A STUDY OF MECHANICAL REFRIGERATION

and test run on M.A. C. Dairy

REFRIGERATION PLANT.

A THESIS SUBMITTED TO

The Faculty of

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HISTORICAL.

THE DEVELOPEMENT OF COLD STORAGE.

Mother earth as a source of available refrigeration, is without doubt a pioneer. In the temperate zone at a depth of a few feet below the surface, a fairly uniform temperature of about 50° to $60^{\circ}F$, is to be obtained at all seasons. In some cases a much lower temperature is obtained. The same principle is true in any climate, the earth acting as an equalizer between extremes of temperature, if such exist. Caves in the rock, of natural formation, are in existance, in which ice remains the year around, and many caves are used for the keeping of perishable goods. The Ruskin Co-operative Colony, located at Ruskin, Tennessee, has a fine large cave on its property which is utilized as a cold storage warehouse. The even temperature, dryness and purity of the atmosphere to be met with in some caves are quite remarkable, owing no doubt to the absorptive and purifying qualities of the rock and earth, as well as to the low temperature obtainable.

CELLARS.

Cellars are practically caves built by the hand of man, and if well and properly built are equally good for the purpose of retarding decomposition in perishable goods. A journey through the Western states reveals many farmers who are possessors of "root-cellars" considered the first necessity of successful farming, the new settler building his cellar at the same time as his log house. A root-cellar is used partly as a protection against frost, but it also enables the owner to keep his vegetables in Fair condition during the warm weather of spring

CELLARS. (CONDT).

and summer months. The use of cellars for long keeping of dairy products is familiar to all. Many of us can recollect how our Mothers put down butter in June and kept it until the next winter, and perhaps it will be claimed by some, that the butter was as good in Janurary as when it was put down. It is not as good, far from it. If you think it was, try the experiment to-day and you will see how it will taste and how much it will sell for in Janurary in competition with the same butter stored in a modern freezer. The butter made years ago was not better either. No better butter was ever made than we are producing to-day. In short, cellars were considered good because they had no competition- they were the best before the advent of improved means of cooling. Cellars are still of value for the temporary safe keeping of goods from day to day, as for the storage of goods requiring only a comparatively low temperature, but with a good refrigerator in the house, the chief duty of a cellar, nowadays, is to contain the furnace, and as a storage for coal and other nonperishable household necessities.

ICE.

The use of ice as a refrigerant during the summer months is a comparatively modern innovation, and not until the nineteenth century did the ice trade reach anything like scptematic developement. The possibility of securing a quantity of ice during cold weather and keeping it for use during the heated term seems not to have occured to the people of revolutionary times. About 1805 the first large ice house for the storage of natural ice

ICE. (CONDT).

was built, and with a constantly increasing growth, the business increased to immense proportions in 1860 to 1870. The amount harvested is now much larger than at that time and constantly increasing, but the business is now divided between natural ice and that made by Mechanical means.

Mechanical refrigeration in which the storage rooms are cooled by frozen surfaces, usually in the form of brine or ammonia pipes, was much superior to ice refrigeration, in that the temperature could be controlled more readily and held at any point desired and that a drier atmosphere was produced. Ice is at present and will probably always remain a very useful and correct medium of refrigeration, especially for the smaller rooms and certain purposes.

THE PRINCIPAL USES OF REFRIGERATION ARE AS FOLLOWS:

(1) Prevent premature decay of perishable products.

(2) Lengthen the period of consumption and thus greatly increase production.

(3) Enable the owner to market his products at will.

(4) Make possible transportation in good condition from point of production to point of consumption, irrespective of distance.

(5) Cooling the air of buildings for the comfort of the inhabitants.

(6) Prevent the destroying of goods by insects, etc.

(7) Manufacture ice cream.

(8) Manufacture ice.

First: Without refrigeration there would be much actual waste from decomposition before it would be possible to place perishable food products in the possesion of the consumers. The immense fruit trade of the Pacific coast would never have been developed without the assistance of refrigeration, nor could the surplus meat products of the southern hemishpere have been brought half way around the globe to relieve the shortage in thickly settled England without its aid. Without the aid of refrigeration to create a constant market, the production of meats, eggs, fruits and other food products would be greatly curtailed.

Second: In many classes of produce the ordinary season of consumption was formerly limited to the immediate period of production, or but briefly beyond. Now nearly all fruits may be purchased at any season of the year and dairy and other products are for sale in good condition and at reasonable prices the year around.

Third: Instead of being obliged to sell perishable goods, when produced or purchased, at any price obtainable, the owner can now put away in cold storage a portion or all of his products to await a suitable time for selling. This not only results in a better average price to the producer, but places perishable food stuffs at the command of the consumer at a reasonable price at all times and greatly extends the period of profitable trading in such products.

Fourth: The certainty and perfection with which food products may be conveyed from the place of production to the large centers of population where they are to be consumed is one of the triumphs of refrigeration; yet the refrigerator car service is only in its infancy as far as perfection of results is concerned. It is safe to say that our immense Pacific coast fruit trade could not exist without it.

Cold storage is a benefit to all mankind in that it allows of a greater variety of food during all seasons of the year. Some of the advantages of preservation by refrigeration are:

(1) It has been proved the most effective as a preservation, surpassing in efficiency, salting, boric compounds, or any other practical method.

(2) It adds nothing and subtracts nothing from the article preserved, not even the water, and in no material sense alters its quality.

(3) It causes no change of appearance or taste, but leaves the meat or other substance substantially in its original condition, while it renders it neither less nutritious nor less digestible, which cannot be said of some other methods in common use.

Fifth: Should artificial cooling of buildings become at all common, considerable care must be excercised by those entering such buildings from a considerably higher outside temperature if "colds" or more serious forms of bodily disorders are to be avaided.

Air cooling has already assumed considerable commercial importance in several industries, notably in the manufacture of chocolate and in the operation of blast furnaces.

In order to determine the capacity of the refrigerating machinery necessary to maintain a given room or building at a predetermined temperature and relative humidity, under certain prescribed conditions of outside temperature and humidity, the engineer must not only be able to predict with considerable accuracy the amount of heat that will enter the room or building in question from the outside, under the conditions assumed, but he

must also make proper allowance for the amount of heat generated within the room or building, both by its human occupants and the illuminants which are used.

Sixth: The placing of furs and such fabrics as carpets, tapestries, clothing, woolens, etc., in cold storage in order to protect them against the inroads of those insects which prey upon them during certain portions of the year, is now generally recognized as the most satisfactory method of dealing with this important problem.

It was found that any temperature below 45° F was sufficient to keep the larvae of both the moth and bettle from doing any damage to furs or fabrics.

Seventh: The wholesale manufactures of ice cream which was begun in this country by Fussell in the early fifties, reached an estimated yearly output of 113,000,000 gallons, valued at nearly $100,000,000 during the year 1911.

Mechanical refrigeration is at present made use of in the ice cream industry in one of three years.

1 st. It may be used only for freezing, hardening and storing the ice cream.

2 nd. It may be employed simply for the manufacture of ice, the freezing, hardening, and storing of the ice cream then being accomplished by the old ice and salt method, or by the use of brine refrigerated by means of ice.

3rd. It may be used directly in the manufacture and storage of the ice cream and, in addition in the production of the ice required in the shipment of the finished product.

ICE MANUFACTURE.

Eighth: Next in importance to the direct utilization of refrigeration for the cooling of perishable products is that of artificial ice making. There are a number of systems which may in the future modify present methods, practically all the ice produced today is made either by the can or plate system. The can system is the more common of the two, being cheaper in first cost and requiring less attention in manipulation. The plate system, however, has the advantage of being more economical in the end and of giving a clearer ice.

The can system:

The apparatus used consists of a larger rectangular wood or iron tank containing the expansion coils or pipes. Galvanized-iron cans are placed between the rows of expansion coils. These cans are filled with distilled water and when the brine is chilled below the freezing point, the water in the cans freezes. If the temperature of the brine is not allowed to fall below 25° and ordinary well-water is used in the cans, the ice produced will be comparatively clear on the outside and rather snowy in the center. If, however, the brine temperature is allowed to fall to about 15°, the ice will be ebtirely opaque.

To get good clear ice, distilled water is used. The white appearance in ice made from non-distilled water is due to minute air-bubbles which are held in suspension in the water and frozen in the ice, forming a sort of snow. In case of distilled water, this air is eliminated by boiling and subsequent evaporation.

In the ordinary ice factory, the distilled water is usually made by condensing the exhaust steam of the engine operating the compressor in case of a compression plant, or by cooling the condensed steam that leaves the generator, still,or retort of the absorption plant. Usually this does not furnish enough condensate for the amount of ice made. It is therefore necessary to draw from the boilers.

Plate system of manufacturing ice:

Mechanically, a plate plant is so constructed that the raw undistilled water to be frozen is brought in contract with plates of sheet metal bolted to either brine or direct expansion coils, in which a sufficiently low temperature is maintained to bring about the necessary heat transfer from the water at 32° . These plates which are not usually less than 14 feet long by 10 feet deep are submerged in the plate tank. The refrigerating agent is allowed to flow through the coils until ice has accumulated to a thickness of 12 to 14 inches on the plate. The cold brine or ammonia is then shut off and hot brine or ammonia is circulated through the coils until the ice is loosened from the plate and floats free in the water. Chains are then fished around the cake and it is hoisted from the tank by a traveling crane and carried to a tilting table, where it is carefully deposited to avoid breaking. Here it is sawed into cakes.

INSULATION.

The vital Importance of Insulation:

For a good many centuries men have known better than to store wine in leaky vessels. To-day no one allows steam, that ought to be turning machinery, to escape from broken pipes. Nor is electric power permitted to go to waste by failure to insulate properly the supports on which the wires are carried. Yet many men pump refrigeration into rooms day after day, making little or no intelligent effort to prevent the heat from constantly leaking back.

Its importance is frequently overlooked. The reason for this neglect may be sought in several quarters. Heat is a very commonplace thing. We experience its effect every hour that passes. There does not seem to be anything particularly wonderful about it. But if we stop to consider, we find ourselves face to face with the fact that all known forms of energy, it is the most powerful and allpervading. We can shut out the light; certain substances are impervious even to X -rays, but as for heat, nothing will completely stop its passage.

No one needs to be told the part of refrigerating machine is to play in keeping a room cooled to proper temperature. One can see the wheels go round and watch the measured stroke of the compressor. As for the insulating material, what good does it do? So the average man is apt to reason. Get anything that will fill up space fairly well, stuff the walls, floors and ceilings, and let it go at that. Insulation does not show; it will all be covered up anyway. Why bother much about it, or spend time and money in designing and installing it?

Good insulation is true economy.

At this point, by following this natural but erroneous reasoning, many plant owners make their first big mistake, the results of which follow hard on their trail for many a year, revealing themselves in the form of increased operating expense, rapid depreciation of machinery and insulation repairs. The fact is that the insulation of any cold storage room is just as important as the refrigerating machinery. Three fourths of the work of the machine in the average plant is done to remove the heat that leaks in through the walls, floors and ceilings; but one-fourth goes to cool the goods in storage.

If you use ice, seventy-five out of every one hundred ounds put in your coolers is melted by the heat that works its way in from all sides. This loss cannot be prevented entirely, because no material is heat-proof. It is possible, though, to cut it down to a point, neither above which nor below which you can profitably afford to go. If any plant is to operate on a truly economical basis, it must be protected against heat to a point where the saving in operating expense, effected by additional insulation, would not be offset by the extra cost involved.

As a well known refrigerating engineer has said: "Insulation should be considered in the light of a permanent investment, just as buildings and equipment, the returns of which should be based on the savings effected by the lower operating cost. It is a great deal cheaper to prevent heat from entering a building than to remove it by means of refrigeration".

The word insulation is derived from a Latin word meaning island. The significance therefore, of the definition of insulate,

as given in the dictionary will be readily grasped. " To place in a detached situation having no communication with surrounding objects". In insulating a cold storage room, what the engineer tries to do, is to make it an island in the ocean of heat.

Heat, though, has several ways of getting about. It can pass through space on the ether waves without appreciably heating the air. Stand in front of a stove and the truth of this assertion is self-evident. Or, perhaps, the sensation of warmth that one feels in bright sunlight on a cool day is a better illustration of the radiation of heat, as this method of its transference is called.

When the problem of insulating a cold storage room is under consideration, however, the other two ways that heat moves are of more importance. By conduction is meant the transference of heat waves from one molecule or particle of matter to another. For instance, put one end of a poker in the fire and soon the other end will get hot, although far removed from the source of heat. This is exactly the process that goes on in the walls of a cold storage rooms. The outisde is heated by the sun's rays as the warm air. The Molecules on the surface are first set in motion. Gradually the vibratory movement spreads and goes deeper and deeper into the wall. When the Molecular excitement gets into the insulation, it travels forward less rapidly. The process of the heat is impeded, just as piling along the water front breaks the force of the incoming waves. Still, some of the heat eventually passes through, the amount depending upon the efficiency of the insulation. Slowly but surely the temperature of the room rises, unless refrigeration is continuously applied to offset the heat leakage.

The heat conductivity of dense substances-metals, whose molecules are heavy and close together- is very high; the conductivity of lighter material, such as wood, is less, while that of the gases is extremely low. Hence, air, the most available gas, is the most efficient insulator that can be had, if a vocumn, impracticable on a large scale, be excepted. But the problem is to confine it so that it cannot circulate; for the transmission of heat is also effected by another means called <u>convection</u> , or in other words, the carrying of heat from one point or object to another by means of some outside agent, such as air or water, or any gas or fluid. Convection is the principal utilized in the ordinary house furnace. The outside air is drawn in through a duct, is heated, and risers through pipes to the various rooms, its place being taken by a new supply of cold, heavy air, which passes through the same process.

On a miniature scale, this is exactly what takes place in every form of insulation. The side next to the outer air is warmer than the side next to thr cold room. The air against the outer wall of each air space in the insulation becomes heated and rises, its place being taken by the cold air from the other side. As this becomes warm, it forces its way upward; the other part, having gradually cooled, drops to the bottom, and thus a constant circulation is set up inside the air space itself. This movement tends to equalize the temperature on both sides of the air space and will continue as long as there is any difference in temperature. The fewer the air spaces, the more rapidly will heat pass from one side of insulation to the other. Therfore, the best insulation is that which embodies the greatest number of the smallest possible air spaces, for the smaller the air spaces the less extensive will be of effect of the circulation of the air confined therein. The problem is then, so far as the nonconductio

of heat is concerned, to find some material which contains a large amount of entrapped air absolutely confined in minute particles.

To meet the demands of modern cold storage construction, however, suitable insulating material has to posses a number of other qualifications besides being an excellant nonconductor of heat. The plant owner demands that the insulation he installs shall retain its efficiency indefinitely. This is merely another way of saying that it must not absorb moisture, for water is a good conductor of heat, and any insulating material that will absorb it, will in a short time become worthless.

Sanitation requires that all insulating material shall keep free from rot, mold and offensive oders, and be varmin and germ proof. The delicacy of certain food stuffs, such as milk, cream, butter and eggs, requires that the insulation shall be odorless, as otherwise there is danger af tante.

Economical building calls for the use of an insulation that will occupy the least possible room and leave the maximum amount of storage space. Expediency demands that the material be easily erected and have ample structural strength. The fire underwriters insist on the fire risk being reduced, as far as possible, by the installation of some material which will not only be slow burning, but will leave no flues in the walls to assist in the spreading of fire once under way. Finally the material must be reasonable in cost.

It next confronts one to supply materials which will meet these requirements.

Such materials as chopped straw, and hay, dried grass, leaves, chaff and various grains have been used especially in

rural districts due to then cheapness and availibility.

They are used very little for cold storage due, to their short life. Sawdust and shavings are somewhat longer lived then the before mentioned materials. Mineral wool, sheet cork, hair felt, quilt insulators, and insulating papers, are most commonly used for cold storage work.

Any one, or a combination of the above named insulating materials may be used.

In its broader sense refrigeration may be defined as the process of cooling, but since cold is but the absence of heat, as dark is the absence of light, refrigeration may be more acurately defined as the process of extracting heat. The best way to abstract heat from any substance is by placing near it another substance materially lower in temperature, under which condition the tendency is for the heat to flow from the substance of the higher temperature to that of the lower- just as water flows from a higher to a lower level. The result being that the colder substance is heated while the hotter is refrigerated.

Refrigerating systems may be divided into two groups: Those producing cold by more or less chemical action or chemical systems, and those producing cold by the evaporation of a compressed gas or mechanical system. Chemical systems are used only occasionally in commercial work, but are frequently found in small sized plants for domestic purposes. Low first cost and the conveniences of handling are the principal advantages. The simple melting of ice is purely mechanical while mixing the ice with salt, sodium chloride, ammonium, chloride and etc. to produce lower temperatures is a chemical process. Many different combinations of

ingredients are used in mixtures to produce cold or maintain low temperatures in storage rooms while repairs are being made upon the regular machinery. The chemical methods of cooling are so simple that there is no cause for further discussion. Mechanical systems include the practical commercial methods of refrigeration. The systems now in use are, the vacuum system, the cold air system, the compressor system, and the absorption system.

The Vacuum System:

The vacuum machine employs water vapor as the refrigerating fluid. From the fact that water vapor in order to have a low temp. must have a very low tension, arises the name "Vacuum" machine.

The operation of the vacuum machine is precisely similar to that of an ammonia compressor machine. The vacuum is formed by a pump, which withdraws the vapor from the refrigerator, where the pressure is about one pound per square inch or less, and compresses it into a condenser at a pressure of about 1.5 pounds. The evaporation of a part of the water in the refrigerator withdraws enough heat from the remainder to turn it to ice: or if the refrigerator contains brine, the heat absorbed by evaporation lowers the temperature of the brine.

In a vacuum machine of this type the vapor cylinder must have a capacity of about 150 times that of an ammonia compression machine for the same tonnage. The number of gallons of condensing water per ton of ice melting capacity, assuming a range of 30^{o} F in the condensing water, is 340. The ice melting capacity per

pound of coal, assuming three pounds of coal per hour per horsepower, is about 25 pounds.

It is evident that the enormous size of a vacuum machine of this type puts it out of competition with other refrigerating-machines.

In another form of vacuum machine, the use of the large compressor in avoided by the use of sulphuric acid as an absorbent. The sulphuric acid maintaining a vacuum by absorbing the vapor from a spray and thus lowering the temperature of the remainder of the spray. The principal objection to the use of sulphuric acid is that the acid is an inconvenient liquid to handle. It must be handled in lead or lead lined pipes.

COLD AIR SYSTEM.

The cold air system is used primarily on ship board. The cycle has four parts, compression in one of the cylinders of the compressor, cooling in the air cooler by giving off heat to the cold water thus removing the heat of compression, expansion in the second cylinder of the compressor thus cooling the air, and refrigeration in the cold storage room where the heat lost during expansion is regained from the articles in cold storage.

Since the specific heat of air is .2377 and that of Ammonia (NH_3) is about .54, and as air is liquified at - 190° F at atmosphere pressure or at room temperature this would require a pressure of about 3000 lbs. per square inch, which would be very impractical. Therfore the latent heat of evaporation cannot be taken advantage of and used with the air machines as in case of the ammonia machines where at atmosphere pressure the ammonia liquifies at

− 28.5^{o} F, or at room temperature the pressure required to liquify the gas is 125 pounds per square inch. The cylinder of the air machine in practice is about twenty times the size of that of an ammonia machine for the same tonnage. This causes the cold air machines to be much less efficient, due to clearence, heating of the compression cylinder, snow in the expansion cylinder, due to moisture in the air, and greater friction losses.

A Comparison between the two systems:

The absorption System is very similar to the compression system in that they both use a refrigerant, that is, a liquid having a comparatively low boiling point. Perhaps the most common refrigerant is anhydrous ammonia which boils at atmosphere pressure, at 28.5 ^{o}F below zero and in doing so absorbs as latent heat 573 B.t.u. Sulphur dioxid (SO_2) is used to a less extent; it boils at 14^{o}F below zero under atmosphere pressure with a latent heat of 162 B.t.u. Carbon dioxide (CO_2) is sometimes used, it boils at 30^{o}F below zero under a pressure of 182 pounds per square inch absolute with a latent heat of 140 B.t.u.

Pictet Fluid was founded by Prof. Pictet, a Swiss physicist who found that a mixture of 97% of sulphur dioxide and 3% of carbon dioxide, commonly known as carbonic acid gas gives a boiling point of 14^{o}F lower than sulphur dioxide. Its latent heat has never been closely determined but is very nearly the same as pure sulphur dioxide.

The choice of a universal refrigerant can scarcely

be made because of the varying conditions of individual plants. The principal difficulty with the use of (SO_2) sulphur dioxide is the fact that any water uniting with it by leakage immediately produces sulphorous acid with its conoding action upon all the iron surfaces of the system. The objection to the use of carbon dioxide are, first, its comparatively low latent heat, and second, the high pressure to which all parts of the apparatus and piping are subjected. Pressures of from 300 to 900 lbs. per square inch are very common. Perhaps the worst charge that can be made against ammonia as a refrigerant is that it is highly poisonous and corodes metals, particularly copper and copper alloys. However, the high latent heat of ammonia, together with the fact that its pressure range is neither so high as with carbon dioxide, nor so low as with sulphur dioxide,[15] perhaps the chief reason for the very general use of ammonia as the commercial refrigerant in compression systems; while its great affinity for, and solubility in water, are what makes the absorption system a possibility.

THE ABSORPTION SYSTEM.

The great affinity of ammonia gas for water and its solubility therein, are what makes the absorption system a possibility and give it the name as well. At atmospheric pressure and 50° F temperature one volume of water will absorb about 900 volumes of ammonia gas. At atmospheric pressure and 100° F temperature one volume of water will absorb only about one half as much of the ammonia gas, or 450 volumes. It is then quite evident that a stream of water may be used as a conveyor of ammonia gas from one place or condition to another, say from a condition of low temperature

and pressure where the absorbing stream of water would be cool, to a condition of high temperature and pressure where the gas would be liberated by simply heating the water. It will be seen that the gas has been transferred as a liquid without a compressor or any compressive action, by pumping a stream of water of approximately one fourth hundred and fiftieth of the vol. of the gas transferred. This is the principal by which the ammonia gas is conveyed from a relatively low temperature and pressure of the evaporator to the high temperature and pressure at the entrance of the condenser, in the absorption system.

The absorption system, when closely compared in principal of operation to the compression system differs, ~~differs~~ only in one respect, that being, the absorption system replaces the gas compressor by a strong and weak liquor cycle.

The typical American absorption machine consists of the following parts: a generator, an analyzer, an exchanger, a rectifier, a condenser, a receiver, an absorber, and an ammonia pump. The operation is as follows: the generator contains a solution of strong ammonia liquor in which the steam coils are immersed. The ammonia in solution, having a lower boiling point than the water, is practically vaporized by the heat from the steam coils leaving a weak solution of ammonia. The gas thus liberated, passes thru the analyzer to the rectifier. Whatever water vapor may have been carried along with the ammonia-gas is condensed here and drips back into the generator.

From the rectifier coils the gas passes into the condenser, is condensed, drains, and is collected in the receiver,

from which it is expanded into the cooler or refrigerator coils. The gas from the cooler passes to the absorber and there meets the incoming weak-liquor from the generator, and is absorbed, forming strong liquor.

This strong liquor is pumped thru the exchanger into the top of the analyzer and runs down over its pans to the generator.

It is desirable to have the strong liquor reach the generator as hot, and the weak liquor reach the absorber as cool, as possible: The exchanger is interposed between the generator and absorber in order that the weak and strong liquors may interchange their heat. The pumps used may be of the direct-acting or gear-driven type.

THE COMPRESSION SYSTEM.

Compression machinery may work well with the use of any one of the following refrigerants: sulphur dioxide, ammonia, carbon dioxide, or Pictet fluid if the proper temperature and pressures are observed and maintained. The common refrigerator for this type is, however, anhydrous ammonia as it presents physical properties which make it a favorite as a frigerant.

To follow the closed cycle of the ammonia, start with a change being compressed in the cylinder of the compressor. From this it is conveyed by pipe to the condenser which, being cooled by water, abstracts the latent heat of the refrigerant See INSERT is conveyed to the expansion valve thru which it expands into the evaporator or brine cooler. In changing from a liquid to a gas in the evaporator it absorbes from the brine an amount of heat

equivalent to the heat of vaporization of the ammonia. Upon leaving the evaporator the refrigerant is again ready for the cylinder of the compressor, thus completing the cycle.

METHOD.

The object of this test was to determine the capacity, efficiency and power input of the M.A.C. Dairy plant under running condition.

In order to take the temperature readings in the water and ammonia pipes it was necessary to place cast iron thermometer wells in the following places:

I AMMONIA TEMPERATURES

(1) On inlet pipe to both hardening and cooling rooms after passing thru the expansion valve.

(2) Outlets to both rooms.

(3) On SUCTION and discharge pipes of compressor.

(4) Between receiver and expansion valves.

II ( ) Water

On outlet cooling water pipe.

(1) On outlet to condensing water and jacket water.

(2) These thermometers, wells were placed on the pipes and packed with plaster of paris.

Alcohol was used in them for low temperatured and machine oil for those on pipes of ordinary temperatures.

Measurements of weight of ammonia and water.

AMMONIA.

As there was no way of measuring the flow of ammonia directly the volume passed was found by the volume of the compressor assuming a volumetric efficiency of 75%.

WATER.

By rearranging the water piping system the jacket and condenser cooling water was collected, each in a separate tank holding a known weight. Knowing the weight of water and the temperature change the B.T.U. abstracted by the cooling water was found.

Brake Test on Motor.

While the plant was not in operation a special cast iron pulley with rim inside for holding water, was placed on the motor.

~~MOTOR TEST~~.

A prony brake consisting of a rectanglar frame, and a rope which was wrapped around the pulley to absorb the power. This frame was placed on platform scales which rested upon a platform under the motor pulley.

Readings were taken as per sheet No 34

Measurements were taken of both the pulleys in order to determine slippage and of the test pulley on the motor to find the length of the lever arm.

The plant consisted of the following apparatus:
One York vertical single acting double cylinder enclosing compressor, six inch bore and six inch stroke. The machine is belt driven, and has a rated capacity of six tons of ice in 24 hours.

One ammonia condenser of York counter current double pipe type, ammonia pipes 1-1/4 dia. The stand is about ten feet long and ten pipes high.

One ammonia receiver and oil separator.

450 feet of 1-1/4 extra heavy continuous welded coils for ice cream hardening room.
750 feet 1-1/4 extra heavy continuous welded coils for cooling milk room.

Two pressure gauges, to indicate the suction and discharge pressures.

One Allis Chalmers electric motor, direct current, 220 volts, 58 amps. 800 R.P.M. No3K196H belted to compressor.

Brine holds in both hardening an milk room to hold the temperature while the machine is not in use.

Oil Separator. Expansion Valves.

The following auxiliary apparatus was used.

5 low reading thermometers.
5 thermometers reading between 0 and 100 degrees.
Two large tanks for measuring the cooling water.
1 speed indicator.
1 voltmeter.
1 prony brake and scales.
2 lengths of hose, about 25 feet each.
1 C.I. Pulley
1 Pr. scales
10 Thermometer Wells
1 Bristol Recorder

In conducting this test the following observations were taken every 30 min.

Ammonia:

Temperature of ammonia entering compressor.

Temperature of ammonia leaving compressor.

Pressure of ammonia gas entering compressor.

" " " " leaving "

Temperature of liquid ammonia after passing through the condenser.

Temperature of gaseous ammonia entering zero room.

" " " " " 32 degree room.

" " " " leaving 32 " " .

" " " " " zero room.

Water:

Temperature of inlet to condenser and jacket.

Temperature of outlet to condenser.

" " " " jacket.

Weight of jacket water.

" " condenser water.

Motor.

Volts, amperes and rev. per min.

R. P. M. of compressor.

A separate test was run on the motor to determine the horse power input to the compressor for each observation of volts and amperes.

The following observations were taken on this test:

R. P. M. of motor.

Volts.

Amperes.

Net weight of brake arm.

Displacement 100% Vol. Eff.

6" x 6" Cyl.

28.27 x 6 = 170 cu. in. in one cylinder.

170 x 2 = 340 cu. in. in two cylinders.

R. P. M. = 102.3

$\frac{340 \times 102.3}{1728}$ = 20.1 cu. ft. Min. Displacement

20.1 x 60 x 24 = 28950 cu. ft. in 24 hrs.

Amount of Ammonia Circulated.

Avg. temperature of gas entering compression = 40.6 F

Gauge Press = 9.1 = 23.8 = ABS.

1# Ammonia at 40.6° F & 23.8# ABS. = 13.3 cu. ft.

According to tables of superheated ammonia in tables in Kent Pg. (1341)
(by interpolation)

$\frac{28950 \text{ cu. ft.}}{13.3 \text{ cu. ft}}$ = 2172 # Ammonia in 24 hr. Theoretical.

Refrigerating Eff. Theoretical.

Latent Heat of Ammonia 9.1 gage press = 561.6 B.T.U.

2172 = wt. of Ammonia circulated.

2172 x 561.6 = 1,235,000 B. T. U. in 24 hr.

Avg. Temp. entering expansion valves. = 67.8 °F

" " after complete expansion = 35.6 "

32.2

Specific heat of Ammonia gas = .508 (~~P 770~~

Wt x Sp heat x t e m change = B.T.U.

2172 x .508 x 32.2 = 35500 B.T.U. Used in cooling the ammonia and not available for refrigerating.

1,235,000 - 35500 = 1,200,000 B.T.U. Available.

Heat Required to Melt 1# Ice = 144 B.T.U.

1 Ton = 2000 x 144 = 288000 B.T.U.

1,200,000 ÷ 288000 = 4.15

4.15 Theoretical Tonnage 100% Eff.

Using 75% Vol. eff.

Tonnage = 3.12 tons per 24 hr.

Work of Adiabatic Compression.

P_1 = 23.8 abs.

T_1 = 40.6° F

P_2 = 167.7 abs.

T_2 = 124°.4 F.

Temp. corresponding to P_1 = - 10° F (Saturated)

40.6 - (-10) = 50.60°F = superheat at suction

Entropy at this point = 1.267164

Assuming adiabatic expansion and

Constant entropy change

From tables

Total heat at P_2 T_2 = 715.6 B.T.U.

Total Heat at P_1 T_1 = 567.9 "

Diff = 147.7

2172# of Ammonia in 24 hrs.

2172 x 147.7 = 321000 B.T.U. in 24 hrs.

Work of Compression (Assuming Adiabatic Change of State)

Cooling Water

Wt. of Water passed (Jacket) = 717#/hr.

Change of temp. in (Jacket) = (68.9° -61.5°) = 7.4° F

717. x 7.4 = 5310 B.T.U. pet hr.

5310 x 24 = 128000 B.T.U. in 24 hr.

Wt. of water/hr. passed (cond) = 1620#

Change of tem. = (71.9 - 61.5) = 10.4° F

1620 x 10.4 = 16850 B.T.U./hr.

16850 x 24 = 405000 B.T.U./DAY.

405000 + 128000 = 533,000 B.T.U.

Absorbed by cooling water in 24 hr

Heat Balance.

(Heat of Refig) + (Heat of comp) = B.T.U. Taken up by water

+ losses

Refig.		Comp.		Water		Rad.
1335000	+	321000	=	533000	+	1023000

EFFICIENCY (Wood P 322)

of Compressor $= \frac{\text{Energy obtained (work done)}}{\text{(Energy Expended)}}$

$E = \frac{H_2}{H_1 - H_2}$

H_1 = heat carried away by condenser

H = heat taken from ref. room

$Eff = \frac{1,200,000}{263,500} = 4.74$

The reason for his eff being greater than unity is because this is a heat engine reversed.

K.W. Hrs. Per Ton Refig.

5.44 K W x 24 = 131 K. W. hrs per day

$\frac{131}{3.12} = 42.$ K.W. houss per ton ref.

Motor Ave. Read.

Load Gross	Net	Volts	Amps	R.P.M.
0	0	211	4	753
25	9.375	210	6.5	750
50	34.375	206	15	730
75	69.375	203	22	709
90	74.375	200	25	701
100	84.375	199	28	695
110	94.375	198	31.	687
120	104.375	196	35	682
130	114.375	195	37	675
140	124.375	195	40	663

Load	Input			Output
Gross	H.P.	K.W.	Eff	B.H.P.
0	1.13	.844	0%	0.%
25	1.83	1.364	47%	.86
50	4.14	3.090	74%	3.06
75	6.1	4.540	95.6	5.83
90	6.7	5.000	94.7	6.35
100	7.47	5.570	95.5	7.15
110	8.23	6.140	96.	7.9
120	9.18	6.850	94.	8.6
130	9.65	7.200	97.4	9.4
140	10.48	7.800	95.5	10

Time.	Cooling Water Temperature C°			Compressor Tempture		Compressor Press			Zero Room Temp.		32° Room Temp.		Receiver Temp.	Motor.			
Inlet	Inlet	Condenser Outlet	Jacket Outlet	Suction f	Discharge c	Suction	Discharge	R.P.M.	Inlet	Outlet	Inlet	Outlet		Volts	Amperes	R.P.M.	
8:30	14	18	16	50	33	4	133	100	60	35	15	60	16	205	26	700	Friday Mar. 31. 1916
9:00				55	42	5	160	102	20	39	2	54	16	205	25	708	
9:30	16	20	20	58	53	6	150	105	12	45	5	51	17	205	24	712	
10:00	17	24	22	61	53	5	150	102	95	49	5.5	50	19	200	24	712	
10:30	17	22	21	63	53	5	145	102	6	49	5	51	19	200	24	715	
11:00	18.5	21	31	64	54	6	180	104	10	48	8	52	20	200	26	718	
11:30	17	20	20	63.5	55	7	145	103	13	46	8	53	21	200	25	712	
12:00	18	24	23.5	63.5	53.5	8	155	102	12	45	10	53	21	200	27	703	
12:30	17.5	25	23.	2	56.5	2	157	104	11	16	2.5	51	22	200	28	715	
1:00	18.	23.5	22	2	54	10	157	103	16	13	10	465	22	200	28	712	
1:30	17	22.5	17	2	51	8	152	100	15	11	10	44	22	125	28	698	
2:00	17	24	17	0	49	8	155	102	15	10	10	41	23	195	28	710	
2:30	16.5	22.5	23.5	3	49	7	157	103	12	9	10	42	22	200	28	712	
3:00	19	22.5	28	1	51	7.5	170	102	13	8	9	47	22	198	29	710	
3:30	17	21	17.5	4	53	7	152	102	12	17	9	50	215	200	27	710	
1:30	15	19	18°	16c	50°	6#	130#	103	13.5	44.5	45	50.2	64°F	200	26	718	Thur. P.M. Mar. 30th
2:00	15	22	19	14	51	8#	150	103	14	29.5	4.5	51	64 F	200	28	721	~~64°F=17.~~
2:30	16	23	20	0F	53	15	155	102	14	12°	12°	40°	17°CF	200	28	720	
3:00	16	21	19	6F	51	8	145	103	9°	11	9	22F	19C	200	28	721	
3:30	16	20	20.5	13	50	7	143	104	7°	10	5	29°	19C	200	26	723	
4:00	17	24	25	23	52	7	153	103	7°	27	6°	44°	20C	200	28	722	
	95/6	129/6	121.5/6	60/6	307/6	51/6	876/6	618/6	64.5/6	134.0/6	41/6	236.2/2	110.4/6		164./6	4325/6	
Mean	15.8	21.5	20.25	10	51.16	8.5	146	103	10.75	22.3	6.8	39.3	18.4	200	2[illegible].3	720.8	
F° =	60.4	70.6	68.4	50	124								65.1				

FARENHEIT.

Time.	Cooling Water. Temperature. Inlet	Cooling Water. Temperature. Condenser Outlet	Cooling Water. Temperature. Jacket Outlet	Compressor. Temp., Suction	Compressor. Temp., Discharge	Compressor. Press, Suction	Compressor. Press, Discharge	Compressor. R. P. M.	Zero. Room. Temperature Inlet	Zero. Room. Temperature Outlet	32° Room, Temp. Inlet	Temperature. Outlet	Temperature. Receiver	Motor. Volts	Motor. Amperes	Motor. R.P.M.
Mar. 30	60.4	70.7	68.4	50	124	8.5	146	103	10.75	22.3	6.8	39.3	65.1	200	27.3	720
30	63.8	72	70.8	32	123	6.85	154.5	102.3	15.77	28.7	8.4	49.7	68.3	200	26.3	710
Apr. 1st	60.2	73	67.4	39.9	126.3	12.08	158.46	101.5	14.94	37.38	16.2	46.2	69	203	27.7	710
otal	184.4	215.7	206.6	121.9	373.3	27.4	459	306.8	41.4	88.4	31.4	125.2	203.4	603	81.3	214
Avc.	61.5	71.9	68.9	40.6	124.4	9.1	153	102.3	13.8	29.5	10.5	41.7	67.8	201	27.1	713.

31

00	14	14.5	14	4°	37	1	135	100	3	37	3.5	24	18	205	
30	14	23	18.5	10	43.5	14	160	100	9	41	12.	39	18	202	
00	14.5	23	21	12	54	13	165	100	16	45	15	46	19	200	
:30	15	22.5	21	12	57	14	165	100	17	45	16	48	20	198	
,00	17	25	24	12	59	16	170	100	19	51	21	47	21	200	
:30	16	23	20	-11	51.5	16	165	100	20	26	20	47.5	22	200	
:00	14.5	19	13	-14	48.5	15	153	100	19	20	20	49	21	205	
:30	14.5	23	14	-10	47.	13	160	101	17	23	21	50	21	203	
:00	15	.22	20	-13	51	11	155	103	15	31	22	50	21	203	
:30	16	24.5	20.5	-12	54	12	163	103	16	37	16	50	21.5	205	
.00	18	24.5	24	12	56	11	160	103	14.5	41	14.5	50	22	205	
:30	18	24	24	15	58	10	157	105	14	44	15	50	22.5	203	
:00	17	24	22	16	58	11	157	105	14	45	15	50	22	207	
~~13~~	203.5	296.0 / 13	2560	67 / 57	6805	157	2065	1320 / 13	193.5	486	210	6005	2690	2637	3
	15.65	22.8	19.7	4.4	52.34	12.08	158.46	101.5	14.9	37.38	16.2	46.2	20.6	203	27
	602	73	67.4	37.9	126.3								69		

Thursday P.M. 1916 March 30

Temp. of F Zero Room	Temp. of F 32° Room	1 Room Temp c	WATER No. 8	No. 9	Time.
-4	23	19			1:30
-6	23	20	1	1	2:00
-8	23	20		1	2:30
-6	24	20	1	1	3:00
-4	23	21		1	3:30
-6	24	21	(5/9)	1(1/8)	4:00

Friday, March 31, 1916.

Time	0° Room	Room Temp. 32° Room	Compressor Ref. Room	870* Comp. Tanks, No. 8	877** Condenser No. 9
8:30 P.M.	0 F	28 F	64 F		
9:00	- 2° F	29 F	66 F		1
9:30	2° F	29	66	1	
10:00	- 2°	28	70		1
10:30	- 4°	28	72	1	1
11:00	- 4	28	75		1
11:30	- 2	28	76		1
12:00 Noon	- 3	27	78		
12:30 P.M.	- 4	26	78	1	1
1:00	- 4	26	78		1
1:30	- 4	25	79	1	1
2:00	- 4	24	79		1
2:30	- 4	24	74	1	1
3:00	- 4	24	73		1
3 :30	- 4	24	76	735	760

Saturday, April 1st, 1916.

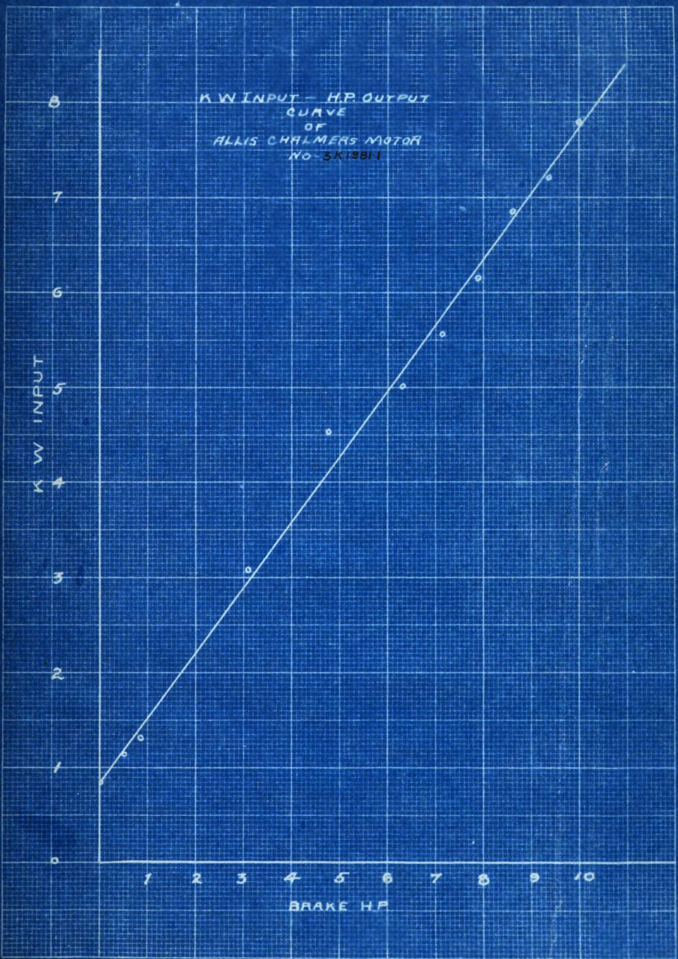
	Room Temperature F			Tanks	
				Compressor 870#	Condenser 877#
Time	0° Room	32° Room	Comp. Room F.	No. 8	No. 9
9:00	4	33	67		
9:30	2	33	66		1
10:00	1	32	68	1	1
10:30	0	30	66		1
11:00	1	30	66		
11:30	2	29	66	1	1
12:00	1	29	68		
12:30	1	28	71		1
1:00	0	27.5	73	1	1
1 :30	0	27	73		1
2:00	-1	26.5	74	1	1
2:30	1	26	74	420	1
3:00	-3	26	75		700

May 2nd, 1916.

Wt. of brake arm	=	15-5/8#
Cir. Brake Pulley	=	4' 3/8"
Dia. Motor "	=	6-11/16"
Cir. Pulley on Comp.	=	12.86'

May 2nd, 1916.

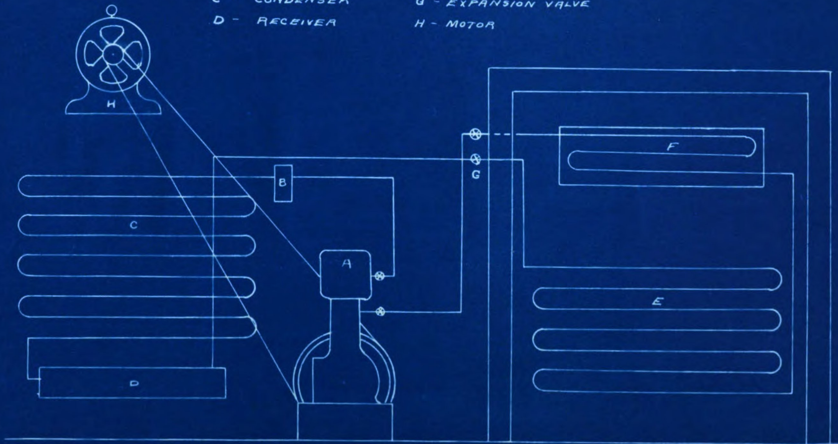
Total	Load	Volts		Amperes		R.P.M.	
1	0	212	211	4	5	750	750
2	25	212	109	6.5	6.5	749	749
3	50	208	204	14	14	731	730
4	75	204	200	20.5	21	708	710
5	90	201	198	24	25	705	698
6	100	200	197	27	27.5	692	696
7	110	200	196	29	30.5	687	685
8	120	196	194	32	32	682	683
9	130	195	194	33	32.5	676	676
10	140	195	192	39.5	39.5	664	662
10	140	195	196	40	40	667	667
9	130	196	197	37	38	674	674
8	120	196	197	35.5	36	682	683
7	110	198	198	32	32	689	690
6	100	199	199	28	28	698	698
5	90	201	202	25	26	699	699
4	75	203	203	22	23	710	710
3	50	206	206	17	17	730	730
2	25	210	110	6.5	7	753	752
1	0	210	212	4.5	4.5	757	758



K W INPUT — H.P. OUTPUT
CURVE
OF
ALLIS CHALMERS MOTOR
NO-3K19811
K W INPUT
BRAKE H.P.
0
1
2
3
4
5
6
7
8
9
10

LINE DIAGRAM OF AMMONIA COMPRESSION SYSTEM

A - COMPRESSOR
B - OIL SEPARATOR
C - CONDENSER
D - RECEIVER
E - EXPANSION COILS
F - BRINE TANK
G - EXPANSION VALVE
H - MOTOR



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