparent that the operation of the refrigerator and condenser of Fig. 6 is continuous, but that the action of the absorber-generators is intermittent. Machines of the type just described are now (1908) used and manufactured in England to some extent.

It is evident that the machine of Fig. 6, which may be called the continuous absorption machine without liquor pump, is open to the objection that personal attention is required to open and shut such necessary valves as will cause the absorber-generators at the proper times to act as absorbers or as generators. If now the apparatus shown in Fig. 6 be still further modified by taking out some pipes and putting in some others and by adding a new element called a liquor pump, we will have the simplest form of continuous absorption machine, as shown in Fig. 7. Here it will be noted that the left-hand absorber-generator of Fig. 6 is now the absorber of Fig. 7, without any modifications whatsoever; while the right-hand absorber-generator of Fig. 6 has, by omitting the gas passage to its bottom, become the generator of Fig. 7. The check valves of Fig. 6 are omitted in Fig. 7, and another new element, the regulating valve, is also added.

This regulating valve has a similar function to that of the expansion valve. The operation of this simplest form of continuous absorption machine with liquor pump (Fig. 7) is as follows: Liquid ammonia at 90° and 170 pounds pressure flows from the condenser, as indicated by the arrows, through the short pipe and past the expansion valve, where it has its pressure reduced to fifteen pounds. The liquid ammonia at fifteen pounds pressure boils at 0° in the refrigerator and is vaporized by taking up the heat from the brine, which flows over the refrigerator, thus cooling the brine from 20° to 10°. The vapor so formed flows from the refrigerator, as indicated by the arrows, to the bottom of the absorber, where it enters it through the little holes in its bottom and bubbles up in the aqua therein, wherein it is absorbed at fifteen pounds pressure; the heat of absorption being taken up by the cooling water which circulates through its coil and which heats the water from 80° to 90° F. The strong 35 per cent, 110°, fifteen-pound pressure, aqua now flows from the bottom of the absorber, as indicated by the arrows, past the suction valve into the cylinder of the liquor pump. Now the piston of the liquor pump recedes until a cylinder full of strong liquor from the absorber is drawn in, then the piston reverses its motion (the piston is reciprocated by any desired means of power) and the strong aqua is discharged at 170 pounds pressure past the discharge valve and, as shown by the arrows, into the generator. In the generator the strong aqua is heated by condensing the steam in the heating coil and is reduced to 25 per cent, 255° aqua. This weak aqua now flows from the generator because of its 170 pounds pressure, past the regulating valve into the 15-pound pressure absorber, as shown by the arrows.

The ammonia vapor formed in the generator from reducing the strong to the weak aqua, flows as indicated by the arrows into the condenser, wherein it is cooled and condensed to a liquid at 90° and 170 pounds pressure by the cooling action of the condensing water flowing over the condenser, so that the condensing water is heated from 70° to 80°. The condensed vapor in the condenser is now a liquid and ready to repeat the cycle just described over again.

Here in Fig. 7 we have the continuous absorption machine cycle with a liquor pump which forms the basis of all the well known absorption machines. New elements will now be added to the apparatus shown in Fig. 7, but they will only so modify it as to produce more capacity or economy.

CHAPTER IV.

Weak Liquor Cooler—Cooling Weak Aqua Before it Enters Absorber—Operation and Advantage of Cooler.

Referring again to Fig. 7 it will be noticed that the weak liquor entering the absorber is very hot, having a temperature of 255° F. Now in order to have the weak 25 per cent aqua in condition to become 35 per cent aqua, it is necessary to cool the aqua from 255° to 110°. It is evident that the weak aqua may, if desired, be so cooled before it enters the absorber. This can be done in a simple coil of pipe and leads us to a new element, the weak liquor cooler. This is shown in Fig. 8, which is a reproduction of Fig. 7, with the difference that the absorber and generator are farther apart and a part of the pipe that conducts the weak liquor from the generator to the absorber leading from the generator to the absorber is exposed to the cooling action of water delivered from a spray pipe as shown. This water, which may be a part of the 80-degree water from the condenser, cools the weak liquor from 255° to 110° and thus the water is heated from 80° to say 100° in so doing. In Fig. 8 the operation is exactly the same as was described in Fig. 7, except as follows: The weak 25 per cent aqua flows from the generator at 255° and 170 pounds pressure up the pipe as indicated by the arrows, and through the weak liquor cooler, where it is cooled to 110° by the cooling water flowing from the spray pipe and over the surface of the weak liquor cooler, the cooling water being heated, in so doing, from 80° to say 100°. The cool 110°, 25 per cent aqua ammonia at 170 pounds pressure now flows past the regulating valve where its pressure is reduced from 170 to fifteen pounds. It enters the absorber and in flowing down through the absorber it gradually absorbs more and more ammonia gas until it becomes 35 per cent aqua at 110° and fifteen pounds pressure. Here the cooling coil of the absorber takes out only the heat of absorption and not the heat to cool the aqua from 255° to 110° and also the heat of absorption as was the case in Fig. 7. It is also noticed that the hot weak liquor is cooled on the high pressure side of the regulating valve, as otherwise the hot weak liquor would form gas on having its pressure reduced, should the pressure of the hot weak liquor be reduced before it became cool weak liquor.

CHAPTER V.

The Exchanger—Ratio of Weights of Strong Liquor to Weak Liquor and Anhydrous Ammonia—Unequal Heating or Cooling Range of Strong and Weak Liquor —The Real Value of an Exchanger.

As we analyze what occurred in the action described in Chapter IV, we see that we are throwing away a great deal of useful heat at the weak-liquor cooler that might be saved, and which would so reduce the heat required in the generator and therefore the quantity of steam to be used in the generator. We notice, referring again to Fig. 7, that we have hot weak liquor of 255° entering the absorber, whereas we desire it to be cold weak liquor. We also notice that we have cold 110° strong liquor entering the generator, whereas we desire hot strong liquor to enter the generator. Now why not exchange this heat and put it, or at least a large part of it, where we want it and where it will do good, and so use less surface in the weak liquor cooler or use no weak liquor cooler at all, and also save steam in the generator? In other words, exchange the heat from the liquor in which less heat is wanted to the liquor in which more heat is wanted, as from the hot weak liquor to the cold strong liquor, thereby making the hot weak liquor colder and the cold strong liquor hotter. All that is necessary to accomplish this is to expose these two liquors, the one to the other, on opposite sides of a heat exchanging surface as on the inside, and on the outside of a coil of pipe.

Referring now to Fig. 9, this is like Fig. 8 with the exception that the pipe, in Fig. 8, leading from the liquor pump to the generator, is enlarged and modified so as to enclose a portion of the pipe, of Fig. 8, that there led from the generator to the absorber. The general operation of Fig. 9 is much the same as that of Fig. 8. The strong liquor flows directly from the pump to the generator and the weak liquor flows directly from the generator to the absorber, but in so doing, and by the combination of modified pipes, as shown in Fig. 9, a new element called the exchanger is added to the apparatus of Fig. 8 to give Fig. 9.

The operation of Fig. 9 is similar to the operation of Fig. 7 except as hereinafter explained, and is like Fig. 8 with the addition of the exchanger, except that now the weak liquor cooler has not so much heat to take out, as will appear from the following: The cold strong liquor at 110° flows along its enlarged pipe on its way from the liquor pump to the generator and comes in contact with the pipe conducting the hot weak liquor from the generator to the absorber, with the natural result that the hot weak liquor is cooled and the cold strong liquor is heated. It is here shown, in Fig. 9, that the cold strong liquor is heated through a range of 114° or from 110° to 224° in receiving the heat from the hot weak liquor. The hot weak liquor is cooled through a range of 130° or from 255° to 125° in giving up its heat to the cold strong liquor. Now we note that the weak liquor is a carrier for the anhydrous ammonia that was evaporated in the refrigerator. The weak liquor absorbed this anhydrous ammonia in the absorber in changing from 25 per cent to 35 per cent aqua, and the strong liquor gave up its load of anhydrous ammonia in the generator in changing from 35 per cent to 25 per cent aqua.

For the present, without further explanation, it may be assumed that for every eight pounds of strong liquor pumped by the liquor pump one pound of anhydrous ammonia is evaporated in the refrigerator, so that the weight of weak liquor circulated per unit of time is seven pounds as against eight pounds of strong liquor circulated in the same time. The difference in weight, as 8 — 7 = one pound of anhydrous ammonia above referred to as evaporated in the refrigerator and absorbed in the absorber and distilled in the generator. The weight of strong liquor being greater than the weight of weak liquor it follows that for a given range of cooling in the weak liquor circulated there will be a less range of heating in the strong liquor. The quantity of heat given up by the weak liquor is the exact equal of the quantity of heat taken up by the strong liquor, but as the weight of the strong liquor is more, its range in temperature will therefore be less than that of the weak liquor. Furthermore the strong liquor cannot be heated above its boiling point at its pressure, so that often a considerable portion of the range of cooling of the weak liquor does not appear as a like range in heating the strong liquor because of the immense amount of heat required for disassociating and evaporating the strong liquor to a weaker liquor as compared with the specific heat required for cooling the weak liquor. In the present case we will assume that the exchanger has 90 per cent efficiency, that is, that it exchanges 90 per cent of all the heat it could exchange if perfect. The greatest possible range for the weak liquor would be from 255°, its hottest temperature, to 110°, the temperature of the coldest strong liquor, or 255° — 110° = 145°, and 90 per cent of 145° = 130°. So 130° is the range of the weak liquor, which gives 255° — 130° = 125°, as the temperature of the weak liquor from the exchanger. If now we assume the specific heats of the weak and strong liquors, for the present as the same, then we have 8/7 as much strong liquor as weak liquor, so the strong liquor will be heated through a range of $\frac{7}{8} \times 130° = 114°$. And 110° + the range of 114° = 224°, is the temperature of the hot strong liquor from the exchanger to the generator.

It is evident, in Fig. 9, that as the strong liquor enters the generator at 224° in place of at 110°, as in Fig. 7, that the heat required to heat the aqua from 110° to 224° will be saved and so less steam will be used in the generator and, further, that as the weak liquor now goes to the weak liquor cooler at 125° in place of 255°, less surface of weak liquor cooler will be required and also less cooling water for the weak liquor cooler need be used. For now the weak liquor is only cooled from 125° to 110° by the weak liquor cooler, which also heats the cooling water from 80° to 100° as before, but here a smaller quantity of cooling water is used than was used in Fig. 8. By having sufficient surface in the exchanger the temperature of the weak liquor may be so lowered as to dispense with the weak liquor cooler altogether, which is what is done in many of the up-to-date machines, and especially with practically all machines operating with dry absorbers, which will be described later.

It is evident that we have saved by the use of the exchanger just described in Fig. 9 all of the heat that would otherwise have been required in the form of extra steam in the generator to heat the strong liquor from 110° to 224°.

Summing up, the exchanger has the following advantages: It saves steam in the generator, saves coil surface in the generator, saves water at the weak liquor cooler, and saves coil surface in the weak liquor cooler or dispenses with the weak liquor cooler altogether.

In general it will be wise to install as large an exchanger as is possible, stopping only at the point where the interest on the investment plus the depreciation is equalled by the saving in cost of steam and water.

We now have all the principal modifications that occur in the modern up-to-date absorption machine between the generator and the absorber, and will next take up the principal modifications that occur between the generator and the condenser.

CHAPTER VI.

The Analyzer—Ammonia Data—Water Vapor in Gas from Generator—Water in Condenser and Refrigerator—Purging for Refrigerators.

The modifications that occur in the absorption machine between the generator and the condenser are those that are least understood of any of the parts of the absorption machine. Yet we will find them as simple in principle, at least, as we have found the other parts, up to this point. In Fig. 9 we saw how the economy and capacity of the machine were increased by the exchanger. Here we exchanged part of the heat from the hot weak liquor and gave it to the cold strong liquor. And here we exchanged heat through a pipe surface from one liquid to another liquid. The next modification might also be called an exchanger, for its function is that of an exchanger, only it exchanges heat from a gas to a liquid in place of from a liquid to a liquid. Such an exchanger is called an analyzer. In the analyzer the strong liquor is still further heated, after leaving the exchanger, by the hot gas flowing from generator to condenser.

Fig. 10 is like Fig. 9, with the addition of the analyzer.* In the operation of the analyzer a new

*As will be discussed at length later, the data for aqua ammonia thus far used have been taken from certain published tables, and those tables were not the results of any personal investigations. From now on conclusion will be based upon some aqua ammonia data of my own, hence some of the data that occurred in the various figures given up to this point must be changed so that later these will lend themselves to the uses required. Data in Fig. 9 have been changed in Fig. 10 as follows: Temperature of water from weak liquor cooler from 100° to 90°; temperature of 25% liquor to absorber from 110° to 101°; temperature of 35% liquor from absorber from 110° to 101°; temperature of 25% liquor from generator from 255° to 253°; temperature of strong liquor from exchanger from 224° to 213°.

action takes place. In the condenser of Fig. 9 was condensed, by cooling, all the vapor from the generator to a liquid. Now we come to the new action. The generator does not distill anhydrous ammonia gas, but distills a mixture of ammonia gas and water vapor or steam. All are familiar with the fact that air absorbs water vapor, so likewise ammonia gas absorbs water vapor.

We know that the hotter the air is, the more water vapor it will hold, likewise with ammonia gas, the hotter it is, at a given pressure, the more water vapor it will hold. One of the most modern applications of refrigeration is the cooling of air for blast furnaces, and the main reason for so cooling the air is to extract most of the moisture from it. Perhaps the most familiar examples of this action are the ice water pitcher and the window pane. It is an everyday observation to see the outside of an ice water pitcher covered with moisture that has been condensed on it by the cooling of the air in contact with the cold pitcher. And also it is common to note the condensation of moisture on the window pane and remark: "It is turning cold," for here the cold on the outside of the window pane has so cooled the glass that it condensed moisture from the air on the inside of the window pane.

The action of the analyzer is the condensation of some of the water vapor from the mixed ammonia gas and water vapor during its passage up through the analyzer.

Its heat of condensation is given up in heating or evaporating some of the strong liquor on its way down to the generator. In Fig. 10 the analyzer is placed on top of the generator and is provided with a number of shelves or shallow pans that will permit the strong liquor to flow by gravity down into and overflow them from one to the other on its way down to the gener ator, while the hot gas from the generator flows up in contact with the bottoms of these shallow pans or shelves.

In Fig. 10 the strong liquor from the exchanger flows to the top analyzer pan in place of directly to the generator as was shown in Fig. 9.*

Here we have 35 per cent aqua at its boiling point of 213° entering the top of the analyzer. It flows into the top pan of the analyzer and overflows this pan into one below it and so on down the analyzer until it flows from the bottom pan, through the short pipe shown, into the top of the generator. The mixture of ammonia gas and water vapor leaves the generator at say 242°, and with say eleven per cent by weight of water vapor.

This hot gas flows up and heats the bottoms of the analyzer pans during its passage until it leaves the underside of the upper pan at say 228°. But this gas in being cooled from 242° to 228° in its passage up the analyzer, gave up heat as part of the water vapor and some ammonia gas became condensed on the under sides of the pans. This condensation formed little drops of liquid on the undersides of the pans and these drops fell into the strong liquor in the pans

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*When studying the exchanger of Fig. 9 we noted that the quantity of strong liquor to carry one pound of ammonia at the strengths of strong and weak liquor given was approximately eight pounds. More exactly, it is 7.5 pounds for 35% strong and 25% weak liquor. The exchanger described in Fig. 9 was designed to exchange 90% of the available heat of the weak liquor to the strong liquor. In what follows it will be more simple to explain, if the exchanger of Fig. 10 is of such proportions that it will just heat the 35% strong liquor to its boiling point of 213° F., that is, no evaporation of the strong liquor occurs in the exchanger, but the strong liquor arrives at the analyzer in such a condition that any more heat added to it will cause part of it to evaporate.

To accomplish this the exchanger of Fig. 10 is proportioned to exchange only 84% of the available heat of the weak liquor, that is, 84% of the range in temperature between the hot weak liquor of 253° and the cold strong liquor of 101°, or $253° - 101° = 152°$; and 84% of $152° = 128°$. That is, the range of the weak liquor in the exchanger is 128°, so that the weak liquor is cooled ($253° - 128° = 125°$) to 125°, and as the quantity of strong liquor in relation to the weak liquor is 7.5 to 6.5, for it takes 7.5 pounds of strong liquor to carry one pound of anhydrous ammonia (evaporated in the refrigerator and absorbed in the absorber), so the range of heating of the strong liquor will be $6.5 \div 7.5 \times$ the range of the weak liquor, or $6.5 \div 7.5 \times 128° = 112°$; 112° being the range of the strong liquor in the exchanger; it is therefore heated to $101° + 112° = 213°$. so 213° is the temperature of the strong liquor from the exchanger.

below them and were returned to the generator with the strong liquor.

But in the meanwhile the heat given up by the vapor, condensed on the bottoms of the pans, heated the strong liquor in the pans so that this strong liquor gave off vapor, and this vapor joined the vapor from the generator on its way to the condenser.

As the weight of gas going to the condenser is much less than the weight of strong liquor going to the generator, both via the analyzer, and as the specific heat of the gas is only about one-half that of the liquid, it is evident that the gas will be cooled through a greater range of temperature than the strong liquor will be heated. For the gas was cooled from 242° to 228° or through a range of 14°, while the strong liquor was heated from 213° to 216°, or through a range of 3°.*

Some of the vapor from the upper tray of the analyzer now joins the 228° gas, so we have, say 227° gas going to the condenser. This 227° gas at 170 pounds pressure still has, say, eight per cent of water vapor in it, and this water vapor now goes to the condenser and is condensed with the ammonia vapor.

Here we have a new and most troublesome condition to contend with. In place of having 100 per cent pure anhydrous ammonia in the condenser, we have only ninety-two per cent ammonia and eight per cent water. If now we had a refrigerator like that shown in Fig. 2 (self purging), we would have no difficulty other than an inefficient absorption machine with temperature well above 0° for the boiling ammonia in the refrigerator due to the raising of the boiling point by the water present in the ammonia. With the form of refrigerator shown in Fig. 10, where the boiling ammonia is held in it by the end partition

*These temperatures are not to be taken as exact, but are only to show the method of action in the analyzer. Later, exact conditions will be given in the more exact study of the analyzer.

there shown, which does not exist in Fig. 2, we have very grave difficulties. It would be bad enough if we had only to put up with temperatures in the refrigerator many degrees higher than that due to the boiling point of anhydrous ammonia, as could be obtained with the type of refrigerator shown in Fig. 2. But here, in Fig. 10, the eight per cent of water coming from the condenser, with the ammonia, to the refrigerator, practically all stays in the refrigerator, and soon accumulates so that in place of ninety-two per cent ammonia in the refrigerator, we have only a very weak ammonia in the refrigerator that soon loses all of its life as refrigerant ammonia and tends to become mostly all water.

The refrigerator shown in Fig. 2 is self-purging, as are all expansion coils with downward expansion. In the refrigerator shown in Fig. 10, which is like an expansion coil with upward expansion, or a shell type brine cooler, or a flooded system, we must provide a new element to take care of this water, the purge pipe that leads from the refrigerator to the absorber, as shown, and which is governed by a purge valve. Here it is necessary, either continuously or from time to time, to purge the watery ammonia from the refrigerator into the absorber.

CHAPTER VII.

The Rectifier—Drip Liquor—Best Temperature for Drip Liquor—Best Temperature for Gas from Rectifier to Condenser—Automatic Aqua Regulating Vaive—Complete Wet Absorber Cycle.

In Fig. 10 ammonia vapor and 8% of water vapor were being condensed in the condenser, and we now wish to have practically pure anhydrous ammonia condensed in the condenser. This gives the last important element in the absorption machine, the rectifier.

Referring now to Fig. 11, which is like Fig. 10, with certain additions that will later be described, it may be noted that the pipe leading from the top of the analyzer to the condenser is the same as in Fig. 10, but there has been added a spray pipe, to spray cooling water from this spray pipe on the before mentioned pipe, and this is the rectifier. Its function is to rectify the gas from the generator so that it is practically pure anhydrous ammonia gas, and to return the water so condensed in the rectifier to the generator via the analyzer. It will be seen that the action of the rectifier is almost exactly like that of the analyzer except that the cooling agent in the rectifier is the water from the spray pipe in place of the strong liquor in the analyzer.

The cold walls of the rectifier condense the water vapor into water, and this water reabsorbs ammonia vapor, due to its (the water's) temperature and pressure. This condensation, called drip liquor, now flows by gravity through a trap as indicated by the arrows into one or more additional pans in the top of the analyzer; here only one such pan is shown.

The hotter the drip liquor is as it comes from the rectifier the less ammonia will it bring with it to the generator via the analyzer, to be re-evaporated at the expense of the steam used in the coil of the generator. In this case it will be assumed that the drip liquor leaves the rectifier at 173°, which would make it 45% liquor. This 45% 173° drip liquor now flows into the upper drip pan of the analyzer and is heated by the gas passing up through the analyzer to the rectifier, thereby cooling and partly rectifying the said gas and thereby being heated and partly evaporated and reduced in strength itself, so that it flows from the drip pan of the analyzer into the upper strong liquor pan as say 35% liquor at 213°, or at just the same temperature and strength as the strong liquor also flowing into this pan from the exchanger. Of course this would never be the case in actual practice, as the drip liquor invariably comes to the strong liquor pan as colder and stronger than this strong liquor coming into the top analyzer pan from the exchanger.

The condition given is ideal, and what we would like to obtain and the approximate approach of the above to the ideal condition depends upon the design of the machine and on the ability of its operator.

The operation of the rectifier has more to do with the capacity and economy of the absorption machine than any other part of the apparatus, is less understood and more abused and neglected than any other part. The improper operation of the rectifier can reduce the capacity of the machine more than 50%, and increase the steam consumption over 100%. In its operation a happy medium must be struck where the capacity of the machine is a maximum and the economy is the best. It is evident that if too much water is used on the rectifier practically all the ammonia gas can be condensed in it and returned to the generator via the analyzer, practically no ammonia being condensed in the condenser. This can occur when the temperature of the gas from the rectifier to the condenser is at or near the temperature due to the condenser pressure, as at 90° in this case. If the gas from the rectifier to the condenser were at or near 90° then the gas evaporated in the generator would nearly all short circuit and go from the generator through the analyzer to the rectifier and back again, without being condensed in the condenser and so do practically no refrigeration, and use excessive quantities of steam in the generator steam coil.

On the other hand if the gas from the rectifier to the condenser were too hot it would carry too much water vapor with it and so cut down the capacity of the machine by giving watery ammonia in the refrigerator. From personal experience in hundreds of tests made under practical operating conditions I find that a temperature of gas from the rectifier to the condenser of from 20° to 40° higher than the condensing temperature of the ammonia at its condensing pressure gives the best results. To govern this temperature a thermometer is placed in the gas line between the rectifier and the condenser, as indicated in Fig. 11, and there is no more important thing in the whole system to be watched and regulated (by supply of rectifier water) than is this temperature as indicated by this thermometer.

With one additional minor modification we have a complete system (with full absorber). It is evident that the regulating valve that governs the flow of the weak liquor from the generator to the absorber (see Fig. 10) will require to be adjusted by hand, as the speed of the liquor pump may vary. This hand governed regulating valve of Fig. 10 is left wide open and an automatic regulating valve is added as is shown in Fig. 11. This automatic regulating valve is governed by a ball float that will open the valve a little as the liquid level in the absorber falls, or will shut the valve a little as the liquid level in the absorber rises and so maintain the liquid level in the absorber at practically a constant level.

The complete cycle of operation for Fig. 11 (the full or wet absorber type) is as follows: Anhydrous ammonia, at 90° and 170 pounds pressure, flows through the expansion valve, where it is partly evaporated by reducing its pressure to fifteen pounds and its temperature to 0°. Now the 0° and 15-pound pressure anhydrous ammonia boils and evaporates in the refrigerator by the heat taken up in cooling the brine from 20° to 10°. The ammonia vapor so formed now flows to the absorber where it bubbles up through the liquor in the absorber in which it is absorbed, its passage from the refrigerator through the pipe and the little holes in the bottom of the absorber being plainly indicated by arrows in Fig. 11. The heat of absorption is taken up by the cooling water circulating through the cooling coil which heats this water from 80° to 90°.

The resultant strong, 35% 101° aqua at fifteen pounds pressure now flows to the liquor pump by which it is pumped into the pipe leading from the liquor pump to the exchanger and at a pressure equal to that in the generator plus the friction of the pipe to the exchanger and of the exchanger and of the hydraulic head to be overcome. This 35% 101° strong liquor now flows through the shell of the exchanger, is heated by the hot weak liquor to 213° and at this temperature, which is the boiling point of 35% aqua at the generator pressure of 170 pounds, it flows into the top strong liquor pan of the analyzer. From this pan it overflows and successively fills and overflows the several pans below during its passage through the analyzer to the generator, being heated and thus partly evaporated on this passage by the hot gas from the generator in it passage up through the analyzer.

The liquor now flows into the generator through the short pipe from this lower pan of the analyzer as, say 34% liquor at 216° and flows through the generator in contact with the steam coil so that it is partly evaporated and raised in temperature to 253° and thus reduced in strength to 25% liquor. The heat so taken from the steam condenses the steam in the steam coil of the generator at forty pounds pressure so that it is hot water at 286° temperature and forty pounds pressure, and this hot water after being further cooled a few degrees by the liquor in the generator is discharged from the generator steam coil, either through a throttling valve into the atmosphere or is pumped back into the boiler, or if the generator is at a higher elevation than the steam boiler, and if the boiler pressure is the same as the steam coil pressure, it is returned directly by gravity to the steam boiler.

Now the 25% 253° weak liquor flows up the pipe in the generator as indicated by the arrows and flows through the exchanger, being cooled to 125° by giving up part of its heat to the strong liquor. The 25% 125° weak liquor now flows through the weak liquor cooler where its temperature is reduced to 101°, the boiling point of 35% aqua at fifteen pounds pressure. The cooling water at the weak liquor cooler is heated from say 80° to 90° in taking up this heat from the weak liquor. Now the 101° 25% weak liquor flows past regulating valve into absorber, and in passage through absorber takes up and absorbs the gas from refrigerator, becoming 35% 101° aqua and is ready to repeat the liquor pump cycle as before explained.

In the meanwhile the 242° gas, with say 11% water vapor in it, from the generator has started up through the analyzer as is shown by the arrows. This gas is cooled and partly rectified and so deposits some of its water on the under sides of the analyzer pans, by being cooled by the strong liquor in these pans, so that this condensation drops off the bottoms of the pans into the strong liquor and returns with it to the generator. This gas is thus cooled in the analyzer to say 228° with say 8% of water left in it after having left the under side of the upper strong liquor pan and having been joined by some additional gas evaporated from the strong liquor in the pan. Now this gas comes in contact with the bottoms of the drip liquor pans (only one shown in diagram) that are conducting the drip liquor from the rectifier to the upper strong liquor pan, and is still further cooled to say 220° and after joining the vapor from the drip liquor pan is still further reduced in temperature to say 216°. Now this 216° gas goes to the rectifier, where it is still further cooled by heating the rectifier water from 80° to say 140°, and this gas finally leaves the rectifier at 120° and is practically pure anhydrous ammonia, after having deposited practically all of its water vapor which was condensed in the rectifier and which reabsorbed ammonia gas due to its (the liquid's) pressure and temperature.

This drip liquor from the rectifier now flows through the trap, as indicated by the arrows, as say 45% liquor at 173° into the top drip liquor pan of the analyzer, wherein it is heated by the gas from the generator, and partly evaporated, so that it flows into the top strong liquor pan of the analyzer as say 35% liquor at 213° and continues its passage to the generator by mixing with the strong liquor in the upper strong liquor pan. In the meanwhile the ammonia vapor at 120° entered the condenser from the rectifier and was cooled to 90° and condensed to practically pure anhydrous ammonia at 90° and 170 pounds pressure by giving up its heat to the condensing water in heating it from 70° to 80°, and so, as 90° liquid ammonia at 170 pounds pressure it flows to the expansion valve and the cycle is repeated.

CHAPTER VIII.

Further Details for Complete (Wet Absorption) System—Pressure Gauges, Gauge Glasses, Purge Valves, Charging Valves, Draw-off Connections, Hydrometers, Proper Strength of Strong and Weak Liquors, Thermometers, Water Supply Refrigerators, Brine Coolers, Weak Liquor Coolers, Condensers, Rectifiers, Exchangers, Etc.

The various different parts of the absorption machine should have pressure gauges as follows: Steam gauge for pressure in generator coils, ammonia gauges for pressures in generator, condenser, refrigerator and absorber. These gauges should be accurate and frequently compared and tested with a certified test gauge. Very few gauges are correct for all readings even if correct at atmospheric pressure; the corrections to apply to the various gauge readings should be tabulated and known. Gauges often get out of order and do not properly indicate pressures, and errors of from five to fity or more pounds often occur in their readings. These gauges should all be mounted on a gauge board in the most prominent place for the engineer to see them.

Gauges glasses should be provided for all pieces of apparatus wherein it is ever desired to know the liquid level. These gauge glasses should always be protected by automatic self-closing gauge cocks having a positive hand-governed stop valve between the cock and the vessel to be gauged. Means should be employed to determine from time to time whether a gauge glass properly indicates the true level of the liquid in the vessel it governs, for they often become stopped up and so mislead. In apparatus of any considerable size, use two or more sets of gauge glasses, one near the top and one near the bottom, in preference to one very long gauge glass. Glasses over about two feet long should not be used if they can be replaced by two or more shorter gauge glasses.

Purge valves to purge air or liquid should be provided on all parts of apparatus where air can collect or where it may be desired to drain a piece of apparatus for repairs or for any other desired purpose. Charging valves should be provided so that the machine may be charged readily with aqua ammonia, water or anhydrous ammonia. The usual aqua charging connection is shown at *A*, Fig. 12, which is like Fig. 11 except for the modifications shown. The aqua is pumped by the liquor pump direct from the drum through this connection either direct to the absorber or to the generator by a proper manipulation of the valves *c, d, f* and by-pass *a-b*. It is advisable to have a pipe connect the condenser purge, *g*, to the purge *j*, so that air or foul gases can be purged from the condenser into the absorber, thereby saving ammonia that would be lost if purging into the air from the condenser were resorted to.

The purge connection *e*, from the top of the absorber should have a pipe or hose that can be dipped under the surface in a pail of water, so as to purge only air and by the presence or absence of air bubbles in the pail of water know when to stop or how long to continue purging. When purging the absorber a peculiar crackling or buzzing noise is heard when very little air is being purged and a great deal of ammonia is being wasted.

Gases other than air are purged from the absorber, usually hydrogen due to the decomposition of the aqua ammonia in the system. This gas can be purged and lighted by a match and will burn like a gas flame until it is nearly all purged from the absorber.

The aqua ammonia used in charging comes in large drums and is what is known as 26° Beaumé aqua ammonia. It contains about 30%, by weight, of ammonia and 70%, by weight, of water. According to the conditions and pressures under which the machine will operate it will be necessary to add some distilled water or some anhydrous ammonia to the system to give the proper and most economical strengths of strong and weak liquors for operation. If distilled water is to be added it can be done just as the aqua ammonia was added through connection *A*. And this distilled water can be taken from the condensation from the steam coil of the generator, provided it is free from oil.

In charging anhydrous ammonia into the system it can be done either at *k* or *m*. The author prefers to do it at *k*, connecting the anhydrous ammonia cylinder to the pipe at *k* and using valve at *k* as an expansion valve and expending the ammonia from the cylinder directly into the refrigerator. Here it does refrigeration as it enters the system, while if charged directly into the absorber at *m* it does no refrigeration and upsets the action of the absorber.

Draw-off connections should be provided for testing the strength of strong and weak liquors; that for the strong liquid is at *A*, the same as the charging connection, if desired, or must be on the pressure side of the liquor pump at *p*, if absorber pressures below the atmosphere are to be used. The weak liquor draw-off connection is shown at *o*. In drawing off liquor for testing its strength at either *o* or *p*, a little liquor should be thrown away first to make sure that none of that which may be dead in the draw-off pipes is taken by mistake.

It is preferable always to draw off these liquors through a little home-made coil of ⅛-inch pipe connected at *o* or *p* and immersed in a pail of ice water. The temperature of the aqua as measured should usually be 60° F, or at the temperature required as per the scale of the hydrometer. If the aqua is too warm or too cold in the hydrometer jar, corrections must be made for its readings, and if the liquor is drawn off too hot part of it will vaporize and so its true strength can not be determined.

The commercial method of determining the strength of strong and weak liquors is by the floating hydrometer, a little glass affair that looks much like a thermometer and is so weighted that it floats in the aqua in a little glass jar. The stem of the hydrometer is graduated much like a thermometer and the readings on the scale either directly give the strength of the aqua in percent or give results whereby the strength is determined by reference to certain tables. Most hydrometers are graduated in Beaumé degrees, an arbitrary and useless scale for our purposes, other scales are divided into true specific gravities as say .8, .9, etc. Other scales are also used, all of which must be referred to proper tables and the corresponding per cents of ammonia determined therefrom unless one is so fortunate as to get a hydrometer that reads directly in per cents, which is the only proper one for our purposes. These hydrometers should be obtained from reliable dealers, and care should be taken in using them that they do not touch the sides of the glass jar, are not greasy and do not have air bubbles in contact with their stems when immersed in the aqua in the hydrometer jar.

All glass floating hydrometers are valuable only for approximate commercial purposes and are not exact enough for test purposes where any reasonable degree of accuracy is required. Where such accuracy is required a Westphal Balance should be used, a description of which can be had from a dealer in chemical apparatus. Some very fine exhaustive tests of absorption machines by good authorities are absolutely worthless in many respects because of failure to properly measure the strength of strong and weak liquor.

The proper strengths of strong and weak liquors are governed by four factors, 1st, absorber pressure, 2nd, generator pressure, 3d, steam pressure in generator coils, 4th, speed of liquor pump. The strength of strong and weak liquors should be such that the combined capacity and economy of the generator and exchanger is at a maximum. Without now attempting to tell why, the rule is given as follows: Have the difference in strengths of strong and weak liquors such that between seven and eight pounds of strong liquor is pumped by the liquor pump for every pound of anhydrous ammonia evaporated in the refrigerator. The strong liquor should be as strong as possible and should correspond with its temperature and the absorber pressure (see aqua ammonia tables), the weak liquor should be as weak as possible and should correspond with its temperature and the generator pressure.

In most plants the strength of the strong liquor is fixed by the desired absorber pressure and temperature of absorber water available, and the generator pressure is fixed by the temperature of the condenser water, so that the variable quantities to adjust are steam pressure in generator coils and speed of liquor pump.

The formula for determining the required strengths of strong and weak liquors to give 7.5 pounds of strong liquor pumped by the liquor pump to one pound of anhydrous ammonia evaporated in the refrigerator is as follows: Let a be a decimal representing the strength of weak liquor as $.20 = 20\%$ and c a decimal to represent the strength of the strong liquor as $.30 = 30\%$; then make c and a so that the following equation holds good: $7.5 = \frac{1—a}{c—a}$. For example, if the strongest strong liquor obtainable is 30% then $c = .30$, so substituting the value .30 for c in the equation we have $7.5 = \frac{1—a}{.30—a}$ and solving for the value of a we get $2.25 — 7.5a = 1 — a$, $1.25 = 6.5a$, $a = 1.25 \div 6.5 = .1925$, or, practically, $a = 20\%$.

Many machines now in operation can have their capacity and economy increased from ten to thirty or fifty per cent by operating them according to this rule, provided the previous instructions for operation of rectifier are also followed.

Various thermometer wells should be provided in the different parts of the apparatus, but their number and location will largely depend upon the engineer in charge and his desire to get the best results from his machine for the least steam used in the generator. If such thermometers are used—I will not now attempt to tell how or where to use them—their indications are not of much value when the machine is once in best working order, but they are most essential to so get it in best working order, and are often required to find out just what the matter is when the machine is not working properly.

The water supply is most important. The cost of the water, or the cost of pumping it, must be put against the saving in economy in the operation of the machine to determine how much water to use. Usually two gallons of water per minute per ton of refrigeration for all purposes is sufficient, more would be better, but just how much more depends upon conditions and the design of the machine. If low absorber pressures are desired, first pass all the water through the absorber; if the reverse, first pass all the water over the condenser. Usually use the water in tandem, through the condenser and absorber or through the absorber and condenser. Then take the water from the final apparatus, the absorber or condenser, for the weak liquor cooler and rectifier. Sometimes it is best to put part of the water to the condenser and part to the absorber, but here again each case should have the most careful study, before the machine is contracted for if possible, or afterwards if not, to determine just how best to use the available water supply which may make a difference of from ten to thirty per cent or more in the capacity and economy of the machine.

The author will not, in this elementary work, go into a discussion of the various and many types of condensers, and refrigerators, for that should be taken up in a more advanced treatise. Of the two types of refrigerators one most often meets, the direct expansion coil in the most common, and for absorption machines it should always be designed for downward expansion, *i. e.,* the liquid ammonia coming in at the top so as to purge the watery ammonia out at the bottom with the vapor. Shell and coil type of coolers require much attention as to operation of rectifier and often require frequent purging of watery ammonia from them. Almost any design of condenser is all right, if large enough, provided it does not hold up the amomnia in its coils or let it down in gulps.

Very few people will ever have anything to say about what kind of an analyzer they will have as that is usually a fixed part of a standard machine. The best rectifier is of the atmospheric or coil type, and has the hot gas going in at the bottom and the cold gas coming out at the top. It should be so designed as to give the hottest possible drip liquor. The exchanger has been discussed before at length. The exchangers of the shell and coil type are most used, but double pipe exchangers give excellent results provided they can be kept tight. The weak liquor cooler is much like an atmospheric coil condenser, should have the liquor go in at the bottom and out at the top, and in some types of machines to be described later it is entirely dispensed with.

CHAPTER IX.

Generators and Absorbers—Liquid Surface in Generators —Length of Steam Coils—Boilovers of Generators— Best Temperature of Strong Liquor from Absorber.

The generator, which is often called the still or ammonia boiler, is of several different types as built by the leading absorption machine builders. The oldest steam coil type is much like a vertical steam boiler except that the heating is done in spiral coils of pipe, by steam, in place of by fire. This type of generator is shown in Fig. 13, and consists of a shell, *A*, carrying the analyzer, *B*. There is a nest of several close-wound spiral coils made from extra strong pipe, welded into continuous coils, one of which is shown at *e-g*. The steam inlet ends of these coils, corresponding to *e*, are gathered together into a steam header and the condensed steam ends, corresponding to *g*, are gathered together into a condensed steam header. The aqua flows down from the lower pan *a*, of the analyzer to the liquid surface *S* in the generator and this aqua circulates down between the coils and out at weak liquor outlet *d*.

The vapor rises from the liquid surface *S* and passes up into the analyzer *B* through spaces *c, c* as shown by the arrows. In this type a great deal of heating surface of the steam coils is used for a very small liquid evaporating surface, *S*, the consequence being that a large part of the heating surface of the coils can not be used to advantage because, if forced, the formation of vapor not only occurs at the liquid surface *S* but also below it and next to the coils, with the result that the whole mass soon fills with vapor bubbles and then the so called boil-over occurs. That is, all the liquid in the generator goes over with a surge into the condenser and naturally the whole system is upset until purged out and started into proper operation again. Even if a complete boil-over does not occur, it partially occurs from time to time, as splashes, so that watery ammonia results in the condenser and the capacity of the machine is diminished.

This type of generator is not much used today in new installations, but is being replaced by the horizontal type of generator having ample liquid surfaces. The horizontal type of generator is shown in Fig. 14, and usually consists of two domed heads, *B* and *C*, a shell *A*, and an opening in the shell to take the analyzer, *D*. The lower pan, *a*, of the analyzer is usually provided with gas passages, *c c*, and a trap, *b*. The aqua flows through the trap *b* into one end of the generator and circulates between the steam coils to weak liquor outlet *d*, *e*. The steam coils are of two different types in the two leading makes of horizontal generators, one type has fittings and straight pipe, the other has continuous pipe in oblong coils. These coils have steam inlets, *g*, *h*, and condensed steam outlets, *i*, *j*, and are supplied with steam from steam header, *f*, *g*, *h* and discharge the condensed steam through the condensed steam header *i*, *j*, *k*. It is important that these coils should drain properly and that they should not have too much length in a single coil, for, if they do, they lose part of their value by being partly filled up with condensed steam.

A modification of the horizontal type of generator is shown in Fig. 15. This type is made by a well known builder and is like a tier of three horizontal generators piled one on top of the other. The liquid circulates from the highest through the middle and out of the lower section. The author could never see any other advantages in this type than those of getting a large total liquid surface, *S*, in smaller diameter of shells and getting rather better circulation of the liquor in the generator because of its smaller cross section. This latter point might, if the steam coils were not too long, make a square foot of coil heating surface in the generator more effective than one in a generator having slower liquid circulation. Another point claimed by the builders is that exhaust steam can be used in the upper section, *A*, to good advantage while live steam is used in the lower sections, but all these points should be established by the builder and attention is called to them only for what they may or may not be worth.

This type of generator consists of the three sections *A, B, C* joined together as shown and carrying the analyzer *D*. The aqua flows from lower pan *b* into hollow cone, *a*, and out the little openings, *d*, in the bottom of cone *a*, through section *A*, out outlet *e*, through pipe *e, f* into section *B*, through section *B*, overflowing into passage g, and into section *C* through outlet of passage *h*, and through section *C* and out weak liquor outlet *i, j*. The vapor passing from the various sections as shown by the arrows through passages, *s, r*, and up into the analyzer *D* through passages *c, c*.

There are one or more steam coils in each of sections *A, B, C*, and they have steam inlets and condensed steam outlets connected to steam header *k, l, m, n*, and they have condensed steam outlets connected to condensed steam header, *o, p, q*.

There are various types of absorbers, but the leading types are the wet absorber, the wet-and-dry absorber and the dry absorber. The wet absorber was diagramatically shown in Fig. 12 and is constructed, approximately, in the manner shown in Fig. 16. This wet absorber consists of a shell *A*, domed heads, *B* and *C*, and a nest of continuous welded spiral pipe coils, one of which is shown as *D-E*. The gas usually enters through a pipe *c*, terminating in one or more perforated cross arms, *d*. The water enters at *D* and leaves the coil at *E*, so that the coldest water is next the strongest liquor. The weak liquor enters at *a* and the strong liquor leaves at *b*, the gas leaving *d* bubbles up through the liquid in the absorber, is absorbed therein and the heat of absorption is taken out by the cooling coil *D-E*. This type of absorber is also constructed with straight tubes in place of spiral pipe coils and may also be of the atmospheric or of the double-pipe type.

A modification of the wet absorber is the wet and dry absorber which is shown in Fig. 17. Here the shell, *A*, heads, *B* and *C*, and coils, *D*, *E*, are as in Fig. 16, the only difference being that some form of weak liquor distributing device is used, as perforated pan, *F*, to spray the weak liquor over the cooling coils *D-E*. It is plain that here the absorber is not full of aqua as it was in Fig. 16, the greater part of the absorber is what is called dry, that is, the gas from pipe *c*, after leaving the perforated pipe *d*, bubbles up through a little strong liquor, being partly absorbed therein, and then is absorbed on the surface of the film of aqua trickling over the coils *D-E*, from the perforated pan *F*. The weak liquor enters at *a* and the strong liquor discharges at *b*. This type of absorber can also be built with straight tubes or be of the atmospheric or double-pipe type.

The dry absorber is shown in Fig. 18. It too has the same style shell, *A*, and heads, *B* and *C*, as in Figs. 16 and 17, and also the same style coils, *D-E*. Here the gas enters the shell through pipe *c*, either directly as shown, or is distributed in the shell through various arrangements of pipe as desired, all of which the writer thinks is much a matter of fancy and not important except that it must be remembered that the gas entering the absorber through pipe *c* is very cold and it must not get into too close contact with the water coil *D-E*, or it will freeze the water in it and so burst it. This form of absorber is called the dry absorber because it has practically no liquid body of aqua in it. The weak liquor usually comes in in some kind of a spray device and through pipe *a*, and sprays so that it falls like rain on a perforated plate *F*, and from the perforations in the plate *F*, it drips and trickles down over the coils *D-E* and absorbes the vapor in contact with it. It is wise to have a few turns of the coils *D-E* immersed in the strong aqua so as to cool it a little below its boiling point and so prevent the liquor pump from "kicking," as otherwise the reduced pressure in the liquor pump cylinder will pull the vapor out of the strong liquor, just as a pump that pumps hot water will do unless it has sufficient head of hot water to overcome the difference in pressure due to suction. The dry absorber can also be built with straight tubes or be of the atmospheric or of the double-pipe type.

The builders of the dry absorber and the combined wet and dry absorber, do not use any weak liqur cooler at all, and, personally, the writer sees no reason to use them in any type of machine, for the work they do can just as easily be done by a little more coil surface in the absorber, and so avoid an extra piece of apparatus to be cared for and looked after.

The absorber can combine all the types described, or any two of them and its structure and modifications are endless, but all involve one or more of the three types described. In operating the absorber, the highest possible absorber pressure should be carried, for the refrigerator temperature required, in order to give the capacity desired, the temperature of the strong liquor from the absorber should be as high as possible, so long as the liquor pump does not kick, for it should be remembered that for every degree the strong liquor is colder than it should be, there will be required just so much more steam in the generator to reheat the strong liquor. Dry absorbers give stronger liquor for the same coil surface used than do wet absorbers. Some people have used the weak liquor as a forcing agent through an injector to suck and carry the gas from the refrigerator into the absorber and to attempt thereby to get a higher absorber pressure. The value of such a method is a point well worth investigation by experimenters.

CHAPTER X.

Complete Dry Absorber Cycle—Steam Reducing Valve—Condensed Steam Receiver.

The next to consider will be an absorption machine cycle similar to the wet absorption machine as shown in Fig. 12, but with the dry absorber and without any weak liquor cooler, and with a few other modifications. Such a system is shown in Fig. 19 and with the modifications above mentioned is like the one shown in Fig. 12. The complete cycle of operation for Fig. 19 (the empty or dry absorber type) is as follows: Anhydrous ammonia at 90° and 170 pounds pressure, flows through the expansion valve, where it is partly evaporated by reducing its pressure to fifteen pounds and its temperature to 0°. Now the 0° and 15-pound pressure anhydrous ammonia boils and evaporates in the refrigerator by the heat taken up in cooling the brine from 20° to 10°. The ammonia vapor so formed flows to the absorber, as shown by the arrows, wherein it diffuses itself and is absorbed by the aqua trickling over the cooling coil, the heat of absorption being taken up by the cooling water circulating through the cooling coil, which heats this water from say 80° to 90° F.

The resultant 35%, 101° strong liquor at fifteen pounds pressure now flows to the liquor pump by which it is pumped into the pipe leading from the liquor pump to the exchanger and at a pressure equal to that in the generator, plus the friction in the pipe to the exchanger and in the exchanger and of the hydraulic head to be overcome. This 35%, 101° strong liquor now flows through the shell of the exchanger, is heated by the hot weak liquor to 213° and at this temperature, which is the boiling point of 35% aqua at the generator pressure of 170 pounds, it flows into the top strong liquor pan of the analyzer. From this pan it overflows and successively fills and overflows the several pans below during its passage through the analyzer to the generator, being heated and thus partly evaporated on this passage by the hot gas from the generator in its passage up through the analyzer.

The liquor now flows into the generator through the short pipe from this lower pan of the analyzer as, say 34% liquor at 216°, and flows through the generator in contact with the steam coil so that it is partly evaporated and raised in temperature to 253° and thus reduced in strength to 25% liquor. The heat so taken from the steam condenses the steam in the steam coil of the generator. This 40-pound, 286° steam enters the coil either directly at boiler pressure or through a reducing valve, as shown, flows through the coil and is condensed and flows by gravity out of the lower end of the coil, as shown, into the condensed steam receiver.

This condensed steam receiver should be on every type of machine and should have a gauge glass and the condensed steam level should always be kept in sight in this glass, for otherwise either the steam coil will fill up with condensation and so cut down the capacity of the machine, or steam will be thrown away and needlessly wasted. It is wise to have an air vent, as *r* on the top of this condensed steam receiver, and to vent air from it once in a while, or better still run the connection from the air valve, *r*, to feed this air and some steam to the steam valve of some auxiliary pump. Many a boil-over occurs by letting the steam coil fill partly with condensed steam and then suddenly letting the condensed steam out, and so greatly increasing all at once the heating effect of the steam coil. The condensed steam is now passed, either through a throttling valve into a reboiler, for ice making, or into the atmosphere, or is pumped back into the boiler, or, if the generator is at a higher elevation than the steam boiler and if the boiler pressure is the same as the steam coil pressure, it is returned directly by gravity to the steam boiler.

Now the 25%, 253° weak liquor flows up the pipe in the generator, as indicated by the arrows, and flows through the exchanger, being cooled to 125° by giving up part of its heat to the strong liquor. Then the 25%, 125° weak liquor flows past the regulating valve* into the absorber through the perforated spray pipe, as shown, and through the perforations, so that it falls as rain over the cooling coil, and trickles down over it, gradually absorbing more and more ammonia vapor and giving up the heat of absorption to the cooling coil so that it becames 35%, 101° aqua in the bottom of the absorber and is ready to again repeat the liquor pump cycle as before explained.

In the meanwhile the 242° gas, with say 11% water vapor in it, from the generator, has started up through the analyzer as is shown by the arrows. This gas is cooled and partly rectified and so deposits some of its water and some ammonia on the under side of the analyzer pans, so that this condensation drops off the bottoms of the pans into the strong liquor and returns with it to the generator. This gas is thus cooled in the analyzer to say 228° with say 8% of water vapor left in it after having left the underside of the upper strong liquor pan, and after having been joined by some additional gas evaporated from the strong liquor in the pans.

*The automatic weak liquor regulator valve of Fig. 12 is omitted, but one of that type or one to govern the speed of the liquor pump can be used if desired, governed by a float in the strong liquor, usually in a little vessel outside of the absorber.

Now this gas comes in contact with the bottom of the drip liquor pans (only one here shown) that are conducting the drip liquor from the rectifier to the upper strong liquor pan, and is still further cooled to say 220° and after joining the vapor from the drip liquor pan is further reduced in temperature, by mixture, to say 216°. This 216° gas goes to the rectifier, where it is still further cooled by heating the rectifier water from 80° to say 140°, and this gas finally leaves the rectifier at 120° and is practically pure anhydrous ammonia, after having deposited practically all its water vapor which was condensed in the rectifier and which later reabsorbed ammonia gas due to its (the liquid's) pressure and temperature.

This drip liquor from the rectifier now flows through the trap, as indicated by the arrows, as say 45% liquor at 173° into the top drip liquor pan of the analyzer, wherein it is heated by the gas from the generator, and partly evaporated, so that it flows into the top strong liquor pan of the analyzer as say 35% liquor at 213° and continues its passage to the generator by mixing with the strong liquor in the upper strong liquor pan. In the meanwhile the ammonia gas at 120° entered the condenser from the rectifier and was cooled to a vapor at 90° and condensed to practically pure anhydrous ammonia liquid at 90° and 170 pounds pressure by giving up its heat to the condensing water in heating it from 70° to 80°, and so, as 90° liquid ammonia at 170 pounds pressure it flows to the expansion valve and the cycle is repeated.

The various pressure gauges, gauge glasses, charging, purging and draw-off connections were all explained with Fig. 12, and need no further explanation as their purpose in the same in Fig. 19 as in Fig. 12. Care has been taken in explaining the dry absorption machine of Fig. 19 to use the same wording, so far as was possible, as was used to explain the wet absorption machine of Fig. 11, and by now re-reading the description of Fig. 11, the likeness of the two systems in operation is more evident. A study of the absorption machine and its tables of operation as shown in the author's book, "Refrigerating Machines, Compression, Absorption," will give much further light on some of the actions in the absorption machine.

CHAPTER XI.

General Construction and Parts of the American Absorption Machine—Lower Temperatures Obtainable by Aid of Absorber—Operation of the Plant.

The general construction of the "American" absorption refrigerating machine is of the straight pipe type, as far as possible eliminating round and bent pipe coils. There are no movable parts except the aqua ammonia pump. No oil is required except the small amount necessary for lubricating the movable parts of this pump.

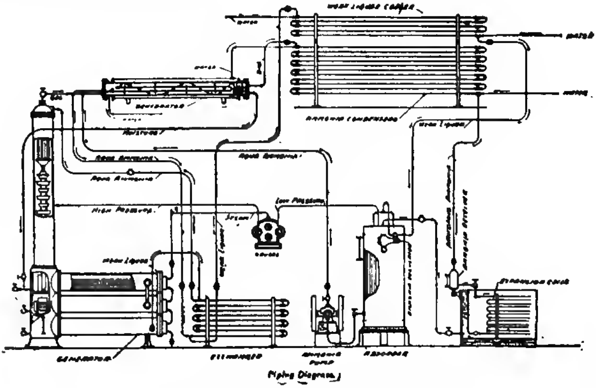


FIG. 20.—AMERICAN ABSORPTION MACHINE SHOWING PRINCIPAL PARTS.

The principal parts of the machine are shown in the diagram, Fig. 20, and consist of absorber, ammonia pump, generator, exchanger, dehydrator, weak liquor cooler, condenser, expansion coils and ammonia regulator.

In operation the aqua ammonia, or strong liquor, is pumped from the absorber into the generator, passing on the way through the exchanger or equalizer where it is partly heated by the returning hot weak liquor from the generator. The generator is a heavy vertical cast iron cylinder or cylinders, the number depending upon the capacity of the machine, which form a part of the apparatus. On top of the vertical tube, a standpipe is mounted, the top section of which contains the rectifier coils and immediately below these are the analyzer pans.

The rectifier consists of a number of straight pipes through which the strong ammonia liquor, which is forced in at the top, passes on its way to the evaporating coils of the generator.

In going down the rectifier pipes the cold strong liquor is surrounded by the hot gas rising from the evaporating pipes of the generator, cooling this gas and causing the moisture rising with it to condense upon the cold surfaces of the rectifier pipes and flow by gravity to the analyzer.

The analyzer consists of a number of perforated cast iron pans of varying sizes down through and over which the strong ammonia liquor is precipitated. The stream of aqua being thus finely divided, rapidly absorbs heat from the rising ammonia gas, so that it enters the evaporating cylinders of the generator at a temperature which greatly expedites evaporation.

The evaporating cylinders of the generator contain coils of extra heavy pipe through which steam is circulated and around which the strong, already partly heated, aqua ammonia flows. The heat of the steam quickly drives off from the strong liquor, the major portion of the contained gas, which rises upward through the standpipe and around the analyzer pans and rectifier coils as already explained.

After passing the rectifier, however, the gas still holds entrained some moisture and in order to remove this, the gas is passed through the dehydrator.

The dehydrator is of the horizontal shell type, and contains a coil through which the cold aqua ammonia from the absorber is passed on its way to the generator. Around this coil is a large pipe or shell supported by baffle plates. This larger pipe or shell is set in a steel trough where it is cooled by a portion of the waste water from the condensers. The flow of gas from the generator passing through the dehydrator is retarded by the baffle plates and cooled by the cold surfaces of the rich liquor coils and the cold walls of the shell, causing the moisture to precipitate. The moisture flows by gravity to the generator and the gas, now freed from moisture, passes on to the condenser where it is liquefied.

The steam after it has served its purpose in the generator is condensed and used to fill the ice cans, in the case of ice making plants; but in refrigerating plants it is trapped back automatically to the boiler as boiler feed.

The ammonia condensers are made either of the double-pipe type or of the submerged or atmospheric types.

The weak liquor cooler is constructed like the double-pipe ammonia condenser of small inner pipes enclosed in larger outside pipes, the weak liquor flowing through the inner pipes and the cooling water through the annular space between the inner and outer pipes.

The exchanger or equalizer is of the double coil type. It is built of extra heavy pipe and fitted with extra heavy headers and return bends and arranged so as to allow a counter-current circulation through both pipes at the same time. The cool aqua drawn from the absorber is forced under pressure through the inner pipe of the exchanger and the hot weak liquor from the generator, also under relatively high pressure, passes through the annular space between the pipes the two currents running counter to one another exchanging temperatures. The hot weak liquor thus partly cooled passes from here to the weak liquor cooler.

The ammonia pump is of heavy double fly-wheel type made to run at a speed of about twenty-five revolutions per minute. The stuffing box on the ammonia cylinder is set in a water chamber, so that the water surrounding the piston rod furnishes constant lubrication and prevents leakage of ammonia through stuffing box.

The absorber is of the vertical type, made of boiler steel and is fitted with small straight tubes in place of coils; the tubes ordinarily used are of 1½ inch diameter and galvanized. When the liquefied ammonia from the ammonia condenser and liquor receiver, has accomplished its refrigerating service in the expansion coils, it is passed to the absorber, where it unites with or is absorbed by the weak liquor flowing from the weak liquor cooler and forms strong ammonia liquor to be used over again in the generator, dehydrator and condenser and evaporator as before.

Much lower temperatures are obtained with an absorption machine because of the fact that lower back (or suction) pressure is maintained by the aid of the absorber. Zero back pressure can be maintained as readily as 15 pounds back pressure, and since ammonia at 0 pounds back pressure boils at 29 degrees below zero, a much lower cooling effect is obtained than is possible at 15 pounds back pressure at which point ammonia boils at 1 degree above zero; a difference of 28 degrees in favor of the lower back pressure, which can be maintained very economically by the absorption machine, and is a great advantage over other types of machines.

Cooling water enters the absorber at the bottom and flows through the small straight tubes to the top where it overflows. The weak liquor enters the absorber at the top as does also the gas. In order to control the flow of weak liquor coming from the generator, through the exchanger and weak liquor cooler, a special patented automatic ammonia regulator is connected to the absorber.

In ordinary operation the weak liquor leaves the generator at a pressure of approximately 150 pounds, while the gas admitted to the absorber is under a pressure varying from five to fifteen pounds. The returning weak liquor will absorb from 27% to 29% of its weight of ammonia gas, but in order to accomplish this it is essential that the pressure of the incoming fluid and that of the incoming gas be equal. This is automatically performed in the regulator by means of a float valve and float chamber, attached to and connected by a pipe with the interior of the absorber. When the flow of weak liquor into absorber reaches a height where the pressure exceeds that of the incoming gas, the float is raised and shuts off the supply. When the float descends the liquid admission valve opens. The regulator can be adjusted so as to carry the required height of liquid in absorber and generator for most efficient operation. The adjustment can be done while the machine is in full operation and without disconnecting any parts.

CHAPTER XII.

How Refrigerating Machines Work—Description of the Carbondale Machine, Including the Tubular System, and the Atmospheric System—Type to Use—Advantages.

The cooling effect in refrigerating machines is produced by the evaporation of ammonia or some other substance. Ammonia gas can be liquefied in a condenser, or cylinder, if subjected to a pressure of from 100 to 200 lbs. per square inch while cooled to about 70° F. by water cooling coils. This liquid flows through a throttling valve into a vessel, or cooler, at much lower pressure, where brine, or some substance inside pipe coils, is cooled by this evaporating liquid, which must be redelivered to the condenser under pressure to be once more condensed by cooling water so it can expand again. Thus the same ammonia is constantly used over and over again.

There are two methods of drawing the gas out of the cooler and delivering it under pressure into the condenser, the compression and the absorption systems.

In the compression system a compressor, or gas pump, can be used to draw the ammonia gas out of the cooler and pump it into the condenser and this system is therefore composed of four main parts:

Compressor.

Engine to drive compressor.

Condenser cooled by water coils.

Cooler warmed by brine coils (that is, the brine is cooled by the ammonia).

In the absorption system the ammonia gas is drawn out of the cooler by the absorbing action in the absorber where the gas meets weak aqua ammonia which flows over from the generator, dissolving this gas and making strong liquor, which is pumped by an aqua pump into a generator or still, where the solution is heated by steam, and the gas is driven off under pressure into the condenser, where it is liquefied the same as in the compression system, and from whence it expands into a cooler to produce the cold again.

The Carbondale absorption system consists of the following principal parts:

Generator with steam coils for driving off gas under pressure.

Condenser with water cooling coils to liquefy gas coming from the generator.

Cooler with brine coils.

Absorber, where the liquor flowing over from the generator absorbs the gas coming from the cooler, forming a strong solution.

Ammonia pump to pump this strong solution back into the generator to be redistilled.

Exchanger, to cool the weak liquor flowing from the generator to the absorber by the cold strong liquor pumped from the absorber to the generator.

Water will absorb 1,000 times its volume of ammonia gas, hence a very small aqua pump is required, in fact a compressor to handle the gas (without first dissolving it in water) must be about 80 times as large.

Heat is needed in the generator to distill off the ammonia, but any waste heat like exhaust steam can be used, while the compression system requires power from a steam engine, gas engine, electric motor, etc.

The absorption system cannot be run by mechanical power and hence cannot be operated by electricity, but there is an enormous field for it in utilizing waste heat.

CONSTRUCTION OF PARTS.

The Carbondale Absorption Refrigerating and Ice Making Machine can be operated by either live or exhaust steam or waste heat, 212° or hotter, and the various parts are constructed as follows:

The generator is of steel or cast-iron, fitted with steam coils.

The rectifier is a coil with patent drips for draining off the moisture and is cooled in a tank of water (submerged type), or by water trickling over it (atmospheric type).

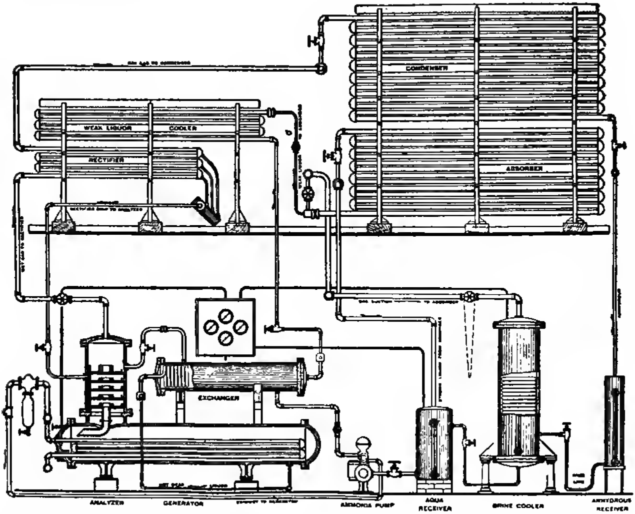


FIG. 21.—CARBONDALE MACHINE—ATMOSPHERIC CONSTRUCTION.

The exchanger consists of a cylinder filled with helical coils or is double tube type (one pipe inside another).

The condenser is of the Carbondale shell type (a cylinder filled with coils), or double tube, or atmospheric type.

The absorber is either the shell and coil type, or horizontal straight tube type, or atmospheric type.

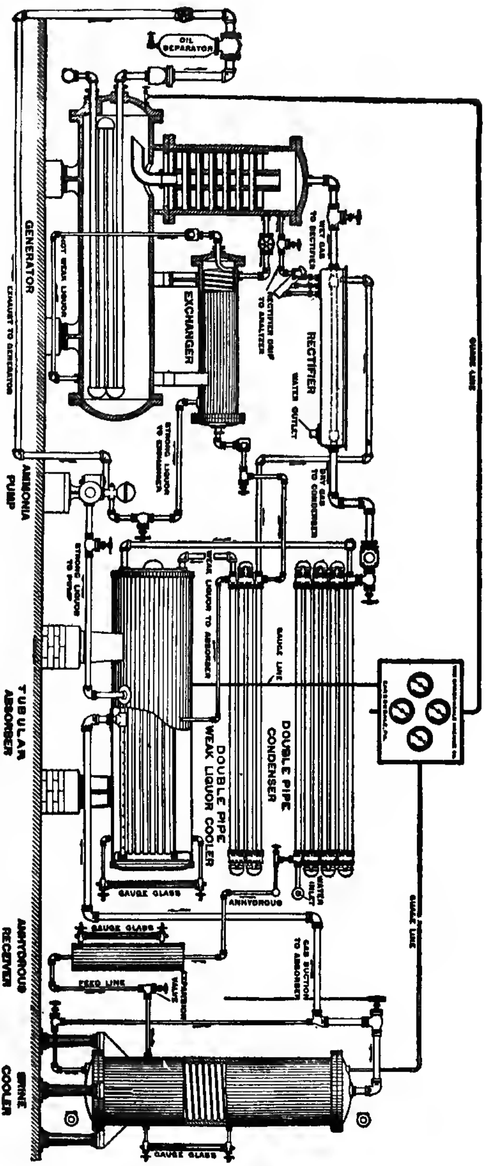


FIG. 22.—CARBONDALE ABSORPTION REFRIGERATING MACHINE—TUBULAR CONSTRUCTION.

The cooler is of the Carbondale shell type, or double tube type.

The ammonia pump is driven by electric motor, belt or steam. Fig. 21 shows the atmospheric type of absorption machine, and Fig. 22 shows the tubular type of absorption machine.

METHOD OF OPERATION OF CARBONDALE MACHINE.

Aqua ammonia, such as can be bought from chemical houses in drums, is put in a horizontal generator, generally pumped in with the aqua ammonia pump after the machine is connected and tight, and this aqua is heated with steam coils to about 220° F., more or less, at which temperature the ammonia gas is driven off and the pressure gradually rises until it reaches about 150 pounds pressure per square inch when it starts to condense in the condenser. If the condenser is of sufficient capacity and the gas is well cooled with the water coils, it is impossible to raise the pressure much above this liquefying point, even though the generator is heated with the steam as hot as possible to force the distillation.

This gas leaving the generator, passes through the analyzer trays where some of the entrained moisture is deposited and then passes through the rectifier where the gas is cooled to about 100° F., which is sufficient to condense the moisture, but not cool enough to condense the ammonia gas. Patent drip pipes drain back this condensed moisture to the generator so that only pure dry gas passes into the condenser, which, as will be seen by the diagram, is composed of a coil of pipe with another coil inside, through which water flows, commonly known as a double pipe condenser. The gas enters the top, flows through the annular space and is gradually condensed by the cold surface of the inside water coil. The liquid anhydrous ammonia which is clear and looks like water, flows down to the anhydrous receiver and when it appears in the gauge glass it is allowed to expand through an expansion valve into the brine cooler at about 15 lbs. pressure, where it evaporates and cools the brine which flows through the coils. This expansion valve is regulated so that only liquid will pass into the cooler. When opened too wide so that the liquid is exhausted, gas will pass into the cooler which has no appreciable cooling effect; in fact if the expansion valve is wide open the ammonia will be merely flowing around without producing any cold whatever.

This liquid in the brine cooler as it is heated by the brine, turns into a gas which must be recovered and delivered again to the generator. For this purpose the outlet pipe is connected into the bottom of an absorber which is kept full of weak ammonia which flows over from the generator and which, when cooled, is capable of reabsorbing the gas that has already been driven from it. This gas has such an affinity for liquor that it often makes a little crackling noise during the absorption which generates heat, and for this reason the absorber is full of tubes through which water flows to keep it cool. This strong solution is pumped back to the generator where it is redistilled. Since the cool liquor in the absorber has to be heated in the generator and the hot liquor in generator has to be cooled before it will reabsorb the gas in the absorber, an exchanger is used to save this heat; in fact, it heats the strong liquor the same as a feed water heater heats the boiler feed water before entering the boiler.

The diagram shows also a double pipe weak liquor cooler where the weak liquor, after leaving the exchanger, is further cooled with water before entering the absorber.

The water for cooling purposes first flows through the condenser, condensing the ammonia, then through the absorber, and then through the weak liquor cooler and rectifier. Generally, cooling water is obtained at about 60° or 70° F., and the temperature on leaving the machine is about 100° F.

ATMOSPHERIC TYPE.

The Atmospheric Type possesses the following advantages:

Where the atmospheric air is cooler than the outlet water, advantage can be taken of the air cooling effect.

If the water is muddy the coils can be easily brushed clean without stopping the machine.

The condenser, absorber, weak liquor and rectifier coils can be placed on the roof, thus saving space in the engine room and requiring a cheaper building.

Any dirt on them can be seen.

They can be galvanized and kept painted so as to protect them from the corrosion of salt water.

TUBULAR TYPE.

The Tubular Type has the following advantages:

All machinery can be placed in the engine room without having any splashing of water.

The water can be pumped through the coils and delivered anywhere without repumping.

There is less pipe surface to renew.

With some kinds of water the pipes corrode and scale less.

TYPE TO USE.

All types of the Carbondale system are designed so they will produce the same results, and that type should be selected which is most suitable for the conditions of operation.

Generally the selection depends on the quality of the cooling water and whether the apparatus is to go in the engine room or on the roof.

ADVANTAGES OF THE CARBONDALE ABSORPTION SYSTEM.

(1) It takes very little steam, viz: 30 lbs. per hour per ton refrigerating effect.

(2) If exhaust steam or waste heat is available it takes no live steam except that required to run the small ammonia pump.

(3) It has no heavy moving parts and cannot be materially damaged by a careless engineer.

(4) It has no oil to clog and insulate the pipes.

(5) It takes a minimum amount of care and attention.

(6) It does not require heavy foundations, can be placed on the top floor of a building and makes no noise or vibration.

(7) It can easily and economically produce low temperatures.

CHAPTER XIII.

Columbus Absorption Machine—Description of Principal Parts—Generator—Ammonia Condenser—Cooler—Absorber—Ammonia Pump—Exchanger—Steam Condenser—Fore Cooler and Distilled Water Storage Tank.

The principal parts of the Columbus improved absorption ice machine are shown in Fig. 23. These parts are the generator, ammonia condenser, ammonia cooler, absorber, ammonia pump, exchanger, steam condenser and feed water heater, and the fore cooler and distilled water tank.

The generator consists of a large semi-steel cylinder, and may be divided into two parts, viz., the bottom half, or generator proper, and the top half, or rectifier. The lower half, or generator proper, contains a series of extra heavy wrought iron pipe coils, the inlets of which connect through the bottom of the generator by a manifold to the steam pipe from the steam boiler. The outlets of these coils are also connected by a manifold to a pipe which returns to the steam condenser. Around these coils is a twenty-six degree aqua ammonia, continuously supplied by the ammonia pump, and from which, as steam passes through the inside of the coils, the anhydrous gas is driven off. This gas then passes to the upper half, or rectifier, which contains a series of deflecting or baffle plates, and, by the arrangement of these deflecting or baffle plates the moisture in the anhydrous gas is taken out, and allows the gas to pass out of the top of the rectifier perfectly dry. From here this gas is taken to the ammonia condensers. This boiling process having taken place, there is left, in the bottom of the boiler, a very weak charge of aqua ammonia (known as poor liquor) which is automatically driven off through the exchanger and cooling coils to the ab-

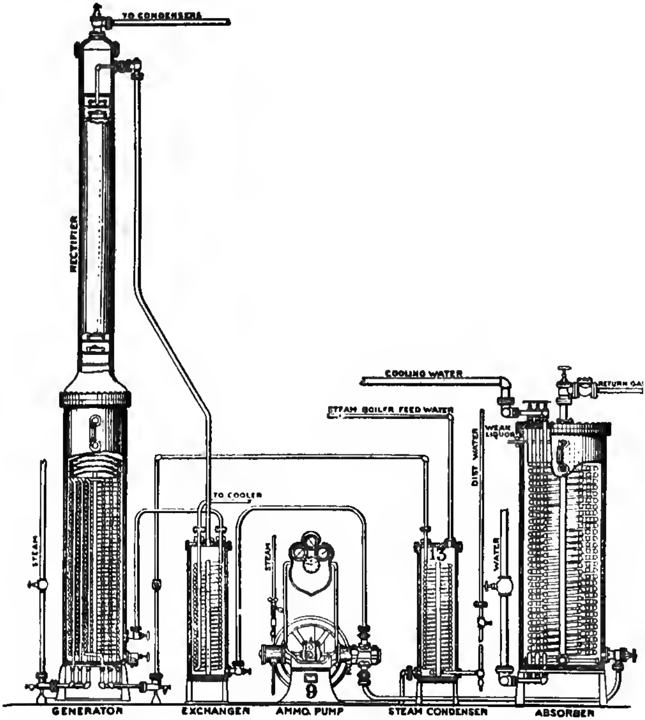


FIG. 23.—SECTIONAL VIEW OF COLUMBUS ABSORPTION MACHINE.

sorber. The steam on passing through the coils in this boiler is next taken into the steam condenser.

AMMONIA CONDENSER.

The ammonia condensers are of two types, viz., submerged and atmospheric. The submerged type consists merely of oblong extra heavy wrought iron pipe coils submerged in an oblong steel tank. The atmospheric is a series of oblong extra heavy wrought iron pipe coils placed on a deck or tower, and by means of sprinkler troughs over the top water is allowed to circulate over the outside of the coils.

The anhydrous ammonia, on leaving the rectifier, passes through these condensing coils and the temperature is reduced below the boiling point of saturated ammonia at the pressure of the ammonia boiler. This leaves the anhydrous ammonia in a liquid state, and it is then passed from these coils to the expansion valve, where it is expanded through the coils in the freezing tank, producing refrigeration. After passing through these freezing tank coils the rich gas is taken through the coil in the distilled water tank, and from there back to the absorber.

COOLER.

The construction of the cooler is similar to the condenser in both the atmospheric and submerged types. Poor liquor being drawn off automatically from the generator through the exchanger, must be reduced in temperature before going to the absorber, as the colder the poor liquor, the more readily will it absorb the rich gas with which it comes in contact in the absorber. This reduction in temperature is accomplished by passing the poor liquor through the cooler coils, over which water is circulated, the same as over the ammonia condensers. From these coils the poor liquor is taken to the absorber and sprayed in at the top.

ABSORBER.

The absorber consists of a large semi-steel cylinder containing extra heavy wrought iron pipe coils, very similar to the generator proper. The gas having been driven out of the aqua ammonia in the generator, and having been condensed and expanded through the freezing tank coils, it is necessary to reclaim it, or mix it again with the poor liquor left in the bottom of the generator, so as to form the original aqua ammonia which is pumped into the generator. Thus the poor liquor is automatically passed through the exchanger and cooling coils, entering the absorber through a spray pipe near the top.

The cold gas from the freezing tank, after passing through the distilled water tank coil, enters the absorber and is sprayed upward through a spray pipe in the bottom of the absorber. In this manner the rich gas is re-absorbed by the poor liquor, and forms the original twenty-six degree aqua ammonia. All of this action takes place in the shell of the absorber, and being a chemical action, heat is generated. This heat is carried off by means of water being circulated through the pipe coils inside of the absorber and leaves a charge of rich ammonia at a temperature below that at which anhydrous is driven out; consequently it is in a complete liquid form, in which shape it is much easier to handle than in gaseous form.

AMMONIA PUMP.

The duplex fly-wheel ammonia pump used is the only moving part of the machine and this is so constructed that either side is sufficiently large to take care of the machine independent of the other, thereby giving practically a duplicate plant. The ammonia stuffing boxes on this pump are of special design, and any leakage that may take place around the ammonia stuffing box is returned through leakage chamber and bypass into the suction line. By this construction it is only required to pack against a liquid instead of gas, and to prevent loss of ammonia to pack only against the suction pressure, ranging from one to twelve pounds. The pump is used for circulating the ammonia, taking its suction from the bottom of the absorber, after the rich gas has been re-absorbed by the poor liquor, and discharging it through the exchanger shell into the top of the rectifier and from there into the ammonia boiler.

EXCHANGER.

The exchanger consists of a semi-steel cylinder containing an extra heavy wrought iron pipe coil, acting merely as an equalizer, or what may be plainer, a feed water heater for ammonia.

The poor liquor coming from the ammonia boiler at a high temperature passes through the coil in this exchanger where it is partially cooled, and from here into the poor liquor cooler coils. The lower the temperature of this poor liquor the less work has to be done in the cooler coils and absorber. The rich ammonia taken from the absorber by the ammonia pump is discharged through the shell of the exchanger, and, of course, the higher the temperature of this ammonia on entering the generator the less work to be done there. Thus the forward flow of rich ammonia is heated, and at the same time the return poor liquor cooled, thus economizing in both steam and water.

STEAM CONDENSER AND FEED WATER HEATER.

The feed water heater consists of a semi-steel shell containing one or more circular coils. The boiler feed pump, taking its suction from the warm water which passes from the ammonia condenser coils, discharges it into the shell of this heater and from there direct to the steam boiler.

The steam from the generator coils, after serving its purpose in boiling the aqua ammonia, passes through the shell of this heater and the same action takes place as in the exchanger. Thus the water going into the steam boiler is heated to a very high temperature, and at the same time the distilled water is condensed and stored in the distilled water tank. This also is a saving in fuel as well as condensing water.

FORE COOLER AND DISTILLED WATER STORAGE TANK.

The fore-cooler and distilled water storage tank is a circular tank made of sheet steel and contains two coils. The distilled water after passing from the feed water heater or steam condenser is sprayed into the top of this tank and passes downward over the two coils. Through the top coil is circulated cold water, which carries off a great deal of the heat from the distilled water as it passes over. Through the bottom coil is circulated the return rich gas from the freezing tank, which, though it has performed its work in the freezing tank, is still at a very low temperature, and by passing it through the fore-cooler brings the temperature down to just a few degrees above the freezing point, thus leaving a minimum amount of work to be done in the freezing tank.

In the top of this distilled water tank is placed a large opening, so that any foul gas coming over from the condenser, and which condenses at a lower temperature than the steam, is allowed to pass out into the atmosphere. This tank is also fitted with a gooseneck water sealed overflow pipe, so that, if for any reason, the ice cans in the freezing tank are not filled, surplus distilled water can be carried off and either allowed to go to waste or stored in an auxiliary tank. This prevents any undue pressure in the distilled water tank, or the backing of the distilled water into the steam condensers.

As a summary, the operation of this machine may be defined as follows:

Steam admitted to coils in the ammonia boiler drives off the gas, which ascends through the rectifier where it is dehydrated. From there this gas passes to the condenser, is liquefied, and then expanded into the freezing tank coils. After passing through these coils it goes through a coil in the distilled water tank, and thence to the absorber where it is re-absorbed by the poor liquor returning from the ammonia boiler, which poor liquor has first been cooled by passing through poor liquor cooler and exchanger coil. This enriched liquor is then pumped through the exchanger shell to the ammonia boiler, and commences the same continuous cycle of operation again.

CHAPTER XIV.

Description of Polar Absorption Machine—Various Parts of Machine—General Construction—Operation—Efficiency—Installation.

The Polar Refrigerating Machine, of the absorption type, consists of a still for evaporating dry ammonia gas from a solution of aqua ammonia; a condenser for liquefying the gas; a brine cooler, expansion coils or other apparatus in which the liquid ammonia expands again into a gas, thus producing the cold; an absorber in which the gas is absorbed by weak aqua ammonia from the still, which is thereby enriched, and an ammonia pump which returns the rich liquor from the absorber to the still, in order that the gas may be re-evaporated, thus making a continuous process.

The generator, analyzer, rectifier and heater or exchanger form the still in Fig. 24, which shows a diagram of the machine. The charge of aqua ammonia in the generator is heated by steam passed through coils *A*. The latent heat of the steam is the principal factor used for this purpose, the steam being condensed in the coils from which it may be trapped and returned to the boiler at practically the temperature corresponding to the pressure under which it is condensed. The heat derived from the steam drives the ammonia gas out of the solution under pressure and it passes upward through the analyzer where any water held in suspension is removed by a series of trays which act as baffle plates. The gas then passes to the rectifier through pipe *B* where any moisture is condensed, trap-

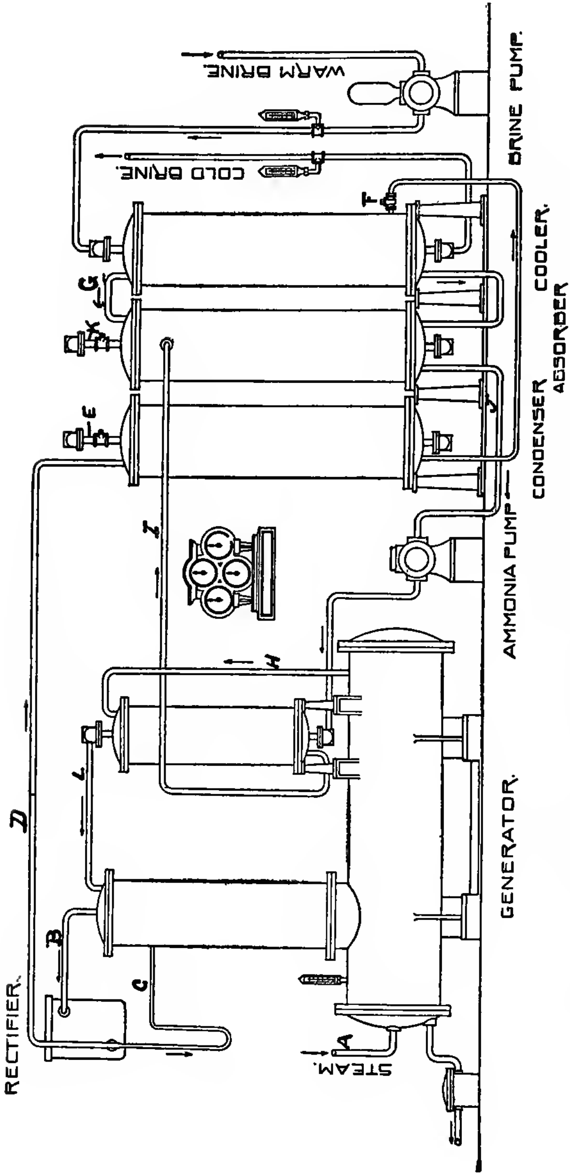


FIG. 24.—DIAGRAM OF POLAR ABSORPTION MACHINE, ARRANGED FOR BRINE CIRCULATION.

ped off and returned to the generator through pipe *C*. In some cases, owing to local conditions, such as the quality of the water, location of the rectifier, etc., atmospheric and double-pipe rectifiers are installed, shown in Figs. 25 and 26, instead of the submerged type shown in Fig. 24. Their operation is similar.

The anhydrous gas thus formed then passes to the condenser through pipe *D*, where it is cooled by contact with the water cooling coils, *E*, and thus liquefied or condensed. Condensers of the atmospheric and double-pipe type, shown in Figs. 27 and 28, are also installed, but they are not as efficient as the shell and coil type of condenser shown. Local water conditions frequently make one of the open types preferable, but it is necessary to allow considerably more floor space for them.

The liquid anhydrous ammonia falls to the bottom of the condenser which serves as a reservoir, or, in some cases, where a condenser of several sections is used, a separate receiver is installed and all sections are drained into it. The ammonia liquid is then conducted by piping to a brine cooler, or some form of expansion coil located in a brine tank or in rooms or boxes to be refrigerated, being fed into the cooler or coils through an expansion or regulating valve *F*, which allows a very fine adjustment of feed.

After passing this regulating valve the liquid may then absorb the heat from the brine, or room, or articles to be refrigerated, and in taking up this heat passes or is changed from the liquid to the gaseous form again. The ammonia, again in the form of anhydrous gas, passes to the absorber, shown in Figs. 24 and 29, by pipe *G*, where it comes into intimate contact with the weak ammonia liquor from the bottom of the generator. The higher pressure in the generator causes the weak aqua, left after the gas is evaporated, to flow through the heater or exchanger to the absorber by

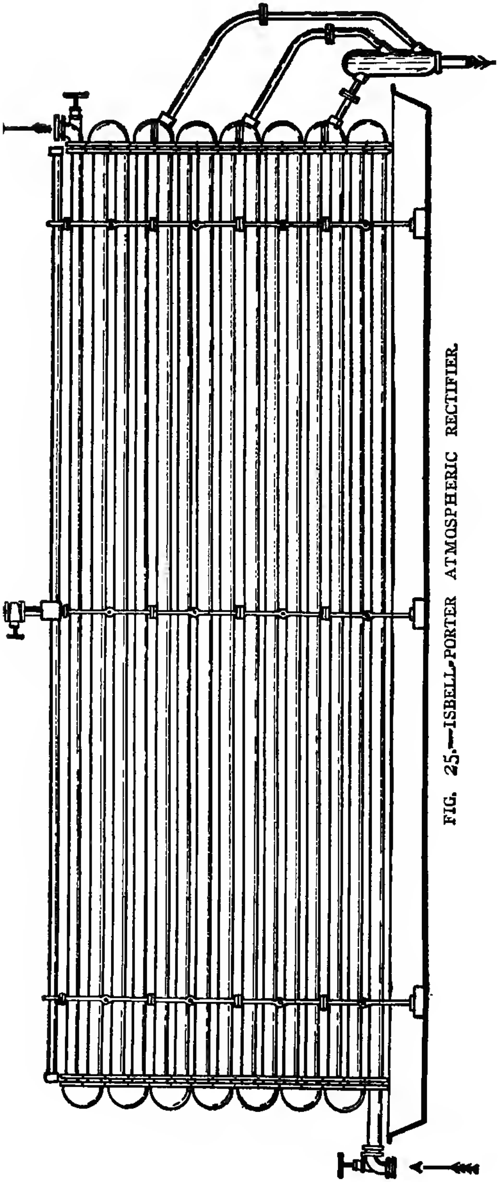


FIG. 25.—ISBELL-PORTER ATMOSPHERIC RECTIFIER.

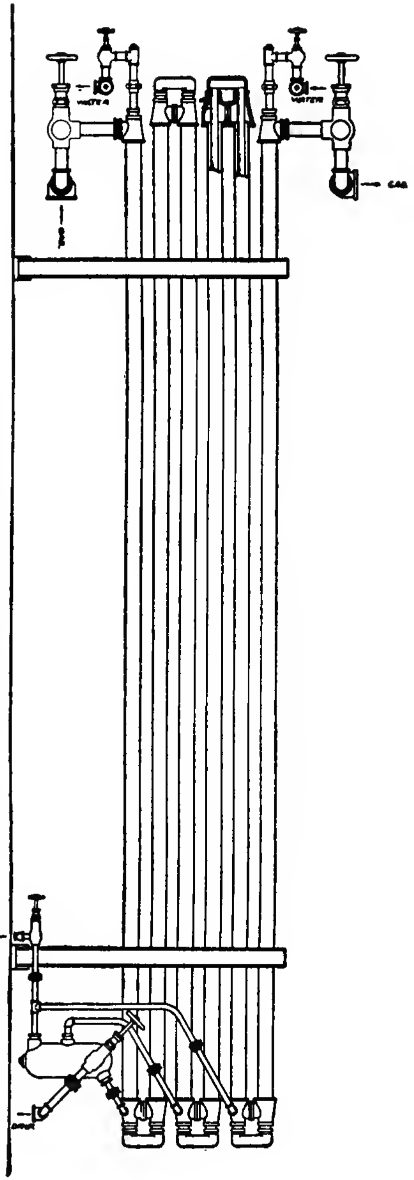


FIG. 26.—ISBELL-PORTER DOUBLE-PIPE AMMONIA RECTIFIER.

pipes *H* and *I*. Upon entering the absorber the weak aqua passes through a regulating valve and it is sprayed out over the cooling coils *K*, through which the cooling water from the condenser is circulated, and which removes the heat generated in the absorber, owing to the absorption of the gas by the aqua ammonia. In some cases the weak aqua on its way to the heater from the absorber is passed through a weak liquor cooler. Horizontal tubular absorbers are also built, for use with salt or scale-forming water, where frequent cleaning is necessary. These are held to be more efficient than the vertical tubular absorbers, owing to the counter current of ammonia and cooling water, but require more floor space.

The rich or strong liquor thus formed in the absorber by the union of the returning gas and weak liquor is then removed by a small, slow-moving ammonia pump, through the pipe *J*, which returns the strong aqua ammonia through the heater to the generator. The heater is simply an economizer, and serves as an exchanger of heat between the strong and the weak aqua, cooling the weak liquor before it goes to the absorber and heating the strong liquor on its return to the generator. From the heater the strong liquor passes to the analyzer through the pipe *L*, and thus flows down through the analyzer trays, being further heated before reaching the generator.

The brine cooler, as its name indicates, is a vessel in which brine is cooled by the ammonia for the purpose of distributing the refrigeration produced by the machine. The shell and coil type, illustrated in Figs. 24 and 30, is the most efficient type of brine cooler made. It consists of a shell with continuously wound coils running through it, the whole vessel being incased in heavy insulation. The brine is pumped through the coils where it is cooled and from there it

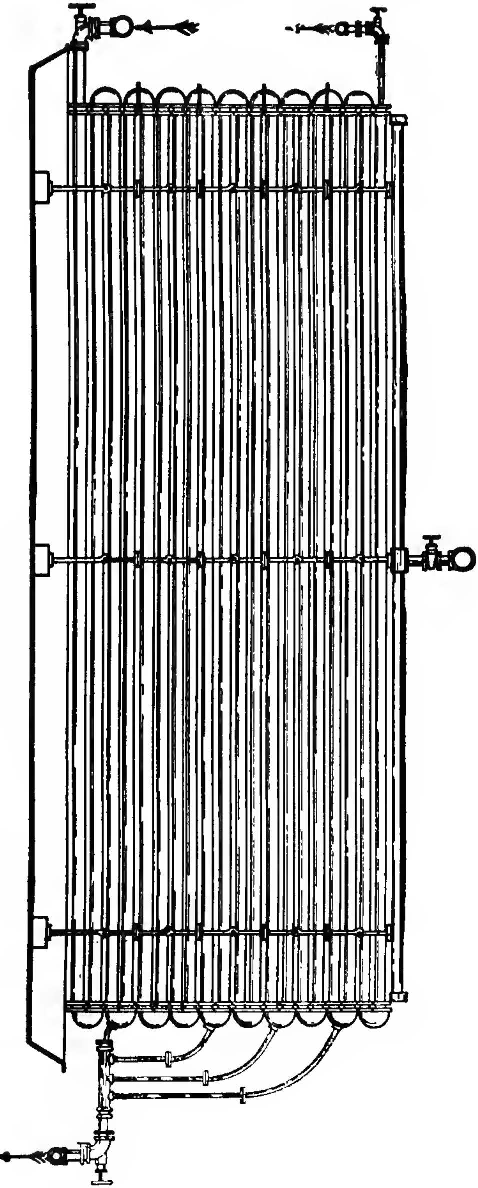


FIG. 27.—ISBELL-PORTER ATMOSPHERIC AMMONIA CONDENSER.

passes to the rooms or apparatus which are to be refrigerated, returning to a brine storage tank, from whence it is again taken by the pump and passed through the cooler, etc., in a continuous operation. In conjunction with the stills and absorbers these coolers, in a number of cases, are commercially cooling brine to thirty-five degrees below zero.

CONSTRUCTION OF THE MACHINE.

The closed vessels of the machine are all made with either heavy cast-iron or steel shells and heads. All continuously wound coils are welded throughout and made of wrought-iron, lap-welded, extra heavy pipe projecting through stuffing boxes in the heads and terminating in headers or junction boxes outside of the shells. The generators and submerged rectifiers have oval coils. The coils on condensers and absorbers are provided with valves and tees so arranged that any one coil may be cut out and opened for cleaning purposes, while the vessel is in operation. All openings in shells for connections are either flanged or tapped, and when tapped, are re-enforced with stuffing boxes and glands, and all valves and fittings are extra heavy to guard against leakage. Each pipe line between vessels is protected by one or more valves easily accessible and care is always taken in erecting the piping to see that it is properly supported. Draining connections are made to the absorber to facilitate emptying the various vessels of ammonia should the occasion require. All vessels are provided with automatically closing liquid level gauges and pressure gauges mounted on a decorative cast-iron gauge board. The ammonia pumps are controlled by automatic governors in order to maintain a constant aqua ammonia level in the absorber.

The coils in the generators are constructed so as to allow of free drainage of the steam condensed in them. In condensers, absorbers and coolers of the shell and

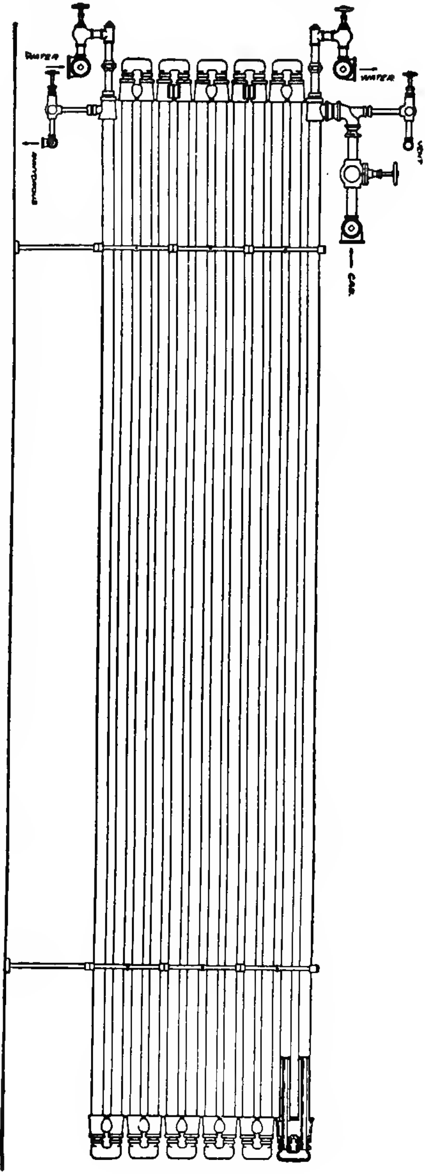


FIG. 28.—ISBELL-PORTER DOUBLE-PIPE AMMONIA CONDENSER.

coil type the double wound coils are frequently used, which, in comparison with the single wound coils, will permit the same amount of water or brine to be circulated through them with about half the friction pressure. Absorbers and coolers with double coil winding are illustrated in Figs. 29 and 30, respectively. This type of double wound coil is always used for the condenser and absorber where warm condensing water is encountered. On exhaust steam machines the generator coils are also frequently of the double wound type.

OPERATION OF THE MACHINE.

The skill required to operate the Polar machine is such as is needed to run a boiler. The engineer has under his control the weak liquor valve and the usual expansion valve or valves depending upon the apparatus to which the high pressure side of the machine is connected. These are the only valves needing adjustment while the machine is in operation. The valves for the steam to the generator and the ammonia pump are controlled by automatic regulators, that for the ammonia pump adjusting itself for any given positions of the expansion and weak aqua valves. The machine has but one moving part, the ammonia pump, its motion being extremely slow; and because of this lack of moving parts the machine can be operated continuously twenty-four hours a day for an entire season without undue wear and tear. Different degrees of temperature may be maintained by very slight changes in the expansion and weak liquor valves.

EFFICIENCY.

The machine receives its power directly from the latent heat of steam without the wasteful losses experienced in a steam engine. The steam condensed in the generator coils may be returned to the boiler at a temperature corresponding to its pressure and always much above that of the average feed water. All hot or cold parts of the machine are thoroughly insulated to avoid any loss to or from the atmosphere or surroundings. This type of machine permits using the exhaust

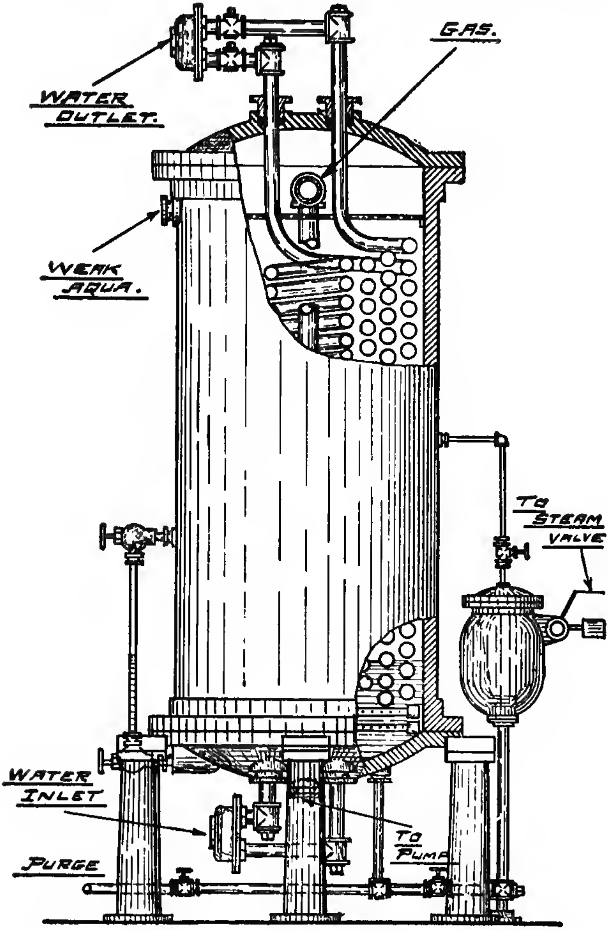


FIG. 29.—ISBELL-PORTER ABSORBER, PUMP GOVERNOR ATTACHED.

steam from the ammonia, brine, water, or other auxiliary pumps in the generator coils. With this use of exhaust steam the machine surpasses in efficiency the most approved form of steam engine that may be used in driving a compressor and also gives an extremely low coal consumption for a plant so equipped. In cold storage work one still and condenser may be used to operate two different sets of absorbers and coolers operating on high and low temperature brine respectively, which is the most efficient manner of carrying high and low temperature rooms in a cold storage warehouse. The machine operates as economically on zero temperatures as at twenty degrees above zero. Where low temperatures are essential, low back pressure may be maintained and a large volume of low pressure gas absorbed by slightly increasing the weak liquor feed and the speed of the ammonia pump.

INSTALLATION.

The absorption machine is absolutely noiseless in operation and free from vibration, owing to the absence of heavy moving parts. This also obviates the necessity of building large and heavy foundations, as the machine may be placed upon any substantial floor. For these reasons, the machine is particularly adapted for use in large steel buildings, hospitals, apartment houses, as well as in the regular line of cold storage warehouses, fish freezers and ice making plants. The different parts of the machine are symmetrically arranged, compact in appearance and, when necessary, may be placed in an extremely small area, although it is of course advisable to have sufficient room around the vessels so that they may be properly and conveniently cared for.

A supply of condensing water is of course essential to the operation of any refrigerating machine. The amount of water must be determined by its temperature and quality. The surfaces of the Polar machine are designed and arranged so that the water from the condenser will be sufficient for use in the absorber through

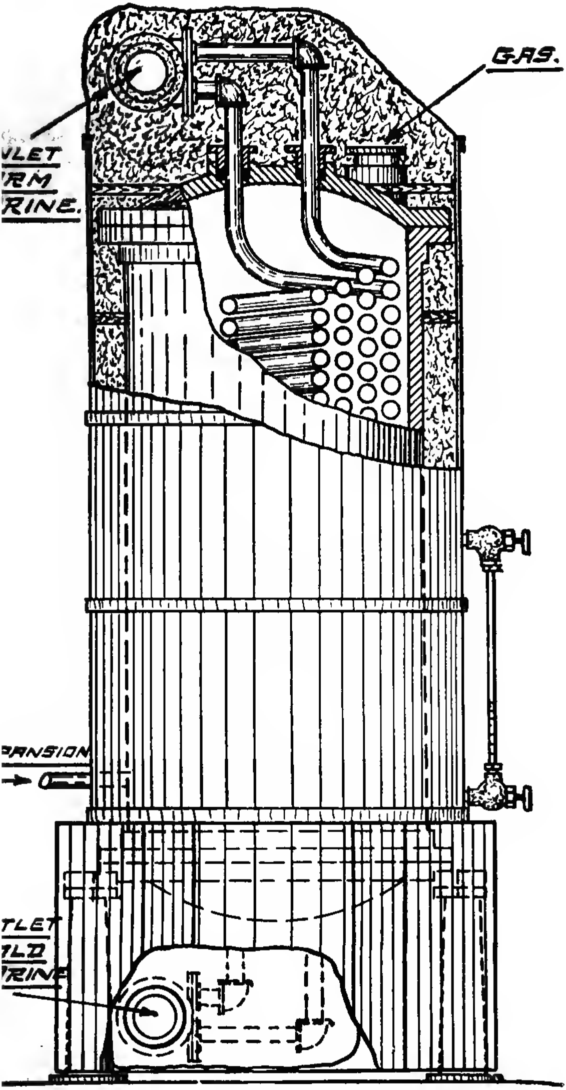


FIG. 30.—ISBELL-PORTER BRINE COOLER, SHELL TYPE.

which it is passed on leaving the condenser, and the water from the machine may at all times be used in the building, for boiler feed and sanitary purposes, cooking, washing, etc.

One of the most important uses of the machine is in connection with plate ice plants. Its high efficiency at low temperatures in connection with a brine cooler makes it possible to freeze and harvest plate ice in forty-eight hours, or less, with the same, or better, economy than may be obtained when the freezing is done at temperatures considerably above zero.

CHAPTER XV.

Description of Vogt Absorption Machine—Construction of Generator, Rectifier, Separator, Condenser, Weak Liquor Cooler, Exchanger, Aqua Ammonia Pump, Absorber and Brine Cooler—Operation of Machine.

The latest type of Vogt absorption machine is illustrated in Fig. 31. It embodies several new features and improvements in construction, yet adheres strictly to the well-known principle of the Vogt machine, that of not having any spiral coils or bent pipes submerged in ammonia.

The generator consists of two or more horizontal cylinders mounted one above the other. These cylinders contain the steam heating coils which are made of extra heavy straight pipe connected with steel return bends. On top of uppermost horizontal cylinder is placed the analyzer, which consists of a cylinder containing a series of perforated trays and baffle plates.

The rectifier or dehydrator is of the double pipe type. The gas from generator enters at the top and travels downward through the annular space between the two pipes and out at the bottom. The strong liquid is used as a rectifying medium and enters the coils at the bottom and passes through the inner pipe in an upward direction and out at the top. A separator containing a series of baffle plates is used with rectifier in order that the watery vapors that have condensed in rectifier may be separated and trapped back to generator.

The condenser is of the double pipe type. The gas from separator enters at the top and travels downward through the annular space between the two pipes and out at the bottom. The cooling water enters at the bottom and passes through the inner pipe in an upward direction and out at the top.

The weak liquor cooler is of the double pipe type, and built exactly like the condenser. The weak liquid enters at the top and travels through the outside pipe like the gas in the condenser. Both the condenser and weak liquid cooler coils are connected up with flushing headers so that each coil may be shut off, the flow of water reversed and mud blown out without interfering with the operation of any other coil. The water bends can be easily disconnected without disturbing the ammonia joints, leaving the inner pipe open at each end for cleaning and inspection.

The exchanger is of the double pipe type. The weak liquid from the generator enters at the top and travels downward through the outside pipe and out at the bottom. The strong liquid from rectifier enters at the bottom and passes upward through the inner pipe and out at the top. All the double pipe constructions of the Vogt machine are made with stuffing boxes on one end of each pipe only; the other end is held firmly threaded in a flange having a tongue and groove joint and bolted to header.

The aqua ammonia pump is of the double-acting, fly-wheel type, of heavy design and usually operates at from 18 to 25 revolutions per minute. It is regulated by a Mason oil governor so as to maintain a constant speed under varying steam pressures. The speed of pump can be instantly changed by simply inserting a key and turning to the right for a lower, and to the left for a higher speed.

The absorber, shown in Fig. 31, is the horizontal tubular type. The shell, made of flange steel, is riveted or welded to heavy steel heads at each end, through which the tubes are inserted and expanded. The tubes

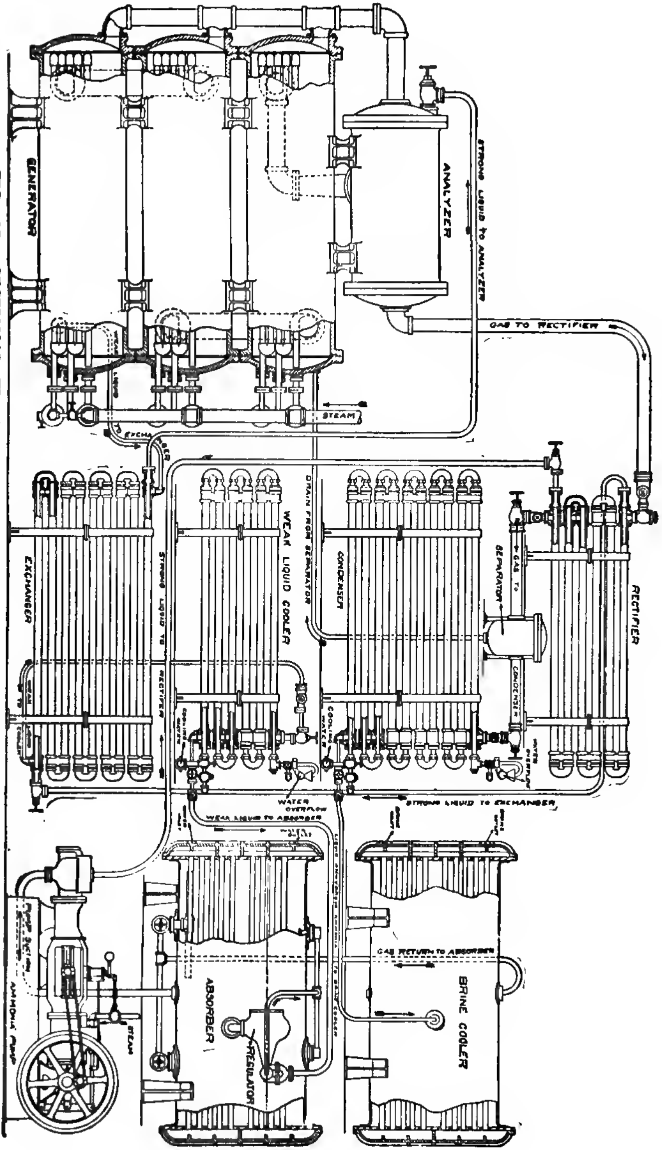


FIG. 31.—SECTIONAL VIEW OF VOGT ABSORPTION REFRIGERATING MACHINE

are made of extra heavy charcoal iron and arranged so that with the baffle heads bolted on each end, the cooling water will pass eight or more times the entire length of the absorber, thus increasing the circulation of the cooling water, and the efficiency of the cooling surface. The gas enters the bottom of the absorber through perforated pipes. The weak liquid enters the top of the absorber through a number of spray nozzles, and any ammonia gas that has passed through the liquid in the shell without being absorbed by same will be instantly absorbed by the weak liquid spray at the top. An automatic regulator is used in connection with the absorber to automatically control the flow of weak liquid to same.

The brine cooler, shown in Fig. 31, is of the horizontal tubular type. It is almost identical in construction with the horizontal tubular absorber just described. The liquid ammonia is contained in the shell, from one-half to three-quarter full; the brine is circulated through the tubes eight or more times the entire length of the cooler. When located in a room exposed to atmospheric temperatures the cooler is usually insulated with sheet cork and lagged with hard wood. While the type of machine illustrated is their latest and preferred construction, the manufacturers of the Vogt machine, when required, use their vertical tubular absorber, and when the cooling water makes it necessary, will use atmospheric type absorber, condenser and weak liquid cooler. A liquid anhydrous ammonia receiver is usually connected in on liquid line from bottom of ammonia condenser to brine cooler; this is not shown in the illustration, because with the shell type brine cooler, the same can be used as a receiver and a separate receiver omitted if desired.

OPERATION OF VOGT MACHINE.

The operation of the Vogt type absorption machine may be summarized as follows:

The strong charge of aqua ammonia is drawn from the absorber and pumped to the bottom of the rectifier and travels upward through the inner pipes, and out at top, and on to the bottom of exchanger; the liquid travels upward through the inner pipes and out at top and on to analyzer, where the liquid falls in a spray from one pan to another until it reaches the top cylinder of generator; it then flows the entire length of top pipe, overflows to the second pipe, travels the entire length of second pipe and overflows into bottom pipe. After having traveled the entire length of the three horizontal cylinders over the steam heating coils, the remaining weak liquid is taken off at the end of bottom cylinder farthest away from the strong liquid inlet, and conducted to the top of the exchanger; here the weak liquid travels downward through the outside pipe and out from bottom to top of the weak liquid cooler, and downward through the outside pipe of same, and out at the bottom, and on to the regulating valve on the absorber. From the regulator the weak liquor is admitted to the absorber in quantities proportional to the liquid pumped out of the bottom of absorber.

The gas generated from the strong aqua by the steam coils, passes out at the top of each horizontal cylinder and up to analyzer where the gas passes through the strong liquid spray, and on through a series of baffle plates to remove moisture from same. From the analyzer the gas is conducted to top of the rectifier and travels downward through the outside pipe and out at bottom to the separator; here the moisture that may yet remain in the gas is separated and drained from bottom of separator and admitted to the top cylinder of the generator. The gas from the separator passes to the condenser at the top and the liquefied ammonia is taken out at the bottom and conducted either to a receiver or direct to the brine cooler. The gas generated by the evaporation of the liquid ammonia in the brine cooler is conducted from top of brine cooler to bottom of the absorber. Here the weak aqua rapidly re-absorbs the gas, forming again a strong solution of aqua ammonia, and the double cycle of circulation is thus completed.

CHAPTER XVI.

Description of the York Absorption Machines—Shell and Coil Generators — Multitubular Generator — Analyzer — Dehydrator — Condenser — Absorber — Exchanger — Weak Aqua Cooler—Aqua Pump—Brine Coolers—The Several Types of Each Apparatus Outlined.

Two types of generators are built, one known as the horizontal shell type with a vertical analyzer, and the other known as the multi-tubular type, having a horizontal analyzer.

The shell and coil type generator is made of flanged steel, having a tensile strength of from 55,000 to 60,000 pounds per square inch. The flanges are made of steel and the heads of air furnace iron. All seams are welded, no rivets whatever being used. The ends of the shell are annealed and flanged over the steel rings which are shrunk on the shell. The flanged portions of the shell are machined so as to form the male part of a male and female joint with the head. After completion the generator is subjected to a hydraulic test of 500 pounds per square inch. The shell contains a series of continuously welded trombone style coils, made of extra heavy lap-welded wrought-iron pipe. When desired, these coils are also made up with special return bends.

The vertical analyzer used on this generator has a welded shell, air furnace iron heads, and steel flanges, constructed same as generator shell, and is connected to the generator by means of a large steel nozzle welded to generator shell, at one end, as shown in Fig. 32, and contains a series of improved perforated cast iron trays.

The multi-tubular generator consists of one or more shells, placed one on top of the other, and supported by cast iron stands. The shells are welded and the heads are of air furnace iron, with steel flanges, same as generator shell described heretofore. The heating surface is of double tube construction. The tubes being made of extra heavy lap welded pipe, the inner or

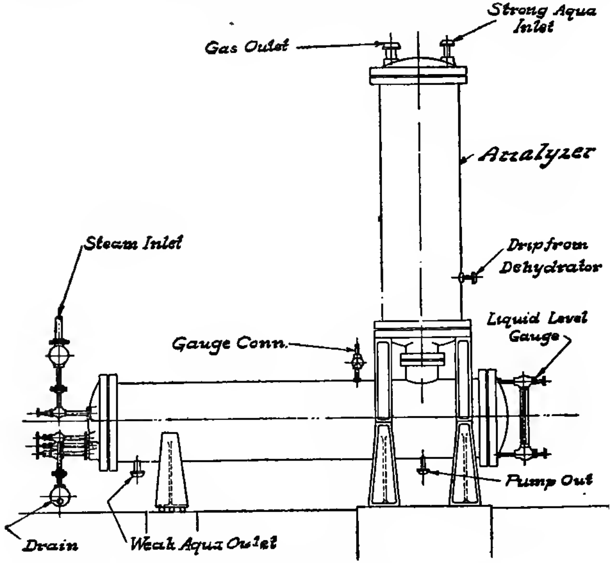


FIG. 32.—YORK SHELL AND COIL GENERATOR AND VERTICAL ANALYZER.

steam inlet tubes being connected to a steam chamber, and extending to the rear of the outer tube which is closed at rear end, and which is connected to a drain chamber at the front end. Each shell is provided with a gas outlet; strong aqua inlet; weak aqua outlet; pump-out; gauge and purge connections. When more than one shell is used, they are usually operated in series, but they are connected in such a manner that they can be operated in multiple.

The horizontal analyzer consists of a welded steel shell, having long cast iron trays, placed in a horizontal position. A gas inlet and outlet connection is provided, also a strong aqua inlet and outlet, and a drip connection from dehydrator, as shown in Fig. 33.

Two types of dehydrators are built, the submerged type and the atmospheric type. The submerged dehydrator consists of a rectangular tank, having one or more extra heavy continuously welded trombone style coils, each coil made to drain to bottom pipe, which is

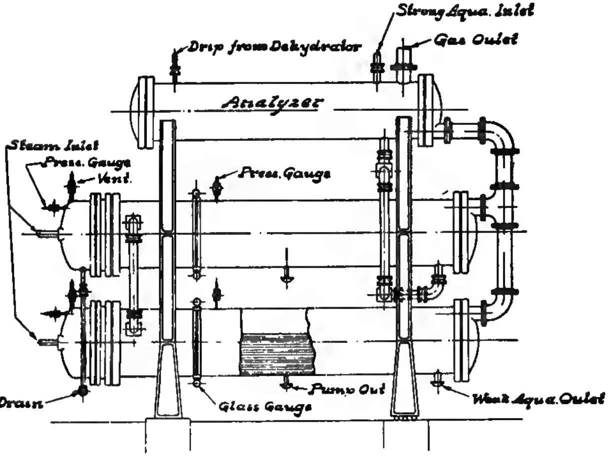


FIG. 33.—HORIZONTAL ANALYZER AND MULTI-TUBULAR GENERATOR.

connected to a high pressure separator, which separates the weak liquor condensed in the dehydrator and returns it to the analyzer; the gas passing through the separator to the ammonia condenser.

The atmospheric type dehydrator consists of one or more coils, return bend type. A drain connection is made from each return bend to the separator, and each coil is provided with a cooling water sprinkling device.

The ammonia condenser is made in three types, the atmospheric, double pipe counter current, and the shell and coil type. The atmospheric type consists of

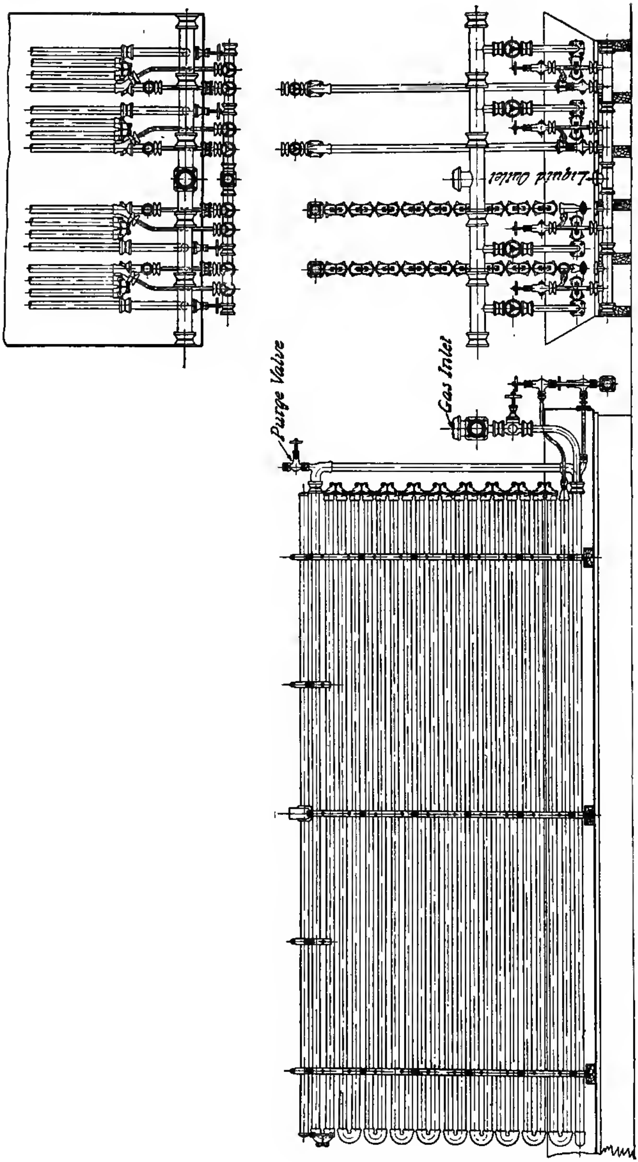


FIG. 34.—YORK AMMONIA CONDENSER AND CONNECTIONS, AT-MOSPHERIC TYPE.

coils made up with return bends. They are provided with slotted pipe or galvanized trough sprinkling device, and are made with either a vertical or horizontal preliminary coil. The illustration, Fig. 34, shows a condenser having a horizontal preliminary.

The double pipe counter current ammonia condenser consists of one or more coils having a pipe within

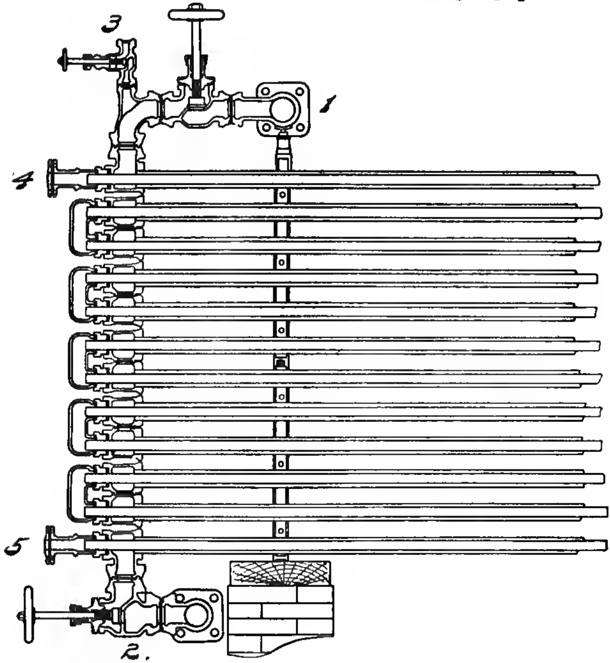


FIG. 35.—YORK DOUBLE-PIPE AMMONIA CONDENSER.

a pipe. The cooling water passes through the inner pipe and the ammonia through the outer pipe. In the condenser shown in Fig. 35, numbers one and two indicate the gas inlet and liquid outlet, while four and five indicate the water connections, and three represents the purge out.

The shell and coil ammonia condenser is made with a welded flange steel shell with air furnace iron heads and steel flanges, and contains a number of extra heavy continuously welded coils, as shown in Fig. 40. The joints on shell are made same as the generator and analyzer, and both shell and coils are tested with a hydraulic pressure of 500 pounds per square inch.

TYPES OF APPARATUS.

The absorber is made in three types, the horizontal tubular, vertical shell and coil, and atmospheric type.

The horizontal tubular type consists of a welded shell with cast iron water heads and heavy flanged steel tube heads, into which are expanded the tubes. The water chambers at each end are divided into a number of parts, causing the water to pass repeatedly

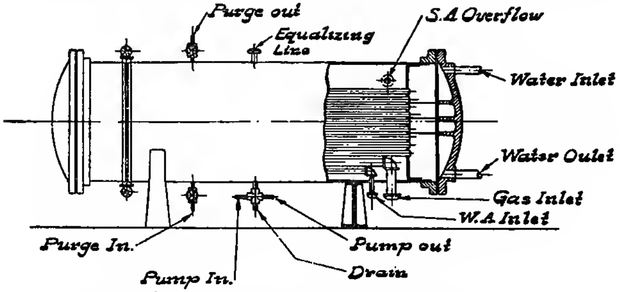


FIG. 36.—YORK HORIZONTAL TUBE ABSORBER.

back and forth through the tubes and various water chambers, the water entering the top set of tubes and finally leaving the bottom set. The gas and weak aqua enters the shell at the bottom through perforated distributing pipes and the strong aqua overflowing at the top as shown in Fig. 36.

The vertical shell and coil absorber consists of a welded shell with steel flanges and air furnace iron heads, made in the same way as the generator and subjected to the same hydraulic test. It contains a series of continuously welded extra heavy pipe coils, and is provided with a perforated gas and weak aqua distributing spreader in the bottom, and a strong aqua

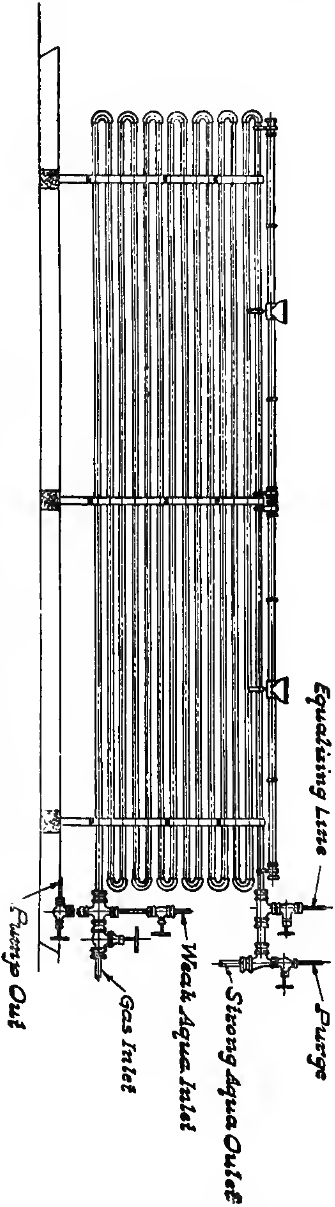


FIG. 37.—YORK ATMOSPHERIC AMMONIA ABSORBER.

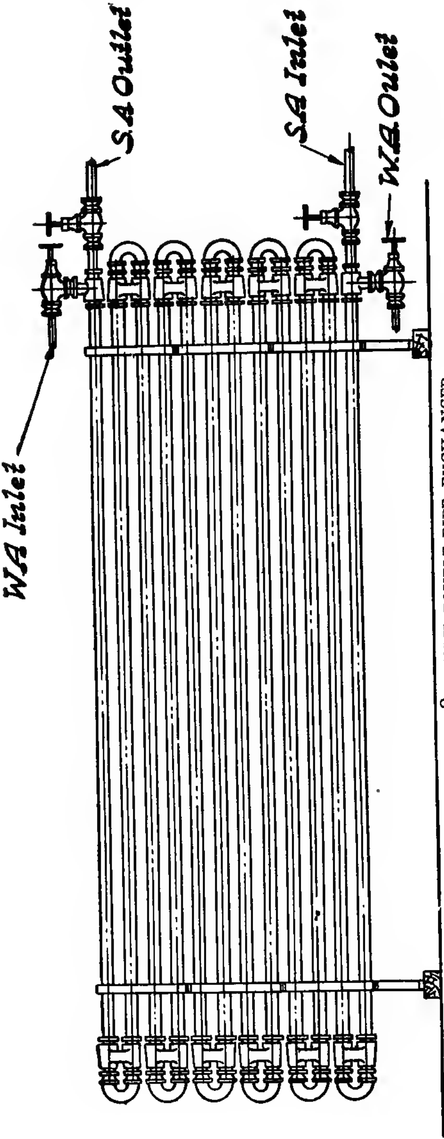


FIG. 38.—YORK DOUBLE-PIPE EXCHANGER.

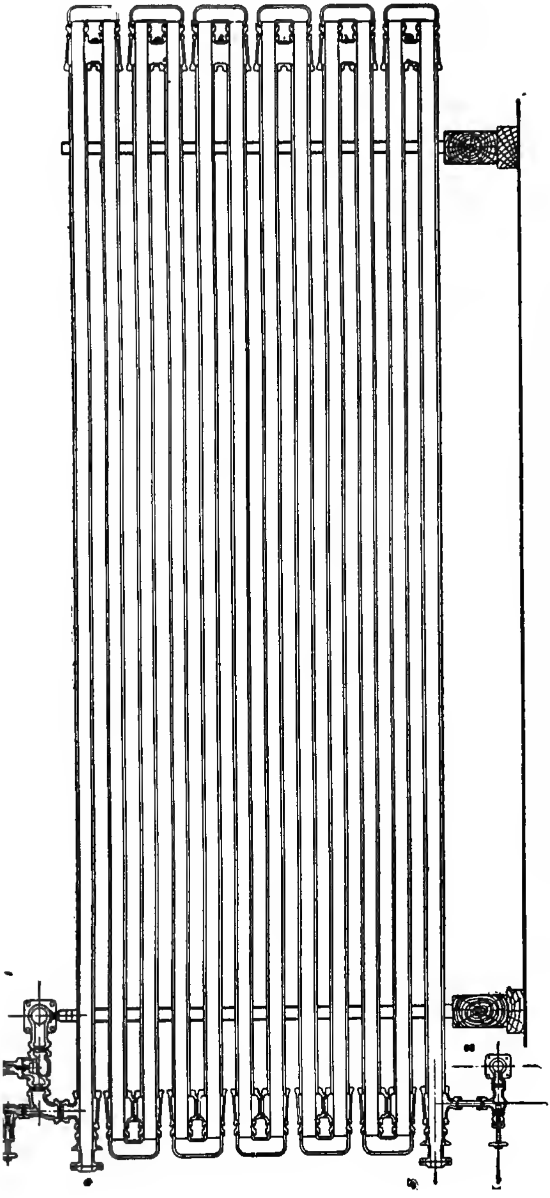


FIG. 39.—YORK DOUBLE-PIPE COUNTER-CURRENT BRINE COOLER.
1 Gas Outlet. 2 Liquid Inlet. 3 Purge Out. 4 Brine Inlet. 5 Brine Outlet.

overflow at the top. The cooling water enters the coils at top and leaves at the bottom.

The atmospheric absorber shown in Fig. 37, consists of one or more coils, made up with return bends. The weak aqua enters the bottom pipe which has a perforated gas distributing pipe, the strong aqua overflowing from the top pipe. Each coil is provided with either a slotted pipe sprinkling device or a galvanized sprinkling trough.

Each absorber, regardless of type, is furnished with a strong aqua tank or receiver, from which the aqua ammonia pump takes its suction; the strong aqua from the absorber overflowing into the tank. This is a cylindrical tank supported on cast iron stands, and is made of flanged steel shell, with welded longitudinal seams; the heads are of flanged steel welded to shell. It is provided with glass liquid level gauges with automatic cocks.

The exchanger is made in two types, the double pipe type, and the vertical shell and coil type.

The double pipe type consists of one or more coils, having a pipe within a pipe, assembled with gland fittings; the strong aqua passing through the inner pipes, and the weak aqua between the inner and outer pipes, as indicated in Fig. 38.

The vertical shell and coil exchanger is made similar to the shell and coil condenser (Fig. 40). It has a welded flange steel shell with heavy air furnace iron heads and steel flanges, and contains a number of continuously welded coils, made of extra heavy lap welded pipe. All joints are made as explained under head of shell and coil generator, and are subjected to the same hydraulic test. The strong aqua enters the bottom of shell and overflows at top, while the weak aqua enters the coils at top of shell and leaves same at the bottom.

The weak aqua cooler is made in two types, the double pipe, and the atmospheric type.

The double pipe type is constructed similar to the double pipe ammonia condenser, having a pipe within a pipe, with gland fittings; the weak aqua entering the outer top pipe and leaving at the bottom, while

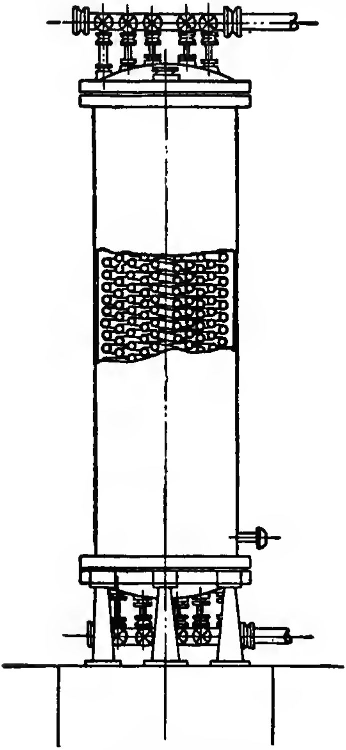


FIG. 40.—SHELL AND COIL EXCHANGER, CONDENSER, BRINE COOLER AND ABSORBER.

the cooling water enters the inner bottom pipe and leaves the top one.

The atmospheric type weak aqua cooler consists of one or more straight coils, made up with return bends, or continuously welded, with slotted cooling water sprinkling device or galvanized trough on top; the weak aqua entering the bottom pipe of coil and leaving at the top.

The aqua ammonia pump is a double acting type, and is capable of handling any strength of aqua without becoming gas bound. Each pump is provided with a suitable cast iron base which acts as a drip pan, and is furnished with a suitable speed regulator which automatically regulates the speed of the pump.

The brine coolers are made in three types, the double pipe counter current; vertical shell and coil, and horizontal shell and tube.

The double pipe counter current type consists of one or more coils, having a pipe within a pipe with gland fittings. It is shown in Fig. 39. Numbers one and two indicate the ammonia outlet and inlet, while four and five show the brine inlet and outlet, and number three is the purging out connection.

The vertical shell and coil brine cooler is made practically the same as the shell and coil ammonia condenser (Fig. 40), having a welded flange steel shell, air furnace iron heads and steel flanges, and is supported by means of cast iron legs attached to the lugs which are provided on the bottom head. It contains a number of coils continuously welded and made of extra heavy lap welded pipe. The liquid anhydrous ammonia is injected into the bottom and the gas leaves the top of shell. The brine is pumped into the bottom of coils and leaves the top.

The horizontal shell and tube brine cooler is made very similar to the shell and tube absorber shown in Fig. 36. It has a welded flange steel shell and tube heads, and cast iron brine heads. The shell is filled with extra heavy tubes expanded into tube head. The brine chambers at each end are divided into a number of compartments; the brine entering the bottom of brine head, passing through the tubes and compartments at a high velocity, and leaving at the top. The shell is supported on heavy cast iron stands.

CHAPTER XVII.

Voorhees' Multiple Effect Receiver—Prevention of Evaporation at the Expansion Valve—Tables Showing Gains Made.

Referring to "Refrigerating Machines, Compression, Absorption," on page 15, is given a copyrighted table which is here reproduced as follows:

Condenser pressure	140 lbs.	170 lbs.	200 lbs.
Condenser temperature	80°	90°	100°
Refrigerator pressure, 0 lbs.	.431 lb.	.441 lb.	.451 lb.
Refrigerator temperature, 29°	19.0%	20.8%	22.5%
Refrigerator pressure, 15 lbs.	.420 lb.	.430 lb.	.440 lb.
Refrigerator temperature, 0°	14.4%	16.2%	18.0%
Refrigerator pressure, 30 lbs.	.415 lb.	.425 lb.	.434 lb.
Refrigerator temperature, 17°	11.6%	13.4%	15.2%

In the above table the pounds of ammonia per minute per ton of refrigeration and the per cent of this amount of ammonia that is evaporated at the expansion valve are given for 0, 15 and 30 pounds gauge back pressure, and for 140, 170 and 200 pounds condenser pressure, together with ammonia temperatures due to these back and condenser pressures.

An inspection of this table will show that from 11.6% to 22.5% of the liquid ammonia is evaporated at the expansion valve in cooling the liquid ammonia from its temperature due to the condensing pressure, to that due to its back pressure.

The ammonia so evaporated at the expansion valve does practically no actual refrigeration in the refrigerator and requires just as much power to get it back into the condenser as does an equal amount of vapor formed from ammonia liquid evaporated in the refrigerator.

If this evaporation at the expansion valve could be prevented, in whole or in part, the capacity of the refrigerating machine would be increased and the power to operate it would be reduced. For example, at 200 pounds condenser and 0 pounds back pressure the per cent of ammonia evaporated at the expansion valve is 22.5%. If this evaporation could be entirely prevented the capacity of the machine would be increased 29%:

$$\frac{100}{100-22.5} = \frac{100}{77.5} = 1.29.$$

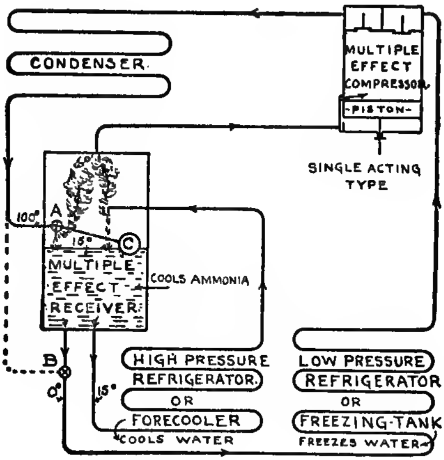
The Voorhees Multiple Effect Receiver (patented), hereafter called M. E. R., is designed to prevent nearly all of such evaporation at the expansion valve. The device is simplicity itself, but in order to use it the refrigerating system must be operated at two different back pressures.

This may be done by means of a Multiple Effect Compressor, hereafter called M. E. C. (for description, see January, 1907, and February, 1911, *Ice and Refrigeration*), or through a multiple effect absorption system, or by using two different back pressures, one on each side of the piston of a double-acting compressor, or by two compressors or two absorbers.

Briefly, the M. E. R. takes out most of the vapor, at a high pressure expansion valve, that would otherwise be formed at the low pressure expansion valve and the resultant liquid ammonia so cooled and freed from vapor is again expanded through the low pressure expansion valve.

In the figure, which is diagrammatic and which has the relative size of the M. E. R. greatly exaggerated for clearness, the ordinary cycle of operations (if the M. E. R. and high pressure refrigerator were not used and if the M. E. C. were operated as a common compressor at one back pressure) is as follows:

Assume 200 pounds condenser and 15 pounds back pressure; under these conditions the liquid ammonia flows from the condenser through the dotted pipe to expansion valve *B*, where its pressure is reduced from 200 to 15 pounds and its temperature from 100° F. to 0° F., thereby evaporating 18% of its weight in so cooling itself. Now, if in place of having the liquid ammonia from the condenser go directly to expansion valve *B*, it passes the float-governed expansion valve *A*, and into the M. E. R., it is evident that the ammonia



liquid will cool itself to the temperature due to the pressure in the M. E. R. and that the vapor so formed will flow out of the top of the M. E. R. to the high pressure suction inlet of the M. E. C. and the resultant cold liquid ammonia free from vapor will flow from the M. E. R. past expansion valve *B*, whereat its pressure is finally reduced to 15 pounds, and a small quantity of vapor is so formed in further cooling the liquid to 0° F.

If the pressure in the M. E. R. were the same as that in the low pressure refrigerator all the vapor that would ordinarily be formed at expansion valve *B* would be formed in the M. E. R., and the liquid ammonia would be cooled to the refrigerator temperature, which, in this case, would be the exact duplicate of the accumulator of a flooded system. This, however, is not the case, for the pressure in the M. E. R. is a little higher than that in the low pressure refrigerator (and therefore the liquid ammonia is a little warmer than the low pressure refrigerator), dependent upon the requirements of the refrigerating system.

In its simplest application the M. E. R. has a pressure just enough higher than that of the low pressure refrigerator to take care of the maximum possible quantity of vapor that would otherwise be formed at the low pressure expansion valve.

If two back pressures are to be used they should be used to their maximum advantage. In all applications of refrigeration the refrigeration is either done at two different back pressures or *could* to advantage be so done; particularly when it is remembered that the capacity and economy of a compressor increases as the back pressure increases.

The two back pressures are determined by the nature of the refrigeration to be done. When any part of the refrigeration of a system could be done at a higher back pressure the whole plant is operated at a daily loss of capacity and increased cost for coal if it is not so done. For high temperature work a high back pressure is used and for low temperature work a low back pressure is used. So for ice making use high back pressure to cool the water to say 34° F. and low back pressure to freeze the water into ice. In cold storage or packing houses use high back pressure for the cooling rooms and low back pressure for the freezing rooms. In breweries use high back pressure for the Baudelot coolers and low back pressure for the cellars. In air cooling for blast furnaces use high back pressure to partly cool the air and low back pressure to finish the cooling, thus cooling the air in two stages, etc.

Looking again at the figure, let us consider an ice making plant with 90° condensing water and 15 pounds back pressure. This will give us 200 pounds condensing pressure and 100° liquid ammonia from the condenser and 100° water from the flat cooler. To cool one pound of this 100° water in a forecooler requires 66 B. T. U. (100—34×1=66). To cool the 34° water to 32°, freeze it into ice and cool the ice to the brine temperature requires 154 B. T. U., or, in all, 220 B. T. U., and to this must be added the various losses due to exposure, meltage from the cans, etc.—in all about 10% more.

But such losses apply to the forecooler nearly as much as to the rest of the system, so that in cooling the water from 100° to 34° we used 30% of the refrigeration required for the whole process (66÷220=.30). Now all of this 30% could be done at a higher back pressure than 15 pounds, and if it were so done it is evident that the ice making capacity of the 15-pound back pressure compressor would be increased thereby by 43% (.70+.30÷.70=1.43).

The high back pressure can be anything desired according to the quality of refrigeration to be done by it, so long as the temperature due it is not too high. In this case it could be anything from 15 pounds to 50 pounds, according to the refrigeration to be done in the forecooler.

With the use of a M. E. C. and a M. E. R. this high back pressure automatically regulates itself without any attention whatsoever on the part of the engineer to the speed of the compressor or the high pressure expansion valve. The automatic float expansion valve *A* in the M. E. R. takes care of this at all times and under all conditions.

In the figure we see that the high pressure refrigerator which is now used as a forecooler to cool the water from 100° to 34° is connected to the M. E. R. just as a flooded system refrigerator would be connected to an accumulator, so the liquid from the M. E. R. circulates from the M. E. R. through the high pressure refrigerator (forecooler), the resultant vapor and some liquid returns to the M. E. R. and the vapor rises and joins that formed at expansion valve *A*, and passes out to the high pressure suction inlet of the M. E. C.

Here we see the M. E. R. has the compound functions, 1st, of cooling all the liquid ammonia for both high and low pressure refrigerators; 2d, of acting as an accumulator for the high pressure refrigerator (forecooler); 3d, of regulating the quantity of ammonia used in the high pressure refrigerator (forecooler). With such a system, which can easily be applied to any existing plant, the following advantages result: More ice for less power per ton of ice; the same quantity of ice for less power per ton of ice for a slower speed of compressor. The ice making case above cited is less severe than most of the Southern ice making conditions.

With a Multiple Effect Receiver the increase in capacity of a common compressor made multiple effect would (if the volumetric efficiency remained constant) be proportionate to the absolute back pressures used, plus the gain of the M. E. R.

When using a compressor M. E. C. the volumetric efficiency is greatly increased over that of a common compressor because the high back pressure gas comes into a comparatively cool cylinder just after suction of the low back pressure vapor—in place of coming in contact with a hot cylinder just after discharging a cylinder of hot gas into the condenser (see p. 20. Ref. Mach. Comp. Abs.).

All common compressors are usually built with large enough engines to operate at high back pressure so such engines will be powerful enough, if such a compressor is made M. E. C., and even if not, a slightly higher boiler pressure would make them so.

Cut out a short piece of your suction pipe, put in a M. E. C. device, put a collar on the piston rod and a link motion to be actuated by collar to move valve in M. E. C. device, and your compressor is made M. E. C. When you remember the cost saved of foundations, extra engine room space, attendance, oil, waste, repair of same, and at the same time the cost to change the simple compressor engine to a compound one you will see where the money inducement lies.

A new compressor M. E. C. would cost practically the same as an old style compressor.

The following table will give a guide as to what can be done as to extra capacity and saving to power:

Comparison of Ice Making Capacities and Horse Power of Compression Machines for 90° Condensing Water, 15 lb. Back Pressure and 200 lb. Condensing Pressure, with Present Compressor Operated at a Constant Speed Under These Conditions, and with Some Additions to or Modifications of Ice Making Plants.

	Increased ice-making capacity.	Decreased h. p. per ton ice.
Present compressor and present apparatus..	0%	0%
Present compressor with a M. E. R. and an additional small compressor to take care of vapor at high back pressure from M. E. R.	18%	4%
Present compressor made M. E. C. with M. E. R. to take care of vapor from M. E. R. at high back pressure......	21%	12%
Present compressor with an additional compressor to take care of vapor from forecooler at high back pressure...........	43%	7%
Present compressor with M. E. R. and an additional compressor to take care of vapor from forecooler and M. E. R.....	69%	10%
Present compressor made multiple effect to take care of vapor from forecooler at high back pressure.....................	43%	18%
Present compressor made multiple effect with M. E. R. to take care of vapor from forecooler and M. E. R. at high back pressure	70%	25%
Present compressor with engine changed from simple to compound non-condensing engine will use about 28% less steam.		

The ice manufacturer of the future, whether he makes can or plate ice, need no longer be tied down to the great losses of the present day. The can ice man can make up his distilled water with the use of a multiple effect still and the plate ice man has all the water he wants anyway. (See table of ice making possibilities, p. 54, Ref. Mach. Comp. Abs.)

It will be noticed that to run two old style compressors, one at high and one at low back pressure, would only save 7% of the power and that naturally has kept machine builders from generally so dividing the compressors for ice plants, as the saving is too small to bother with. But when 70% gain in capacity and 25% saving in power becomes possible by changing the present compressor to a M. E. C. and using a M. E. R., the matter would seem too attractive to let pass without most careful consideration.

In most all application of refrigeration, the refrigeration can be divided into high temperature refrigeration and low temperature refrigeration. The following are some of the gains for M. E. C. and M. E. R. for very much less horse-power per ton of refrigeration than if one compressor at the low back pressure were used, or if two common compressors were used at two back pressures:

	Increase of refrigeration M. E. C. and M. E. R.
Brewery cellars and Baudelots	46%
Ice making and brewery	70%
Low temperature cold storage and ice making	77%
Air cooling for blast furnaces	102%
Low temperature and high temperature refrigeration for cold storage or packing house	107%
Street pipe line refrigeration and cooling offices and theaters	197%

In ice making it is evident that to cool water from, say, 100° to 32°, and freeze it into ice with liquid ammonia at 100°, if the water is cooled from 100° to 34° and the liquid ammonia is cooled from 100° to 15° without using any refrigeration at the low back pressure for this cooling of water and ammonia, the capacity of the compressor for freezing ice at the low back pressure will be greatly increased.

Any make of compressor operated its present speed, whether single or double acting, retaining the same size piston and same length of stroke, changed to a

Multiple Effect Compressor and used in connection with a Multiple Effect Receiver, will then operate at two different back pressures, a low back pressure the same as at present for freezing the ice and a higher back pressure to cool the water before it goes to the cans and to cool the liquid ammonia before it goes to the expansion valve. The gain in ice making capacity and saving in horse-power per ton of ice for various condensing water temperatures is as follows:

Condensing water temperature.	Per cent increased ice making capacity.	Per cent decreased h. p. per ton ice.
100°	80%	35%
90°	70%	25%
80°	58%	22.5%
70°	48%	20%
60°	38%	17.5%
50°	29%	15%

CHAPTER XVIII.

Voorhees' Multiple Effect Absorption System, Used with Voorhees' Multiple Effect Receiver.

It is often desired to do refrigerating by taking up heat at two or more different planes of temperature. Such refrigeration has been done in the past either by taking up the heat at the lower plane of temperature or by employing as many different refrigerating machines as there are planes of temperature.

The Voorhees Multiple Effect Absorption System (patented) consists of an absorption apparatus having two or more sets of refrigerators and absorbers arranged to maintain different pressures in the refrigerators and absorbers so that the refrigeration may be done at two or more planes of temperature without requiring a complete absorption machine for each plane of temperature. The different pressures in the refrigerators and absorbers are controlled by the temperature and per cent of strength of the absorbent in the absorbers. For a given absorber temperature a low absorber pressure requires a less strength of absorbent than does a higher absorber pressure. Low temperature in the refrigerator requires less absorber pressure than does high temperature in the refrigerator; and when the absorbent in an absorber is saturated with gas at a low pressure it will still have a capacity, even at a higher temperature, to absorb more gas at a higher pressure.

In general, in an absorption ammonia system embodying my invention, aqua ammonia from a single still by being exposed, *seriatim,* to ammonia gas in a series of absorbers, each absorber being at a higher pressure than the absorber before it in the circuit, can *seriatim* absorb more and more ammonia gas and become resaturated in each absorber.

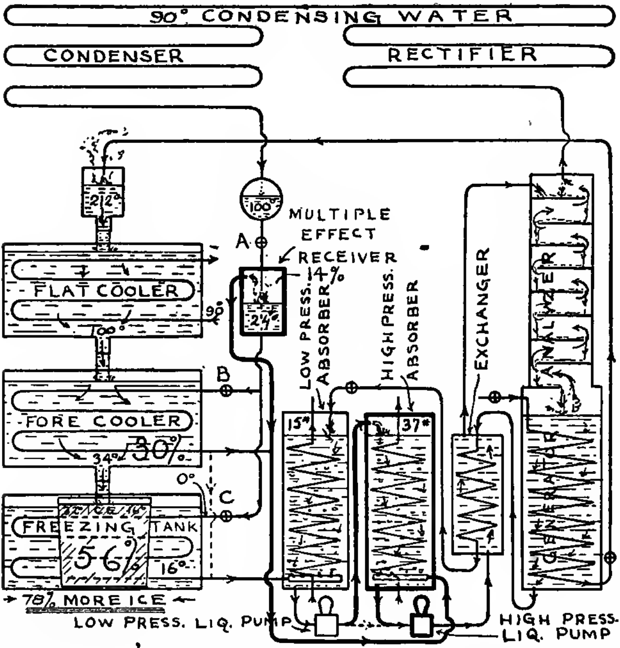
During absorption, the liquor which has absorbed gas in the lowest pressure absorber is passed to that absorber in which the next higher pressure is maintained, and so on; though if preferred the several absorbers may be connected in parallel to the still so that different portions of the weak liquor from the still may pass through the several absorbers and may be discharged thence into the still from the several absorbers separately.

This improved method and device requires much less apparatus than when refrigeration at a number of different temperature planes is conducted according to the prior methods, and there is a great saving in cooling water and steam, as well as a great saving in the first cost of apparatus.

A Multiple Effect Receiver was fully described in *Ice and Refrigeration* (August and September, 1909), and it automatically partly evaporates and cools the liquid ammonia for the low pressure refrigerator without the use of cooling coils at the pressure of the high pressure refrigerator and so makes the ammonia of the low pressure system just that much more effective.

An adaptation of the multiple effect absorption system and the M. E. R. is shown in the accompanying illustration, where 90° condensing water is used. Assuming that the reader is familiar with the common absorption system, the illustration should practically explain itself with this brief additional description. Heavy lines show new parts. Here 100° liquid anhydrous ammonia flows past expansion valve *A*, where its pressure is reduced in the M. E. R. to 37 pounds, so that part of it evaporates and thus cools the balance to 24°.

This 24° F. liquid ammonia flows through regulating valve *B* to the forecooler and through expansion valve *C* to the freezing tank coil. The gas from the freezing tank coil at 15 pounds pressure flows to the



VOORHEES' MULTIPLE EFFECT ABSORPTION SYSTEM & MULTIPLE EFFECT RECEIVER

low pressure absorber and the combined gases from the M. E. R. and forecooler at 37 pounds flow to the high pressure absorber. The forecooler cools the water from 100° to 34° and the freezing tank coil cools the brine to 16°, which freezes the water into ice and cools the ice to 16°; 20% weak liquor from the generator flows into the low pressure absorber and in absorbing the 15-pound gas becomes 30% liquor, and is pumped by the low pressure liquor pump to the high pressure absorber (in place of, as of old, via the dotted line to the exchanger). This 30% liquor now absorbs the 37-pound gas in the high pressure absorber and becomes 36% liquor and is then pumped by the high pressure pump to the generator via the exchanger and analyzer as of old.

We see the M. E. R. cooled the liquid ammonia from 100° to 24° and the forecooler cools the water from 100° to 34°, both at 37 pounds back pressure and so take just that much refrigerating load off the low pressure apparatus so it can do just that much more freezing. Formerly 14% of the refrigeration was used to cool the ammonia from 100° to 24° and 30% to cool the water from 100° to 34° at 15 pounds back pressure. Now all the refrigerating capacity of the low pressure system is devoted to freezing ice, whereas of old only 56% was so devoted. Therefore the old absorber, exchanger, liquor pump, generator, etc., will, with the M. E. R. and the high pressure absorber and liquor pump, do 100% of freezing; therefore 100 ÷ .56 = 1.78, *i. e.*, the low pressure apparatus will now make 78% more ice. The following table shows what gains in ice making can be had by the addition to the old absorption system of an extra absorber and liquor pump and a multiple effect receiver for various temperatures of condensing water:

Temp. Cond. Water.	% More Ice by M. E. A. & M. E. R.
100°	94%
90°	78%
80°	63%
70°	49%
60°	37%
50°	26%

Any absorption machine, as for ice making, cold storage or any other purpose, can be made "Multiple Effect" and its capacity greatly increased by installing an extra absorber and liquor pump under this patent.

CHAPTER XIX

Useful Tables

COMPARISON OF FAHRENHEIT AND CENTEGRADE THERMOMETER SCALES.

°F.	°C.
330	165.6
329	165.
328	164.4
327	163.9
326	163.3
325	162.8
324	162.2
323	161.7
322	161.1
321	160.6
320	160.
319	159.4
318	158.9
317	158.3
316	157.8
315	157.2
314	156.7
313	156.1
312	155.6
311	155.
310	154.4
309	153.9
308	153.3
307	152.8
306	152.2
305	151.7
304	151.1
303	150.5
302	150.
301	149.4
300	148.9
299	148.3
298	147.8
297	147.2
296	146.7
295	146.1
294	145.6
293	145.
292	144.4
291	143.9
290	143.3
289	142.8
288	142.2
287	141.7
286	141.1
285	140.6
284	140.0
283	139.4
282	138.9
281	138.3
280	137.8
279	137.2
278	136.7
277	136.1
276	135.6
275	135.
274	134.4
273	133.9
272	133.3
271	132.8
270	132.2
269	131.7
268	131.1

°F.	°C.
267	130.6
266	130.
265	129.4
264	128.9
263	128.3
262	127.8
261	127.2
260	126.7
259	126.1
258	125.6
257	125.
256	124.4
255	123.9
254	123.3
253	122.8
252	122.2
251	121.7
250	121.1
249	120.6
248	120.
247	119.4
246	118.9
245	118.3
244	117.8
243	117.2
242	116.7
241	116.1
240	115.6
239	115.
238	114.4
237	113.9
236	113.3
235	112.8
234	112.2
233	111.7
232	111.1
231	110.6
230	110.
229	109.4
228	108.9
227	108.3
226	107.8
225	107.2
224	106.7
223	106.1
222	105.6
221	105.
220	104.4
219	103.9
218	103.3
217	102.8
216	102.2
215	101.7
214	101.1
213	100.6
Water boils	
212	100.
211	99.4
210	98.9
209	98.3
208	97.8
207	97.2

°F.	°C.
206	96.7
205	96.1
204	95.6
203	95.
202	94.4
201	93.9
200	93.3
199	92.8
198	92.2
197	91.7
196	91.1
195	90.6
194	90.
193	89.4
192	88.9
191	88.3
190	87.8
189	87.2
188	86.7
187	86.1
186	85.6
185	85.
184	84.4
183	83.9
182	83.3
181	82.8
180	82.2
179	81.7
178	81.1
177	80.6
176	80.
175	79.4
174	78.9
173	78.3
172	77.8
171	77.2
170	76.7
169	76.1
168	75.6
167	75.
166	74.4
165	73.9
164	73.3
163	72.8
162	72.2
161	71.7
160	71.1
159	70.6
158	70.
157	69.4
156	68.9
155	68.3
154	67.8
153	67.2
152	66.7
151	66.1
150	65.6
149	65.
148	64.4
147	63.9
146	63.3
145	62.8
144	62.2

°F.	°C.
143	61.7
142	61.1
141	60.6
140	60.
139	59.4
138	58.9
137	58.3
136	57.8
135	57.2
134	56.7
133	56.1
132	55.6
131	55.
130	54.4
129	53.9
128	53.3
127	52.8
126	52.2
125	51.7
124	51.1
123	50.6
122	50.
121	49.4
120	48.9
119	48.3
118	47.8
117	47.2
116	46.7
115	46.1
114	45.6
113	45.
112	44.4
111	43.9
110	43.3
109	42.8
108	42.2
107	41.7
106	41.1
105	40.6
104	40.
103	39.4
102	38.9
101	38.3
100	37.8
99	37.2
98	36.7
97	36.1
96	35.6
95	35.
94	34.4
93	33.9
92	33.3
91	32.8
90	32.2
89	31.7
88	31.1
87	30.6
86	30.
85	29.4
84	28.9
83	28.3
82	27.8
81	27.2

°F.	°C.
80	26.7
79	26.1
78	25.6
77	25.
76	24.4
75	23.9
74	23.3
73	22.8
72	22.2
71	21.7
70	21.1
69	20.6
68	20.
67	19.4
66	18.9
65	18.3
64	17.8
63	17.2
62	16.7
61	16.1
60	15.6
59	15.
58	14.4
57	13.9
56	13.3
55	12.8
54	12.2
53	11.7
52	11.1
51	10.6
50	10.
49	9.4
48	8.9
47	8.3
46	7.8
45	7.2
44	6.7
43	6.1
42	5.6
41	5.
40	4.4
39	3.9
38	3.3
37	2.8
36	2.2
35	1.7
34	1.1
33	0.6
Water freezes	
32	0.
31	−0.6
30	−1.1
29	−1.7
28	−2.2
27	−2.8
26	−3.3
25	−3.9
24	−4.4
23	−5.
22	−5.6
21	−6.1
20	−6.7

°F.	°C.
19	−7.2
18	−7.8
17	−8.3
16	−8.9
15	−9.4
14	−10.
13	−10.6
12	−11.1
11	−11.7
10	−12.2
9	−12.8
8	−13.3
7	−13.9
6	−14.4
5	−15.
4	−15.6
3	−16.1
2	−16.7
1	−17.2
0	−17.8
−1	−18.3
−2	−18.9
−3	−19.4
−4	−20.
−5	−20.6
−6	−21.1
−7	−21.7
−8	−22.2
−9	−22.8
−10	−23.3
−11	−23.9
−12	−24.4
−13	−25.
−14	−25.6
−15	−26.1
−16	−26.7
−17	−27.2
−18	−27.8
−19	−28.3
−20	−28.9
−21	−29.4
−22	−30.
−23	−30.6
−24	−31.1
−25	−31.7
−26	−32.2
−27	−32.8
−28	−33.3
−29	−33.9
−30	−34.4
−31	−35.
−32	−35.6
−33	−36.1
−34	−36.7
−35	−37.2
−36	−37.8
−37	−38.3
−38	−38.9
−39	−39.4
Mercury freezes	
−40	−04

COMPARISON OF CENTEGRADE, FAHRENHEIT AND REAUMUR SCALES.

C.	F.	R.	C.	F.	R.	C.	F.	R.
+100°	+212.0°	+80.0°	+63°	+127.4°	+42.4°	+ 6°	+42.8°	+4.8°
99	210.2	79.2	62	125.6	41.6	5	41.0	4.0
98	208.4	78.4	61	123.8	40.8	4	39.2	3.2
97	206.6	77.6	60	122.0	40.0	3	37.4	2.4
96	204.8	76.8	49	120.2	39.2	2	35.6	1.6
95	203.0	76.0	48	118.4	38.4	1	33.8	0.8
94	201.2	75.2	47	116.6	37.6	Zero	32.0	Zero
93	199.4	74.4	46	114.8	36.8	– 1	30.2	– 0.8
92	197.6	73.6	45	113.0	36.0	2	28.4	1.6
91	195.8	72.8	44	111.2	35.2	3	26.6	2.4
90	194.0	72.0	43	109.4	34.4	4	24.8	3.2
89	192.2	71.2	42	107.6	33.6	5	23.0	4.0
88	190.4	70.4	41	105.8	32.8	6	21.2	4.8
87	188.6	69.6	40	104.0	32.0	7	19.4	6.6
86	186.8	68.8	39	102.2	31.2	8	17.6	6.4
85	186.0	68.0	38	100.4	30.4	9	15.8	7.2
84	183.2	67.2	37	98.6	29.6	10	14.0	8.0
83	181.4	66.4	36	96.8	28.8	11	12.2	8.8
82	179.6	65.6	35	95.0	28.0	12	10.4	9.6
81	177.8	64.8	34	93.2	27.2	13	8.6	10.4
80	176.0	64.0	33	91.4	26.4	14	6.8	11.2
79	174.2	63.2	32	89.6	25.6	15	5.0	12.0
78	172.4	62.4	31	87.8	24.8	16	3.2	12.8
77	170.6	61.6	30	86.0	24.0	17	1.4	13.6
76	168.8	60.8	29	84.2	23.2	18	–0.4	14.4
75	167.0	60.0	28	82.4	22.4	19	2.2	15.2
74	165.2	59.2	27	80.6	21.6	20	4.0	16.0
73	163.4	58.4	26	78.8	20.8	21	5.8	16.8
72	161.6	57.6	25	77.0	20.0	22	7.6	17.6
71	159.8	56.8	24	75.2	19.2	23	9.4	18.4
70	158.0	56.0	23	73.4	18.4	24	11.2	19.2
69	156.2	55.2	22	71.6	17.6	25	13.0	20.0
68	154.4	54.4	21	69.8	16.8	26	14.8	20.8
67	152.6	53.6	20	68.0	16.0	27	16.6	21.6
66	150.8	52.8	19	66.2	15.2	28	18.4	22.4
65	149.0	52.0	18	64.4	14.4	29	20.2	23.2
64	147.2	51.2	17	62.6	13.6	30	22.0	24.0
63	145.4	50.4	16	60.8	12.8	31	23.8	24.8
62	143.6	49.6	15	59.0	12.0	32	25.6	25.6
61	141.8	48.8	14	67.2	11.2	33	27.4	26 4
60	140.0	48.0	13	55.4	10.4	34	29.2	27.2
69	138.2	47.2	12	63.6	9.6	35	31.0	28.0
58	136.4	46.4	11	61.8	8.8	36	32.8	28.8
67	134.3	46.6	10	50.0	8.0	37	34.6	29.6
66	132.8	44.8	9	48.2	7.2	38	36.4	30.4
55	131.0	44.0	8	46.4	6.4	39	38.2	31.2
64	129.2	43.2	7	44.6	5.8	40	40.0	32.0

CONVERSION OF THERMOMETER DEGREES.

°C to °R, multiply by 4 and divide by 5.
°C to °F, multiply by 9, divide by 5, then add 32.
°R to °C, multiply by 5 and divide by 4.
°R to °F, multiply by 9, divide by 4, then add 32.
°F to °R, first subtract 32, then multiply by 4 and divide by 9.
°F to °C, first subtract 32, then multiply by 5 and divide by 9.

PROPERTIES OF SATURATED AMMONIA—(Wood).

Temperature.		Pressure, absolute.		Heat of vaporization, thermal units.	External heat, thermal units.	Internal heat, thermal units.	Volume of vapor per lb., cu. ft.	Volume of liquid per lb., cu. ft.	Weight of a cu. ft. of vapor, lbs.
Degrees F.	Absolute.	Lbs. per sq. ft.	Lbs. per sq. in.						
− 40	420.66	1540.9	10.59	579.67	48.23	531.44	24.37	.0234	.0410
− 35	425.66	1773.6	12.31	576.69	48.48	528.21	21.29	.0236	.0467
− 30	430.66	2035.8	14.13	673.69	48.77	624.92	18.66	.0237	.0535
− 25	435.66	2329.5	16.17	570.68	49.06	521.62	16.41	.0238	.0609
− 20	440.66	2657.5	18.45	567.67	49.38	518.29	14.48	.0240	.0690
− 16	445.66	3022.5	20.99	564.64	49.67	514.97	12.81	.0242	.0779
− 10	450.66	3428.0	23.77	561.61	49.99	511.62	11.36	.0243	.0878
− 5	455.66	3877.2	25.93	658.56	50.31	508.25	10.12	.0244	.0988
0	460.66	4373.6	30.37	555.50	50.68	504.82	9.04	.0246	.1109
+ 5	465.66	4920.5	34.17	653.43	50.84	501.69	8.06	.0247	.1241
+ 10	470.66	5522.2	38.55	649.35	51.13	498.22	7.23	.0249	.1384
+ 15	475.66	6182.4	42.93	646.26	51.33	494.93	6.49	.0250	.1540
+ 20	480.66	6905.3	47.95	643.15	51.61	491.54	5.84	.0252	.1712
+ 25	485.66	7695.2	53.43	640.03	51.80	488.23	5.26	.0253	.1901
+ 30	490.66	8596.0	59.41	636.92	52.01	484.91	4.75	.0254	.2105
+ 35	495.66	9493.9	65.93	533.78	52.22	481.56	4.31	.0256	.2320
+ 40	500.66	10512	73.00	530.63	52.42	478.21	3.91	.0257	.2583
+ 45	505.66	11616	80.66	627.47	52.62	474.85	3.56	.0260	.2809
+ 50	510.66	12811	88.96	524.30	52.82	471.48	3.25	.0260	.3109
+ 55	515.66	14102	97.93	521.12	53.01	468.11	2.96	.0260	.3379
+ 60	520.66	15494	107.60	517.23	53.21	464.72	2.70	.0265	.3704
+ 65	525.66	16993	118.03	514.73	53.38	461.35	2.48	.0266	.4034
+ 70	530.66	18605	129.21	511.52	53.57	457.85	2.27	.0268	.4405
+ 75	635.66	20336	141.25	508.29	63.76	454.53	2.08	.0270	.4808
+ 80	540.66	22192	154.11	604.66	63.96	450.70	1.91	.0272	.5252
+ 85	545.66	24178	167.86	601.81	54.15	447.66	1.77	.0273	.5649
+ 90	550.66	26300	182.8	498.11	54.28	443.83	1.64	.0274	.6098
+ 95	555.66	28565	198.37	495.29	54.41	440.88	1.51	.0277	.6622
+100	560.66	30980	215.14	491.50	54.54	436.96	1.39	.0279	.7194
+105	565.66	33550	232.98	488.72	54.67	434.08	1.289	.0281	.7757
+110	570.66	36284	251.97	485.42	54.78	430.64	1.203	.0283	.8312
+115	575.66	39188	272.14	482.41	54.91	427.40	1.121	.0285	.8912
+120	580.66	42267	293.49	478.79	55.03	423.75	1.041	.0287	.9608
+125	585.66	45528	316.16	475.45	55.09	420.39	.9699	.0289	1.0310
+130	590.66	48978	340.42	472.11	55.16	416.94	.9051	.0291	1.1048
+135	595.66	52626	365.16	468.76	55.22	413.53	.8457	.0293	1.1824
+140	600.66	65483	392.22	465.39	55.29	410.09	.7910	.0295	1.2642
+145	605.66	60550	420.49	462.01	65.34	406.67	.7408	.0297	1.3497
+150	610.66	64833	450.20	458.62	55.39	402.23	.6946	.0299	1.4696
+155	615.66	69341	481.54	455.22	65.43	399.79	.6511	.0302	1.5358
+160	620.66	74086	514.40	451.81	55.46	396.35	.6128	.0304	1.6318
+165	625.66	79071	549.04	448.39	56.48	392.94	.5765	.0306	1.7344

The critical pressure of ammonia is 115 atmospheres; critical temperature at 266° F. (Dewar); critical volume .00482 (calculated).

PROPERTIES OF SATURATED AMMONIA.

CALCULATED FROM THE ORIGINAL FORMULA OF PROF. DE VOLSON WOOD BY GEO. DAVIDSON, M. E.

Compiled especially for and originally published in *Ice and Refrigeration* for December, 1904.

Temperature.		Pressure, absolute.		Gauge pressure, lbs. per sq. in.	Heat of vaporization, thermal units. h.	Vol. of vapor per lb., cu. ft. v.	Vol. of liquid per lb., cu. ft. v_1.	Wt. of vapor in lbs. per cu. ft. w.	Wt. of liquid in lbs. per cu. ft. w_1.	Degrees F. Temp.
Degrees F. t.	Absolute. T.	Pounds per sq. ft. P.	Pounds per sq. in. p.							
—40	420.66	1539.90	10.69	— 4.01	679.67	24.388	.02348	.0410	42.589	—40
39	1	1584.43	11.00	— 3.70	579.07	23.735	.02351	.0421	42.635	39
88	2	1630.03	11.32	— 3.38	678.42	23.102	.02354	.0433	42.483	38
37	3	1676.71	11.64	— 3.06	677.88	22.488	.02357	.0444	42.427	37
36	4	1724.51	11.98	— 2.72	577.27	21.895	.02359	.0457	42.391	36
—36	426.66	1773.43	12.31	— 2.39	676.68	21.321	.02362	.0469	42.337	—35
34	6	1823.60	12.66	— 2.04	676.08	20.763	.02364	.0482	42.301	34
33	7	1874.73	13.02	— 1.68	576.48	20.221	.02366	.0495	42.265	33
32	8	1927.17	13.38	— 1.32	574.89	19.708	.02368	.0507	42.213	32
31	9	1980.78	13.76	— 0.95	574.39	19.204	.02371	.0521	42.176	31
—30	430.66	2035.69	14.13	— 0.57	573.69	18.693	.02374	.0535	42.123	—30
29	1	2091.83	14.53	— 0.17	573.08	18.225	.02378	.0549	42.052	29
28	2	2149.23	14.92	+ 0.22	572.48	17.759	.02381	.0563	42.000	28
27	8	2207.94	15.33	+ 0.63	571.89	17.307	.02384	.0577	41.946	27
26	4	2267.97	15.75	+ 1.05	571.28	16.869	.02387	.0593	41.893	26
—26	436.66	2329.34	16.17	+ 1.47	570.68	16.446	.02389	.0608	41.858	—25
24	6	2392.09	16.61	1.91	570.08	16.034	.02392	.0624	41.806	24
23	7	2456.23	17.05	2.35	569.48	16.633	.02395	.0640	41.764	23
22	8	2620.46	17.60	2.80	568.88	15.262	.02398	.0656	41.701	22
21	9	2588.77	17.97	3.27	568.27	14.876	.02401	.0672	41.649	21
—20	440.66	2667.33	18.46	+ 3.76	567.67	14.607	.02403	.0689	41.615	—20
19	1	2727.17	18.94	4.24	567.06	14.163	.02406	.0706	41.563	19
18	2	2798.62	19.43	4.73	666.43	13.807	.02409	.0725	41.611	18
17	3	2871.61	19.94	5.24	665.86	13.476	.02411	.0742	41.480	17
16	4	2946.17	20.46	5.76	565.25	13.150	.02414	.0760	41.425	16
—15	445.66	3022.31	20.99	+ 6.29	564.64	12.834	.02417	.0779	41.374	—15
14	6	3100.07	21.53	6.83	564.04	12.527	.02420	.0798	41.322	14
13	7	3179.45	22.08	7.38	563.43	12.230	.02423	.0818	41.271	13
12	8	3260.62	22.64	7.94	662.82	11.939	.02426	.0838	41.237	12
11	9	3343.29	23.22	8.52	662.21	11.659	.02428	.0858	41.186	11
—10	460.66	3427.75	23.80	+ 9.10	561.61	11.385	.02431	.0878	41.135	—10
9	1	3513.97	24.40	9.70	560.99	11.117	.02434	.0899	41.084	9
8	2	3601.97	25.01	10.31	560.39	10.860	.02437	.0921	41.034	8
7	3	3691.75	26.64	10.94	559.78	10.604	.02439	.0943	41.000	7
6	4	3783.37	26.27	11.57	559.17	10.362	.02442	.0965	40.950	6
—5	455.66	3876.86	26.92	+12.22	558.56	10.126	.02446	.0988	40.900	—5
4	6	3972.62	27.59	12.89	557.94	9.894	.02448	.1011	40.845	4
3	7	4069.48	28.26	13.56	557.33	9.669	.02451	.1034	40.799	3
2	8	4168.70	28.96	14.25	556.73	9.449	.02454	.1058	40.749	2
1	9	4269.90	29.65	14.96	556.11	9.234	.02457	.1083	40.700	1
+0	460.66	4373.10	30.37	+15.67	555.50	9.028	.02461	.1107	40.650	+0
1	1	4478.32	31.10	16.40	554.88	8.825	.02463	.1133	40.601	1
2	2	4486.60	31.84	17.14	554.27	8.630	.02466	.1159	40.551	2
8	3	4694.96	32.60	17.90	553.65	8.436	.02469	.1186	40.502	3
4	4	4806.46	33.38	18.68	553.04	8.250	.02472	.1212	40.453	4

PROPERTIES OF SATURATED AMMONIA—Continued.

Temperature.		Pressure, absolute.		Gauge pressure, lbs. per sq. in.	Heat of vaporization, thermal units. *h*.	Vol. of vapor per lb., cu. ft. *v*.	Vol. of liquid per lb., cu. ft. v_1.	Wt. of vapor in lbs. per cu. ft. *w*.	Wt. of liquid in lbs. per cu. ft. w_1.	Degrees F. Temp.
Degrees F. *t*.	Absolute. *T*.	Pounds per sq. ft. *P*.	Pounds per sq. in. *p*.							
+ 5	465.66	4920.11	34.16	+19.46	552.43	8.070	.02475	.1240	4.0404	+ 5
6	6.	5035.95	34.97	20.27	551.81	7.892	.02478	.1267	4.0355	6
7	7.	5153.99	35.89	21.09	551.19	7.717	.02480	.1296	4.0322	7
8	8.	5274.28	36.63	21.93	550.58	7.553	.02483	.1324	4.0274	8
9	9.	5396.83	37.48	22.78	549.96	7.388	.02486	.1353	4.0225	9
+10	470.66	5521.71	38.34	+23.64	549.35	7.229	.02490	.1383	4.0160	+10
11	1.	5649.48	39.23	24.53	548.73	7.075	.02493	.1413	4.0112	11
12	2.	5778.50	40.13	25.43	548.11	6.924	.02496	.1444	4.0064	12
13	3.	5910.52	41.04	26.34	547.49	6.786	.02499	.1474	4.0016	13
14	4.	6044.96	41.98	27.28	546.88	6.632	.02502	.1507	3.9968	14
+15	475.66	6182.00	42.94	+28.24	546.26	6.491	.02505	.1541	3.9920	+15
16	6.	6321.24	43.90	29.20	545.63	6.355	.02508	.1573	3.9872	16
17	7.	6463.24	44.88	30.18	545.01	6.222	.02511	.1607	3.9872	17
18	8.	6607.77	45.89	31.19	544.39	6.093	.02514	.1641	3.9777	18
19	9.	6754.90	46.91	32.21	543.74	5.966	.02517	.1676	3.9729	19
+20	480.66	6904.68	47.95	+33.25	543.15	5.843	.02520	.1711	3.9632	+20
21	1.	7057.15	49.01	34.31	542.53	5.722	.02523	.1748	3.9635	21
22	2.	7211.33	50.09	35.39	541.90	5.605	.02527	.1784	39.572	22
23	3.	7370.27	51.18	36.48	541.28	5.488	.02529	.1822	39.541	23
24	4.	7530.96	52.30	37.60	540.66	5.378	.02533	.1860	39.479	24
+25	485.66	7694.52	53.43	+38.73	540.03	5.270	.02536	.1897	39.432	+25
26	6.	7860.89	54.59	39.89	539.41	5.163	.02539	.1937	39.386	26
27	7.	8030.16	55.76	41.06	538.78	5.058	.02542	.1977	39.339	27
28	8.	8202.38	56.96	42.26	538.16	4.960	.02545	.2016	39.292	28
29	9.	8377.56	58.17	43.47	537.53	4.858	.02548	.2059	39.246	29
+30	490.66	8555.74	59.42	+44.72	536.91	4.763	.02551	.2099	39.200	+30
31	1.	8736.96	60.67	45.97	536.28	4.668	.02554	.2142	39.115	31
32	2.	8921.26	61.95	47.25	535.66	4.577	.02557	.2185	39.108	32
33	3.	9108.71	63.25	48.55	535.03	4.486	.02561	.2229	39.047	33
34	4.	9299.32	64.58	49.88	534.40	4.400	.02564	.2273	39.001	34
+35	495.66	9493.07	65.92	+51.22	533.78	4.314	.02568	.2318	38.940	+35
36	6.	9690.04	67.29	52.59	533.13	4.234	.02571	.2362	38.894	36
37	7.	9890.75	68.68	53.98	532.52	4.157	.02574	.2413	38.850	37
38	8.	10093.91	70.09	55.39	531.89	4.068	.02578	.2458	38.789	38
39	9.	10300.88	71.53	56.83	531.26	3.989	.02582	.2507	38.729	39
+40	500.66	10511.16	72.99	+58.29	530.63	3.915	.02585	.2554	38.684	+40
41	1.	10724.95	74.48	59.78	529.99	3.839	.02588	.2605	38.639	41
42	2.	10942.18	75.99	61.29	529.36	3.766	.02591	.2655	38.595	42
43	3.	11162.93	77.52	62.82	528.73	3.695	.02594	.2706	38.550	43
44	4.	11387.21	79.08	64.38	528.10	3.627	.02597	.2757	38.499	44
+45	505.66	11615.12	80.66	+65.96	527.47	3.559	.02600	.2809	38.461	+45
46	6.	11846.64	82.27	67.57	526.83	3.493	.02603	.2863	38.417	46
47	7.	12081.80	83.90	69.20	526.20	3.428	.02606	.2917	38.373	47
48	8.	12320.71	85.56	70.86	525.57	3.362	.02609	.2974	38.328	48
49	9.	12563.36	87.25	72.55	524.93	3.303	.02612	.3027	38.284	49
+50	510.66	12808.91	88.96	+74.26	524.30	3.242	.02616	.3084	38.226	+50
51	1.	13080.21	90.70	76.00	523.66	3.182	.02620	.3143	38.167	51
52	2.	13314.43	92.46	77.76	523.03	3.124	.02623	.3201	38.124	52
53	3.	13572.52	94.25	79.55	522.39	3.069	.02626	.3258	38.080	53
54	4.	13834.64	96.07	81.37	521.76	3.012	.02629	.3320	38.037	54

PROPERTIES OF SATURATED AMMONIA—Continued.

Temperature. Degrees F. t.	Temperature. Absolute. T.	Pressure, absolute. Pounds per sq. ft. P.	Pressure, absolute. Pounds per sq. in. p.	Gauge pressure, lbs. per sq. in.	Heat of vaporization, thermal units. h.	Vol. of vapor per lb., cu. ft. v.	Vol. of liquid per lb., cu. ft. v_1.	Wt. of vapor in lbs. per cu. ft. w.	Wt. of liquid in lbs. per cu. ft. w_1.	Degrees F. Temp.
+ 55	515.66	14100.74	97.92	+ 83.22	521.12	2.958	.02632	.3380	37.994	+ 55
56	6	14370.92	99.80	85.10	520.48	2.905	.02636	.3442	37.936	56
57	7	14646.18	101.70	87.00	519.84	2.853	.02639	.3505	37.893	57
58	8	14923.98	103.64	88.94	519.20	2.802	.02643	.3568	37.835	58
59	9	15206.28	105.60	90.90	518.57	2.753	.02646	.3632	37.793	59
+ 60	520.66	15493.09	107.59	+ 92.89	517.93	2.705	.02651	.3697	37.736	+ 60
61	1	15784.23	109.61	94.91	517.29	2.658	.02654	.3762	37.678	61
62	2	16079.67	111.66	96.96	516.65	2.610	.02658	.3831	37.622	62
63	3	16379.51	113.75	99.05	516.01	2.565	.02661	.3898	37.579	63
64	4	16663.75	115.86	101.16	515.37	2.520	.02665	.3968	37.523	64
+ 65	525.66	16992.50	118.09	+103.33	514.73	2.476	.02668	.4039	37.481	+ 65
66	6	17305.70	120.18	105.48	514.09	2.433	.02671	.4110	37.439	66
67	7	17623.45	122.38	107.68	513.46	2.399	.02675	.4189	37.383	67
68	8	17946.89	124.62	109.92	512.81	2.351	.02678	.4254	37.341	68
69	9	18272.81	126.89	112.19	512.16	2.310	.02682	.4329	37.285	69
+ 70	530.66	18604.53	129.19	+114.49	511.52	2.272	.02686	.4401	37.230	+ 70
71	1	18941.00	121.64	116.84	510.87	2.233	.02689	.4479	37.188	71
72	2	19282.21	133.90	119.20	510.22	2.194	.02693	.4558	37.133	72
73	3	19628.32	136.31	121.61	509.58	2.153	.02697	.4645	37.079	73
74	4	19979.22	138.74	124.04	508.93	2.122	.02700	.4712	37.037	74
+ 75	535.66	20335.16	141.22	+126.52	508.29	2.087	.02703	.4791	36.995	+ 75
76	6	20696.00	143.72	129.02	507.64	2.052	.02706	.4873	36.954	76
77	7	21061.85	146.26	131.56	506.99	2.017	.02710	.4957	36.900	77
78	8	21432.82	148.84	134.14	506.34	1.995	.02714	.5012	36.845	78
79	9	21808.85	151.45	136.75	505.69	1.962	.02717	.5123	36.805	79
+ 80	540.66	22190.15	154.10	+139.40	505.05	1.921	.02721	.5205	36.751	+ 80
81	1	22576.51	156.58	142.08	504.40	1.889	.02725	.5294	36.696	81
82	2	22968.88	159.50	144.80	503.75	1.858	.02728	.5382	36.657	82
83	3	23365.38	162.26	147.56	503.10	1.827	.02732	.5473	36.603	83
84	4	23767.81	165.05	150.35	502.45	1.799	.02736	.5558	36.549	84
+ 85	545.66	24175.61	167.88	+153.18	501.81	1.770	.02739	.5649	36.509	+ 85
86	6	24588.92	170.75	156.05	501.15	1.741	.02743	.5744	36.466	86
87	7	25007.80	173.66	158.96	500.50	1.714	.02747	.5834	36.407	87
88	8	25432.16	176.61	161.91	499.85	1.687	.02751	.5927	36.360	88
89	9	25862.14	179.59	164.89	499.20	1.660	.02754	.6024	36.311	89
+ 90	550.66	26297.88	182.62	+167.92	498.55	1.634	.02758	.6120	36.258	+ 90
91	1	26739.88	185.69	170.99	497.89	1.608	.02761	.6219	36.219	91
92	2	27186.56	188.79	174.09	497.24	1.583	.02765	.6317	36.166	92
93	3	27639.43	191.94	177.24	496.59	1.558	.02769	.6418	36.114	93
94	4	28098.26	195.13	180.43	495.94	1.534	.02772	.6518	36.075	94
+ 95	555.66	28563.00	198.35	+183.65	495.29	1.510	.02776	.6622	36.023	+ 95
96	6	29033.86	201.62	186.92	494.63	1.486	.02780	.6729	35.971	96
97	7	29510.69	204.94	190.24	493.97	1.463	.02784	.6835	35.919	97
98	8	29993.52	208.29	193.59	493.32	1.442	.02787	.6934	35.831	98
99	9	30482.52	211.68	196.98	492.66	1.419	.02791	.7047	35.829	99
+100	560.66	30977.78	215.12	+200.42	492.01	1.398	.02795	.7153	35.778	+100

NOTE—For values at temperatures higher than 100° F. see Wood's table of Saturated Ammonia, page 136.

PROPERTIES OF AMMONIA LIQUOR—Starr.

% NH_3 by wt.	°Baumé.	Pounds gauge pressure (top line) and degrees Fahrenheit.												
		0	5	10	15	20	25	30	35	40	45	50	55	60
1.		206.3	223.6	234.9	247.4	256.2	263.8	270.4	277.1	282.8	288.1	292.9	297.5	301.9
1.84	11	201.4	219.3	231.5	243.3	251.7	259.4	266.4	272.7	278.4	283.7	288.5	293.1	297.5
2.		201.1	218.5	230.8	242.1	250.9	258.6	265.5	271.9	277.6	282.8	287.7	292.2	296.7
3.		195.8	213.2	225.5	236.6	245.6	253.3	260.2	266.8	272.3	277.5	282.4	286.9	291.4
3.80	12	191.5	208.8	221.0	232.3	241.0	248.7	255.7	262.0	267.7	272.9	277.8	282.4	286.8
4.		190.5	207.7	220.0	231.2	240.0	247.6	254.7	260.9	266.7	271.8	276.1	281.4	285.7
5.		185.2	202.4	214.6	225.8	224.6	242.2	249.3	255.6	261.4	266.5	271.4	276.1	280.4
5.30	13	183.5	200.7	212.8	224.1	232.8	240.5	247.5	253.8	259.6	264.8	270.2	274.1	279.2
6.		180.0	197.1	209.2	220.5	229.2	237.0	243.9	250.2	256.1	261.2	266.7	271.2	275.6
6.80	14	175.8	193.0	205.0	216.2	224.9	232.6	239.6	246.0	251.8	257.0	262.1	266.7	271.1
7.		174.9	192.1	204.0	215.3	223.9	231.7	238.6	245.1	250.8	256.1	261.1	265.8	270.1
8.		170.0	187.2	199.1	210.3	218.9	226.9	233.7	240.1	245.9	251.2	266.2	260.8	265.2
8.22	15	168.8	185.8	197.8	209.0	217.7	225.4	232.4	238.6	244.2	249.3	254.1	258.7	263.1
9.		165.4	182.5	194.5	205.0	214.3	222.0	229.0	235.2	240.8	245.9	250.7	255.3	259.7
10.	16	160.8	177.7	189.6	200.6	209.2	216.9	223.9	230.1	235.5	240.6	245.4	250.0	254.4
11.		156.4	173.2	185.1	196.1	204.7	212.4	219.4	225.6	231.0	236.1	240.9	244.5	249.9
12.		151.9	168.9	180.6	191.9	200.6	208.3	214.8	221.0	226.4	231.5	236.4	240.0	245.4
12.17	17	151.0	168.0	179.9	191.0	199.6	207.3	213.6	219.6	225.0	230.3	234.4	239.0	243.4
13.		147.5	164.4	176.4	187.4	196.1	203.7	210.1	216.1	221.4	226.8	230.8	235.5	239.9
13.88	18	143.7	160.5	172.3	183.4	192.0	199.7	206.0	212.1	217.6	222.7	227.2	231.8	236.2
14.		143.2	160.0	171.8	182.9	191.5	199.2	205.5	211.6	217.1	222.2	226.7	231.3	235.7
15.		139.0	155.8	167.6	178.7	187.3	195.0	201.3	207.4	212.9	218.0	222.5	227.1	231.5
16.		134.8	151.6	163.4	174.5	183.1	190.8	197.1	203.2	208.7	213.8	218.3	222.9	227.3
16.22	19	133.8	150.6	162.3	173.3	181.4	189.5	196.0	201.8	207.1	212.3	217.1	221.7	226.1
17.		130.6	147.4	159.1	170.1	178.2	186.3	192.8	198.6	203.9	209.1	213.9	218.5	222.9
18.03	20	126.2	142.9	154.6	165.6	174.2	181.9	188.9	195.1	200.7	205.7	209.5	214.1	218.5
19.		122.3	138.9	150.7	161.6	170.3	177.9	185.0	191.1	196.8	201.7	205.6	210.1	214.6
19.87	21	119.4	135.9	147.6	158.6	167.2	174.4	181.5	187.2	192.5	197.5	202.3	206.9	211.3
20.		118.9	135.5	147.1	158.2	166.7	174.4	181.1	186.7	192.1	197.0	201.9	206.4	210.8
21.		115.2	131.8	143.4	154.5	163.0	170.7	177.4	183.0	188.4	193.3	198.2	202.7	207.1
21.75	22	112.9	129.4	141.0	151.9	160.5	168.2	174.6	180.1	185.3	190.3	195.1	199.7	204.1
22.		112.0	128.5	140.1	151.0	159.6	167.3	173.7	179.2	184.4	189.4	194.2	198.8	203.2
23.03	23	108.0	124.5	136.1	147.0	155.6	163.3	170.0	175.4	180.2	185.2	190.0	194.6	199.0
24.		114.8	121.3	132.9	143.8	152.4	160.1	166.8	172.2	177.0	182.0	186.8	191.4	195.8
24.99	24	101.5	117.8	129.3	140.1	148.6	156.3	163.0	168.4	173.6	178.6	183.2	187.8	192.2
26.		98.3	114.6	126.2	136.9	145.5	153.1	159.8	165.3	170.4	175.5	179.9	184.7	189.1
27.		95.1	111.4	123.1	133.7	142.3	150.0	156.6	162.1	167.2	172.4	176.7	181.5	185.9
27.66	25	93.0	109.4	121.0	131.7	140.1	147.9	154.5	159.9	165.1	170.3	174.4	178.9	183.3
28.		92.0	108.3	120.0	130.6	139.1	146.8	153.4	158.9	164.0	169.3	173.3	177.9	183.2
29.		88.9	105.2	117.0	127.5	136.0	143.8	150.3	155.8	161.0	166.2	170.2	174.8	180.2
29.60	26	87.0	103.3	114.7	125.4	133.9	141.6	148.2	153.8	159.0	164.3	168.1	172.7	178.1
30		85.8	102.1	113.5	124.2	132.7	140.4	147.0	152.6	157.8	163.1	166.9	171.6	176.9
31.05	27	82.6	98.8	110.2	120.9	129.4	137.1	143.5	149.2	154.5	159.8	163.6	168.3	173.5
32		80.1	96.2	107.6	118.3	126.8	134.5	140.9	146.6	151.9	157.2	161.0	165.7	170.9
33		77.4	93.5	104.9	115.6	124.1	131.8	138.7	143.9	149.2	154.5	158.3	163.0	168.2
33.25	28	76.5	92.6	103.9	114.6	123.1	130.8	137.8	143.0	148.3	153.6	157.4	162.1	167.3
34		74.6	90.7	102.0	112.7	121.2	128.9	135.9	141.1	146.4	151.7	155.5	160.2	165.4
35		72.0	88.1	99.4	110.1	118.6	126.3	133.3	138.5	143.8	149.1	152.9	157.6	162.8
35.60	29	70.4	86.5	97.8	108.5	117.0	124.7	131.7	137.9	142.2	147.5	151.3	156.0	161.2
36		60.5	85.6	96.9	107.5	116.1	123.8	130.8	137.0	141.7	147.2	151.0	155.7	160.8
37		67.2	83.3	94.6	105.2	113.8	121.5	128.5	134.7	140.7	146.8	150.2	154.9	159.7
38		65.0	81.0	92.3	104.9	111.5	119.2	126.2	132.5	138.4	143.9	149.4	154.0	158.6
38.20	30	64.5	80.5	91.8	102.5	111.0	118.7	125.7	132.0	138.1	143.6	149.3	153.9	158.3
		0	5	10	15	20	25	30	35	40	45	50	55	60
% NH_3 by wt.	°Baumé.	Pounds gauge pressure (bottom line) and degrees Fahrenheit.												

PROPERTIES OF AMMONIA LIQUOR—Continued.

% NH_3 by wt.	°Baumé	Pounds gauge pressure (top line) and degrees Fahrenheit. 65	70	75	80	85	90	95	100	105	110	115	120
1.		306.3	310.4	314.4	318.2	321.8	325.2	328.5	331.7	334.8	337.8	340.7	343.5
1.84	11	301.8	306.0	810.0	313.8	317.4	320.8	324.1	327.3	330.4	333.4	336.3	339.1
2.		300.9	305.2	309.2	312.9	316.6	320.0	323.2	326.6	329.6	332.6	335.4	338.2
3.		295.6	300.0	303.9	307.6	311.8	314.7	317.9	321.2	324.3	327.3	330.1	332.9
3.80	12	291.1	295.3	299.3	303.1	306.7	310.1	313.4	316.6	319.7	322.7	325.6	328.4
4.		290.1	294.2	298.3	302.1	305.6	309.1	312.4	315.6	318.7	321.6	324.5	327.4
5.		284.8	288.9	293.0	296.3	300.3	303.8	307.1	310.2	313.4	316.3	319.2	322.1
5.30	13	283.5	287.1	291.7	295.5	299.1	302.6	305.8	309.0	312.1	315.1	318.0	320.8
6.		280.0	284.1	288.2	291.9	295.5	299.0	302.2	305.5	308.5	311.6	314.4	317.3
6.80	14	275.4	279.6	283.6	287.4	291.0	294.4	297.1	300.9	304.0	307.0	309.9	312.7
7.		274.5	278.6	282.7	286.4	290.1	293.5	296.7	300.0	303.0	306.1	308.9	311.8
8.		269.6	273.7	281.7	281.5	285.2	288.6	291.7	295.1	298.1	301.2	303.9	306.9
8.22	15	267.4	271.6	275.6	279.4	283.0	286.4	289.7	292.4	296.0	299.0	301.9	304.7
9.		264.0	268.2	272.2	276.0	279.6	283.0	286.3	289.6	292.6	295.6	308.5	301.3
10.	16	258.7	262.9	266.9	270.7	274.3	277.7	281.0	284.2	287.3	290.3	298.2	296.0
11.		254.2	268.4	262.4	266.2	268.8	273.2	276.5	279.7	282.8	286.8	288.7	291.5
12.		249.8	253.9	257.9	261.7	264.3	268.7	272.0	275.2	278.3	281.3	289.2	287.0
12.17	17	247.7	251.9	255.4	259.7	263.3	266.7	270.0	273.2	276.3	279.3	282.2	285.0
13.		244.2	248.4	251.8	256.2	259.8	263.1	266.5	269.6	272.8	275.7	278.6	281.5
13.88	18	240.5	244.0	248.7	252.5	256.1	259.8	262.8	266.0	269.1	272.1	276.0	277.8
14.		240.0	243.5	248.2	252.0	255.6	259.0	262.3	265.6	268.6	271.6	274.5	277.3
15.		235.8	239.4	244.0	247.8	251.4	254.8	258.1	261.3	264.4	267.4	270.3	273.1
16.		231.6	235.1	239.8	243.6	247.2	250.6	253.7	257.1	260.2	263.2	266.1	268.9
16.22	19	280.4	234.6	238.6	242.4	246.0	249.4	252.7	255.9	259.0	262.0	264.9	267.7
17.		227.2	231.4	235.4	239.2	242.8	246.2	249.5	252.7	265.8	258.8	261.7	264.5
18.03	20	222.8	227.0	231.0	234.8	238.4	241.8	245.1	248.3	251.4	254.4	257.3	260.1
19.		218.8	223.1	227.0	230.9	234.4	237.9	241.1	244.4	247.4	250.5	253.4	256.1
19.87	21	215.6	219.8	223.8	227.6	231.2	234.6	237.9	241.1	244.2	247.2	250.1	252.9
20.		215.2	219.3	223.4	227.1	230.7	234.1	237.4	240.7	243.8	246.7	249.6	252.4
21.		211.5	215.6	219.7	223.3	227.0	230.4	233.7	237.0	240.1	243.0	245.9	248.7
21.75	22	208.4	212.6	216.6	220.4	224.0	227.4	230.7	233.9	237.0	240.0	242.9	245.7
22.		207.5	211.7	215.7	219.5	223.1	226.5	229.8	233.0	236.1	239.1	242.0	244.8
23.03	23	203.3	207.5	211.5	215.3	218.9	222.3	225.6	228.8	231.9	234.9	237.8	240.6
24.		200.1	204.2	208.3	212.1	215.7	219.1	222.4	225.6	228.7	231.7	234.6	237.4
24.99	24	196.5	200.7	204.7	208.5	212.1	215.6	218.8	222.0	225.1	228.1	231.0	233.8
26.		193.3	197.5	201.6	205.3	208.9	212.2	215.6	218.9	221.9	225.0	237.8	230.6
27.		190.2	194.3	198.4	202.2	205.7	209.0	212.5	215.8	218.7	221.8	234.7	227.4
27.66	25	187.6	191.8	195.8	199.6	203.2	206.6	209.9	213.1	216.2	219.2	222.1	224.9
28.		186.6	190.7	194.8	198.5	202.2	205.6	208.8	212.1	215.1	218.2	221.0	223.9
29.		183.5	187.6	191.8	195.4	199.1	202.6	205.7	209.0	212.1	215.1	217.9	220.9
29.60	26	181.4	185.6	189.6	193.4	197.0	200.4	203.7	206.9	210.0	213.0	215.9	218.7
30		180.2	184.4	188.4	192.2	195.8	199.2	202.6	205.7	208.8	211.8	214.7	217.5
31.05	27	177.0	181.2	185.2	189.0	192.6	196.0	199.3	202.5	206.6	209.6	212.5	215.3
32		174.4	178.6	182.6	186.4	190.0	193.4	196.7	199.9	204.0	207.0	209.9	212.7
33		171.7	175.9	179.9	183.7	187.3	190.7	194.0	197.2	201.3	204.3	207.2	210.0
33.25	28	170.8	175.0	179.0	182.8	186.4	189.8	193.1	196.3	200.4	203.4	206.3	209.1
34		168.9	173.1	177.1	180.9	184.5	187.9	191.2	195.4	198.5	201.5	204.4	207.2
35		166.3	170.6	174.5	178.3	181.9	185.3	188.6	192.8	195.9	198.9	201.8	204.6
35.60	29	164.7	168.9	172.9	176.7	180.3	183.7	187.0	191.2	194.3	197.3	200.2	203.0
36		164.6	168.7	172.7	176.6	180.1	183.5	186.8	191.0	193.9	196.9	199.8	202.6
37		163.7	167.9	171.9	175.8	179.3	182.7	186.0	190.2	192.8	195.8	198.7	201.5
38		162.9	167.1	171.1	175.0	178.5	181.9	185.2	189.4	191.7	194.7	197.6	200.4
38.20	30	162.6	167.0	171.0	174.8	178.4	181.8	185.1	188.3	191.4	194.4	197.3	200.1
% NH_3 by wt.	°Baumé	65	70	75	80	85	90	95	100	105	110	115	120

Pounds gauge pressure (bottom line) and degrees Fahrenheit.

PROPERTIES OF AMMONIA LIQUOR—Continued.

% NH_3 by wt.	°Baumé	Pounds gauge pressure (top line) and degrees Fahrenheit.											
		125	130	135	140	145	150	155	160	165	170	175	180
1.		346.2	348.8	351.3	353.7	356.0	358.2	360.3	362.3	364.2	366.1	367.4	369.5
1.84	11	341.8	344.4	346.9	349.3	351.6	353.8	355.9	357.9	359.8	361.7	363.5	365.1
2.		341.0	343.6	346.1	348.2	350.8	352.9	355.1	357.1	358.9	360.9	362.7	364.3
3.		335.7	338.3	340.8	342.9	345.5	347.6	349.8	351.8	353.6	355.6	357.4	359.0
3.80	12	331.1	333.7	336.2	338.6	340.9	343.1	345.2	347.2	349.2	351.1	352.8	354.4
4.		330.0	332.6	335.2	337.6	339.8	342.1	344.1	346.2	348.2	350.1	351.7	353.4
5.		324.7	327.3	329.9	332.3	334.5	336.8	338.8	340.9	342.9	344.9	346.4	348.1
5.30	13	323.3	325.9	328.4	330.8	333.1	335.3	337.4	339.4	341.3	343.2	345.0	346.6
6.		319.7	322.4	324.8	327.3	329.5	331.8	333.8	335.9	337.7	339.6	341.4	343.7
6.80	14	315.2	317.8	320.3	322.7	325.0	327.2	329.3	331.3	333.3	335.2	336.9	338.5
7.		314.2	316.9	319.3	321.8	324.0	321.3	328.3	330.4	332.3	334.1	335.9	336.6
8.		309.3	312.0	314.3	316.9	319.1	321.4	327.3	325.5	327.4	329.2	330.9	331.7
8.22	15	307.2	309.8	312.3	314.7	317.0	319.2	321.3	323.3	325.3	327.2	328.9	330.5
9.		303.8	306.4	308.9	311.3	313.6	315.8	317.9	319.9	321.8	323.7	325.5	327.2
10.	16	298.5	301.1	303.6	306.0	308.3	310.5	312.6	314.6	316.6	318.5	320.2	321.8
11.		294.0	296.6	299.2	301.5	303.8	305.0	308.2	310.2	312.1	314.0	315.8	317.5
12.		289.5	292.1	294.7	297.0	299.3	300.5	303.8	305.8	307.6	309.5	311.3	313.0
12.17	17	287.5	290.1	292.6	295.0	297.3	299.5	301.6	303.6	305.6	307.6	309.2	310.8
13.		284.0	286.6	289.1	291.5	293.7	296.0	298.1	200.1	302.0	304.0	306.7	307.3
13.88	18	280.3	282.9	285.4	287.8	290.1	292.3	294.4	296.4	298.3	300.1	302.0	303.6
14.		280.0	282.4	284.9	287.3	289.6	291.8	293.9	295.9	297.8	299.6	301.5	303.1
15.		275.8	278.2	280.7	283.1	285.4	287.6	289.7	291.7	293 6	295.4	297.3	298.9
16.		271.6	274.0	276.5	279.9	281.2	283.4	285.5	287.6	289.4	291.3	293.1	294.7
16.22	19	270.2	272.8	275.3	277.7	280.0	282.2	284.3	286.3	288.3	290.3	292.0	293.6
17.		267.0	269.6	272.1	274.6	276.8	278.0	281.1	283.1	285.1	287.1	288.8	290.4
18.03	20	262.6	265.2	267.7	270.1	272.4	274.6	276.7	278.7	280.7	282.6	284.3	285.9
19.		258.7	261.2	263.8	266.1	268.5	270.6	272.8	274.7	276.8	278.6	280.4	282.0
19.87	21	255.4	258.0	260.5	262.9	265.2	267.4	269.5	271.5	273.5	276.4	277.1	278.7
20.		255.0	257.5	260.1	262.4	264.7	266.9	269.0	271.1	273.0	275.0	276.6	278.2
21.		231.3	253.8	256.4	259.7	261.0	263.2	265.3	267 4	269.3	271.3	272.9	274.5
21.75	22	248.2	250.8	253.3	255.7	258.0	260.2	262.3	264.3	266.3	268.2	269.9	271.5
22.		247.3	249.9	252.4	254.8	257.1	259.3	261.4	263.4	265.4	267.3	269.0	270.6
23.03	23	243.1	245.7	248.2	250.6	252.9	255.1	257.2	259.2	261.2	263.1	264.8	266.4
24.		240.0	242.6	246.0	247.4	249.7	251.9	254.0	256.0	257.9	259.8	261.5	263.1
24.99	24	236.3	238.9	241.4	243.8	246.1	248.3	250.4	252.4	254.4	256.3	258.0	259.6
26.		233.1	235.8	238.3	240.6	242.9	245.2	247.3	249.3	251.2	253.1	254.9	256.5
27.		230.0	232.6	235.2	237.4	239.8	242.1	244.2	246.1	248.0	249.9	251.7	253.4
27.66	25	227.4	230.0	232.5	234.9	237.2	239.4	241.6	243.5	245.3	247.2	248.9	250.5
28.		226.3	229.0	231.4	233.9	236.1	238.4	240.4	242.6	244.3	246.1	247.8	246.5
29.		223.2	225.9	228.4	230.8	233.0	235.4	237.3	239.4	241.3	243.1	244.8	243.5
29.60	26	221.2	223.8	226.3	228.7	231.0	233.2	235.3	237.3	239.3	241.2	242.9	244.5
30.		220.0	222.6	225.1	227.5	229.8	232.0	234.1	236.1	238 1	240.0	241.7	243.3
31.05	27	217.8	220.4	222.9	225.3	227.6	229.8	231.9	233.9	235.8	237.5	239.2	240.8
32.		215.2	217.8	220.3	222.7	225.0	227.2	229.5	231.3	233.2	234.9	236.5	238.2
33.		212.5	215.1	217.6	220.0	222.7	224.5	226.6	228.6	230.6	232.2	233.8	235.5
33.25	28	211.6	214.2	216.7	219.1	221.8	223.6	225.6	227.6	229.3	231.1	232.8	234.4
34.		209.7	212.3	214.8	217.2	219.9	221.7	223.7	225.6	227.4	229.2	230.9	232.5
35.		207.1	209.7	212.2	214.6	217.3	219.1	221.1	223.8	224.8	226.8	228.2	231.3
35.60	29	205.5	208.1	210.6	213.0	215.7	217.6	210.5	221.4	222.2	224.2	226.9	230.3
36.		205.1	207.7	210.2	212.6	215.2	217.1	219.2	220.9	221.9	224.0	226.4	229.4
37.		204.0	206.6	209.1	211.6	214.0	216.0	218.1	219.7	221.1	223.1	225.3	227.9
38.		202.9	205.5	208.0	210.4	212.8	214.9	217.0	218.6	220.3	222.2	224.1	225.7
38.20	30	202.6	205.2	207.1	210.1	212.4	214.6	216.7	218.1	220.1	222.0	223.7	225.3
% NH_3 by wt.	°Baumé	125	130	135	140	145	150	155	160	165	170	175	180
		Pounds gauge pressure (bottom line) and degrees Fahrenheit.											

SOLUBILITY OF AMMONIA IN WATER AT DIFFERENT TEMPERATURES AND PRESSURES—Sims.

One pound of water (also unit volume) absorbs the following quantities of ammonia:

Absolute pr'sure in lbs. per sq. in.	32° F.		68° F.		104° F.		212° F.	
	Lbs.	Vols.	Lbs.	Vols.	Lbs.	Vols.	Grams	Vols.
14.67	0.899	1.180	0.518	.683	0.338	.443	0.074	.970
15.44	0.937	1.231	0.535	.703	0.349	.458	0.078	.102
16.41	0.980	1.287	0.556	.730	0.363	.476	0.083	.109
17.37	1.029	1.351	0.574	.754	0.378	.496	0.088	.115
18.34	1.077	1.414	0.594	.781	0.391	.513	0.092	.120
19.30	1.126	1.478	0.613	.805	0.404	.531	0.096	.126
20.27	1.177	1.546	0.632	.830	0.414	.543	0.101	.132
21.23	1.236	1.615	0.651	.855	0.425	.558	0.106	.139
22.19	1.283	1.685	0.669	.878	0.434	.570	0.110	.140
23.16	1.336	1.754	0.685	.894	0.445	.584	0.115	.151
24.13	1.388	1.823	0.704	.924	0.454	.596	0.120	.157
25.09	1.442	1.894	0.722	.948	0.463	.609	0.125	.164
26.06	1.496	1.965	0.741	.973	0.472	.619	0.130	.170
27.02	1.549	2.034	0.761	.999	0.479	.629	0.135	.177
27.99	1.603	2.105	0.780	1.023	0.486	.638	.....	....
28.95	1.656	2.175	0.801	1.052	0.493	.647	.....	....
30.88	1.758	2.309	0.842	1.106	0.511	.671	.....	....
32.81	1.861	2.444	0.881	1.157	0.530	.696	.....	....
34.74	1.966	2.582	0.919	1.207	0.547	.718	.....	....
36.67	2.020	2.718	0.955	1.254	0.565	.742	.....	....
38.60	.....	.....	0.992	1.302	0.579	.764	.....	....
40.53	.....	.....	.....	.....	0.594	.780	.....	....

SOLUBILITY OF AMMONIA IN WATER AT DIFFERENT TEMPERATURES.

Degrees Fahr.	Lb. of NH_3 to 1 lb. of water.	Vol. of NH_3 in 1 vol. of water.	Degrees Fahr.	Lb. of NH_3 to 1 lb. of water.	Vol. of NH_3 in 1 vol. of water.
32.0	0.899	1,180	125.6	0.274	359
35.6	0.853	1,120	129.2	0.265	348
39.2	0.809	1,062	132.8	0.256	336
42.8	0.765	1,005	136.4	0.247	324
46.4	0.724	951	140.0	0.238	312
50.0	0.684	898	143.6	0.229	301
53.6	0.646	848	147.2	0.220	289
57.2	0.611	802	150.8	0.211	277
60.8	0.578	759	154.4	0.202	265
64.4	0.546	717	158.0	0.194	254
68.0	0.518	683	161.6	0.186	244
71.6	0.490	643	165.2	0.178	234
75.2	0.467	613	168.8	0.170	223
78.8	0.446	585	172.4	0.162	212
82.4	0.426	559	176.0	0.154	202
86.0	0.408	536	179.6	0.146	192
89.2	0.393	516	183.2	0.138	181
93.2	0.378	496	186.8	0.130	170
96.8	0.363	478	190.4	0.122	160
100.4	0.350	459	194.0	0.114	149
104.0	0.338	444	197.6	0.106	139
107.6	0.326	428	201.2	0.098	128
111.2	0.315	414	204.8	0.090	118
114.8	0.303	399	208.4	0.082	107
118.4	0.294	386	212.0	0.074	97
122.0	0.284	373	......	......	....

STRENGTH OF AMMONIA LIQUOR.

% of ammonia by wt.	Sp. grav.	° Beaumé water 10.	° Beaumé water 0.	% of ammonia by wt.	Sp. grav.	° Beaumé water 10.	° Beaumé water 0.
0	1.000	10	0	20	0.925	21.7	11.2
1	0.993	11	1	22	0.919	22.8	12.3
2	0.986	12	2	24	0.913	23.9	13.2
4	0.979	13	3	26	0.907	24.8	14.3
6	0.972	14	4	28	0.902	25.7	15.2
8	0.966	15	5	30	0.897	26.6	16.2
10	0.960	16	6	32	0.892	27.5	17.3
12	0.953	17.1	7	34	0.888	28.4	18.2
14	0.945	18.3	8.2	36	0.884	29.3	19.1
16	0.938	19.5	9.2	38	0.880	30.2	20.0
18	0.931	20.7	10.3				

SOLUBILITY OF AMMONIA IN WATER AT DIFFERENT TEMPERATURES—Roscoe.

Degrees Celsius.	Degrees Fahrenheit.	Pounds of NH_3 to one lb. water.	Degrees Celsius.	Degrees Fahrenheit.	Pounds of NH_3 to one lb. water.
0	32.	0.875	28	82.4	0.426
2	35.6	0.833	30	86.	0.403
4	39.2	0.792	32	89.6	0.382
6	42.8	0.751	34	93.2	0.362
8	46.4	0.713	36	96.8	0.343
10	50.	0.679	38	100.4	0.324
12	53.6	0.645	40	104.0	0.307
14	57.2	0.612	42	107.6	0.290
16	60.8	0.582	44	111.2	0.275
18	64.4	0.554	46	114.8	0.259
20	68.	0.526	48	118.4	0.244
22	71.6	0.499	50	122.	0.229
24	75.2	0.474	52	125.6	0.214
26	78.8	0.449	54	129.2	0.200
			56	132.8	0.186

COMPARISON OF DEGREES BEAUME WITH SPECIFIC GRAVITY.

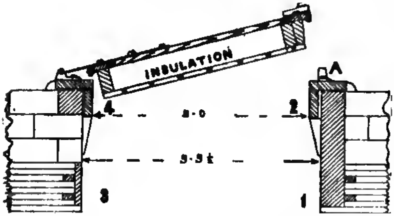
°B.	Sp. grav.	°B.	Sp. grav.	°B.	Sp. grav.
10	1.000	23	0.918	36	0.849
11	0.993	24	0.913	37	0.844
12	0.986	25	0.907	38	0.839
13	0.980	26	0.901	39	0.834
14	0.973	27	0.896	40	0.830
15	0.967	28	0.890	41	0.825
16	0.960	29	0.885	42	0.820
17	0.954	30	0.880	43	0.816
18	0.948	31	0.874	44	0.811
19	0.942	32	0.869	45	0.807
20	0.936	33	0.864	46	0.802
21	0.930	34	0.859	47	0.798
22	0.924	35	0.854	48	0.794

DOORS

Doors are a weak point in all storage rooms. Their insulation is important, but their tightness and quick operation is vastly more so. A leak is an endless expense. Slow moving doors are hardly less so. Doors that bind and work badly are shut only when the workman can find no excuse for leaving them open, which is seldom, if ever.

The following sketches show constructions which are patented and which are especially contrived to avoid these troubles.

The door makes an overlapping contact, with a soft hemp gasket in the joint, and is held to its seat against the front of the door frame by powerful elastic hardware. The thick portion of the door fits loosely, so that considerable change of size, form and position, due to wear, swelling, etc., does not make it leak or bind.



Where all old style doors, when they work badly or leak, must be eased, thus forever destroying their fit, a slight readjustment of the doorframe of these doors, restores them to their original perfection of fit and freedom in a minute, at no expense.

As these doors do not stand in the doorways when open, it can be six inches less in width than old style doorways—an important economy in refrigeration.

As remodeled this year, 1911, our time honored locking fastener is vastly improved, both in strength and security. Our new automatic roller fastener, used, if preferred. The opening in wall to receive these doorframes should be 3½ inches wider and 4½ inches higher than size of doorway in the clear.

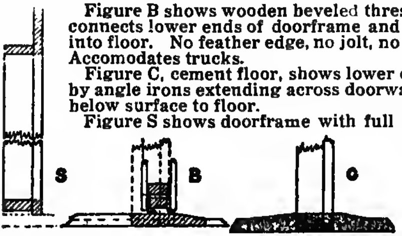


Figure B shows wooden beveled threshold, 1¾ inches thick, which connects lower ends of doorframe and forms a part of it, let down into floor. No feather edge, no jolt, no splinters. For warehouses. Accomodates trucks.

Figure C, cement floor, shows lower end of doorframe connected by angle irons extending across doorway from one side to the other below surface to floor.

Figure S shows doorframe with full standard sill and head used on all sizes of doorframes. Suited only to walking through.

Special doors on a modified plan for intermittent or continuous freezers, as well as for general purposes, perfectly tight and perfectly free, regardless of temperature, moisture or accumulation of ice in any degree.

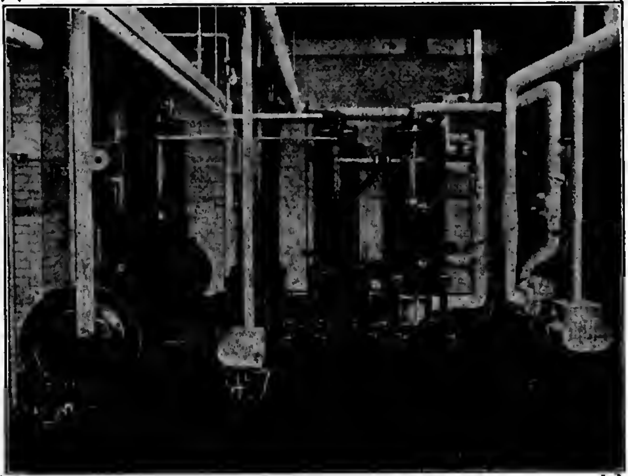
Metal covered fireproof doors.

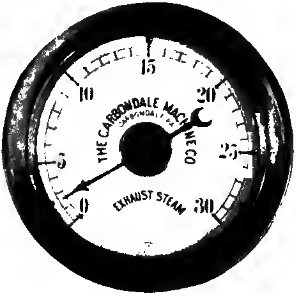
Vertical sliding insulated doors, counterbalanced. A perfect seal when closed. For breweries, racking rooms and bottling houses.

Combined Self Closing Ice Door and Chute of three styles, and Ice Counters.

Patents are granted or applied for on every valuable feature of this work. Infringers will be prosecuted.

STEVENSON COMPANY - - - CHESTER, PA.

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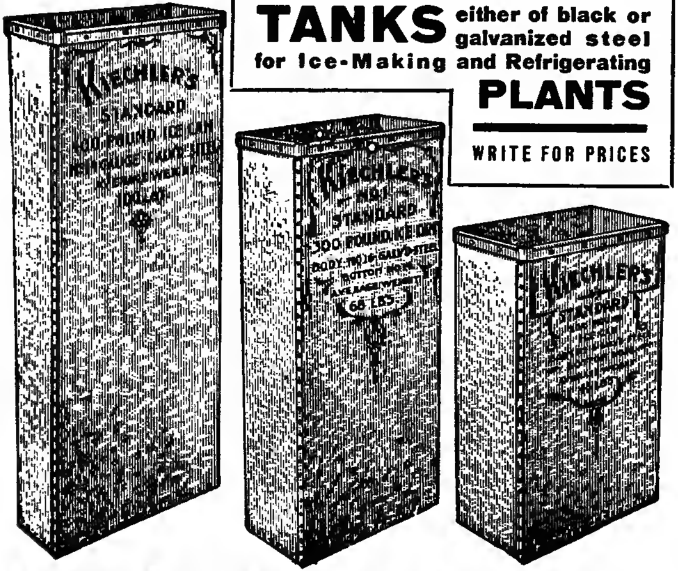
THE CARBONDALE MACHINE CO
EXHAUST STEAM



TANKS either of black or galvanized steel for Ice-Making and Refrigerating **PLANTS**

WRITE FOR PRICES

Manufactured from "APOLLO" BEST BLOOM GALVANIZED SHEETS

KIECHLER'S

STANDARD
GALVANIZED
STEEL

ICE CANS

ALSO MANUFACTURERS OF

TANKS, RE-BOILERS

Filters, Skimmers, Distributing Troughs, Etc.

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The Kiechler Manufacturing Co.

Established 1861 POWER SHEET METAL WORKS Incorporated 1890

CINCINNATI, OHIO, U. S. A.

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