THE INVENTION OF

THE CENTRIFUGAL REFRIGERATING MACHINE

"PROPOSED" SCRIPT FOR A TAPE RECORDING

FOR THE SMITHSONIAN INSTITUTION

PLUS A COMPLETE HISTORICAL SKETCH

When the Smithsonian decided to display the compressor of the Original Centrifugal Machine, it requested a tape recording for the Archives. This type of description would institute a new practice, and consequently, there were no definite ideas about what it should be. To write the script was the original objective--but, as the story was developed by research and thought, it became increasingly evident that a complete coverage would be too long for an oral presentation.

There was entirely too much substance to the story for it to be left half told: The invention had projected a revolutionary development into the art of refrigeration; it had given a tremendous impetus to the development of air conditioning. The story had to depend too much upon memories that were fading rapidly with age; and it had to draw a clear distinction between the Centrifugal Compressor that would constitute the sole exhibit and an entirely new method of refrigeration in which the compressor was only one of numerous functional elements.

This led to a plan by which one document could be made to serve two purposes: One was to provide an abridged version for the oral presentation, and the other was to provide a complete and well-rounded Historical Sketch for the studious reader and the Archives.

The division between short and long could be shown by the style of typing. The short would be double-spaced in full-length lines; and the long would consist of the short plus all that was single-spaced and indented. With a little extra effort, good contunity could be maintained and the reader could be given a free choice according to time and interest.

The idea may have had some merit; but as research brought more and more facts to light, length got more and more out of hand. The upshot was a complete change of plan: An appropriate history would be written in the original short-long style, divided into chapters, and reinforced with some last minute illustrations--and the script for the tape could come later.

The author is not too happy about the length of the current edition (about 7500 words for the short, and 10,000 for the long); but he does feel that justice to the story has been reasonably well done.

Logan Lewis Logan Lewis
March 1, 1962

1962

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ILLUSTRATIONS*

*If, in the course of events, this type-script is printed, it should be more adequately illustrated with more photos that are on file.

THE INVENTION OF
THE CENTRIFUGAL REFRIGERATING MACHINE

This is the story of the invention and development of the first successful system of refrigeration in which the refrigerant vapor was compressed with a centrifugal compressor--and which soon became universally known as Centrifugal Refrigeration.

THE INVENTOR

Willis H. Carrier (1876-1950) was the creative genius and inventor. Widely known as "The Father of Air Conditioning," he became in 1915 one of the Seven Founders of Carrier Engineering Corporation--and thereby helped to organize the Company which, under the business management of his lifetime associate, J. Irvine Lyle, provided the necessary facilities--and which in 1930 became the nucleus of Carrier Corporation.

He will be designated by the single word Carrier; and for the sake of a clear distinction, all of the Carrier Companies will be called by their full names.

THE NARRATOR

The story is being told by Logan Lewis whose main qualification is that of an on-the-spot observer. He was one of the Seven who founded Carrier Engineering Corporation in 1915, and who continued on with Carrier Corporation until retirement in 1957. As Chief of Application Engineering, he had struggled with the frustrating problem of how to apply the refrigerating machines that were then available with reasonable safety and efficiency. It was this work together with long association that provides the background for a clear understanding of the inventors problems and the value of his achievements.

THE STORY

The story will cover a period extending from the middle 1910's into the 1920's when the first commercial models were produced and sold. Some parts of it must necessarily be taken from memory and from the very helpful suggestions of associates, but the real substance is based upon documents in the Archives of Carrier Corporation.

It will go rather deeply into background--in the belief that the problems of the inventor can be more fully appreciated when viewed in the environment in which he met them, face to face.

THE INVENTION

Another point that is essential to a clear understanding is that the invention was not the mere substitution of a centrifugal compressor for a reciprocating compressor in a conventional cycle. Records in the French Patent office show that in 1910-15 Maurice LeBlanc constructed a machine in which water was chilled by evaporation in a vacuum, and the resultant vapor forced into a condenser by means of a centrifugal compressor. LeBlanc failed primarily because he was too far ahead of the several arts upon which he was dependent--but, it is significant to note that in 1935 a water vapor machine was manufactured in the U.S. but discontinued after a few years of unsatisfactory experience.

In contrast, the immediate success of the Carrier Centrifugal

Machine was due to the invention of various components which, when integrated, made it possible and practical to use a centrifugal compressor with an entirely new kind of refrigerant. In fact, the first five years of intensive development (1920-25) provided material for fourteen patents, three of which were basic.

THE MOTIVATION

The motivation consisted primarily of a mixture of economic pressure and altruism. It seems perfectly clear in retrospect that Carrier, the inventor, and Lyle, the General Manager of Carrier Engineering Corporation, saw that with a better and safer means of chilling water, the Company could greatly expand its market for air conditioning and add a worthwhile value to Company prestige.

II STATE OF THE ART

Air Conditioning Equipment
Refrigerating Equipment -- Ammonia
-- Carbon Dioxide
-- Space Requirements
-- Water Circulation
Operating Characteristics
Carrier's Conclusion

Air conditioning was not entirely new in the early 1920's--inasmuch as it had been applied in many industrial plants in which materials or processes were benefited by a control of humidity. Practically all of these were central station systems in which the air was pre-conditioned in an air washer or humidifier. Some cooling was done by the evaporation of some of the spray water, but the temperature to which the air could be cooled was variable and entirely dependent upon outside weather conditions.

The observation of results showed that although this kind of air conditioning was done entirely for the benefit of the industrial process, the small amount of incidental cooling brought a very favorable response from the workers. The control of humidity not only made the work easier, but the incidental cooling was condusive to an increase in human efficiency.

This led to a simple deduction: Inasmuch as people in all walks of life objected to excesses of temperature and humidity, the additional cooling which could be obtained with refrigeration could also be a profitable investment in such as movie theaters, department stores, restaurants, and many other places catering to the general public. In short--there was a market for Comfort Cooling, and it could be even greater than the market for Industrial Air Conditioning.

AIR CONDITIONING EQUIPMENT

This vision of the future seemed perfectly clear, but the road to a realization of it was full of obstructions.

The air washer had been developed into a highly efficient and satisfactory means for cooling and dehumidifying air with sprays of chilled water. Other means, such as cooling coils, were not unknown; but none had been developed to the point at which they could be considered as satisfactory. In effect, Carrier was wholly dependent upon the air washer--but had no satisfactory means for supplying it with chilled water.

REFRIGERATING EQUIPMENT

At that time, refrigerating systems utilizing either ammonia or carbon dioxide were commercially available in suitable capacities. Machines using methyl chloride and sulphur dioxide were also available, but only in sizes that were much too small. All of these machines could be used for chilling water, but the deficiencies of the entire lot were discouraging if not prohibitive.

AMMONIA

Ammonia systems were efficient and were acceptable as calculated risks in industrial plants. Experience, however, proved that leaks were unavoidable and consequently that ammonia would constitute a panic hazard which was entirely too great for places frequented by crowds of people.

CARBON DIOXIDE

Carbon dioxide systems were reasonably safe in spite of the fact that mid-summer condensing pressures would approach 100 atmospheres. They were efficient when supplied with condenser water somewhat cooler than 70°F, but suffered severe losses as water temperatures rose into the 80's. This meant that a carbon dioxide system suffered its maximum loss of efficiency and maximum loss of capacity at the same time that the air conditioning load reached its maximum. This disqualified it from many downtown buildings where condenser water usually had to be taken from cooling towers.

SPACE REQUIREMENTS

> The spaces in which the several parts of ammonia systems could be safely isolated could normally be found in industrial plants---but, in downtown buildings, such spaces were usually unavailable or prohibitively expensive.

Compressors were massive, slow speed machines, either driven directly by Corliss engines or connected to electric motors by means of cumbersome leather belts. Condensers usually consisted of 1-1/4 and 2-inch pipe, concentrically assembled in such a manner that the cooling water could be forced through the inner pipe, and the refrigerant condensed in the annular space between the two. They were usually built in stands 12 pipes high by 20 feet long. Assembled on 15-18 inch centers, they could be placed on a roof top or in some interior space.

The water chilling coils were of the Baudelot type, in which the water was flooded over vertical stands of 2-inch galvanized pipe. Normally, they were placed in a shallow collecting tank and enclosed in an insulated chamber.

Carbon dioxide systems were similar, but actually required somewhat less space inasmuch as the cooling coils could be located within the spray chamber of the washer. But, nevertheless, its requirements for space were also excessive.

CHILLED WATER CIRCULATION

The problem of getting the chilled water to and from the dehumidifier and the cooling coils could be either fairly simple or rather complex. If there was only one dehumidifier, and it was elevated above the cooling coils, controlling the water level in both tanks was not difficult. But, if there were several dehumidifiers at various levels, the problem of getting it from one open tank to another could be a tough one. And, floods could be costly as the rates of flow frequently ran into hundreds of gallons per minute.

While ammonia compressors and condensers could be remotely located and well isolated, this water circulation made isolation of the cooling coils quite impractical. If a leak developed in the Baudelot chamber, the ammonia vapor would be absorbed by the chilled water and then released to the air in the spray chamber of the dehumidifier. This was an acceptable risk in industrial plants, inasmuch as the build up and release might be slow enough to give ample warning of impending danger--but was totally unacceptable in public buildings.

OPERATING CHARACTERISTICS

And, on top of it all, both systems had operating characteristics which were quite unsuitable for air conditioning duty. They had been developed primarily for such duties as chilling brine in ice freezing tanks, holding sub-freezing temperatures in cold storage warehouses, and other similar applications. Most of these loads were quite steady, and most of the systems were under the close supervision of skilled operating engineers---whereas the air conditioning load was a volatile one, changing rapidly from hour-to-hour and day-to-day. The one did not require much attention, but the other demanded frequent readjustment of expansion valves and compressor rpm's---not to mention readjustments for the conservation of condenser water.

CARRIER'S CONCLUSION

To meet this situation, Carrier Engineering Corporation had, with the co-operation of the manufacturers thereof, adapted standard ammonia equipment to air conditioning duty./ The results were good; but, in principle, the practice was an expedient utilization of machinery that had been designed primarily for an entirely different kind of duty.

In brief, air conditioning was developing rapidly in the Industrial Field and was ready to advance into the Comfort Field; but, was being held back in both by lagging refrigeration. As Carrier sized it up in the 1920's "....the refrigeration art had made little technical progress except in its applications. The same refrigerating machines and the same refrigerants

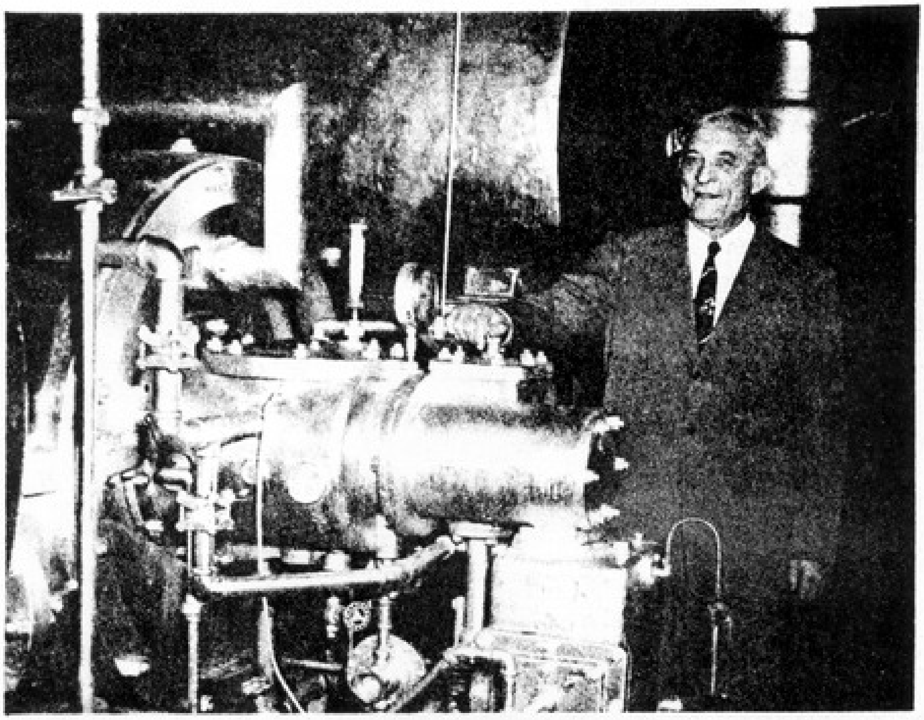

FIG. 1. WILLIS H. CARRIER (1876-1950) IS SHOWN WITH THE COMPRESSOR which is to be exhibited in the Smithsonian Institution--photographed in February 1950.

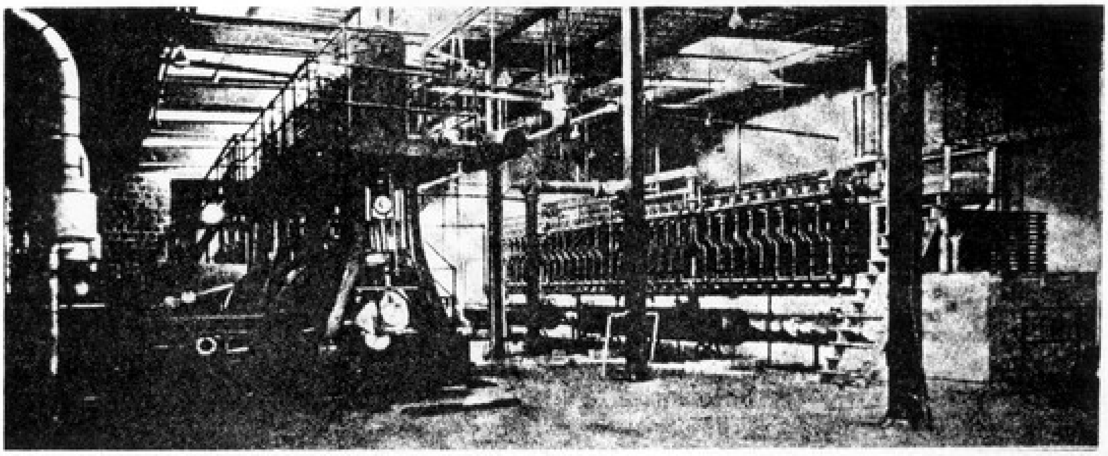

FIG. 2. A TYPICAL 350-TON AMMONIA SYSTEM IN A WORLD WAR I PLANT IN 1917. Engine-driven A-frame compressors on the left; double-pipe condensers on the right; shell and tube brine coolers on far side of compressors. Two 175-ton centrifugals would have required only a fraction of the space and about half of the head room.

were those that had been in use for fifty years...."

He also recalled that in 1916 he had reached the conclusion "....that if the air conditioning art was to advance....existing practices (in refrigeration) would have to be completely abandoned and a new method.... developed...." In view of this situation, it seemed rather obvious that if any great advances in refrigeration were to be made, someone outside of that industry would have to take the initiative.

III EVOLUTION OF THE CONCEPT

The Earliest Record
An Ideal Machine
A Plan of Action

At the same time (1916-17) an upsurge in experience with ammonia systems in World War I munitions plants began to clarify the picture: A machine that would be ideal for air conditioning should be capable of chilling water in a closed circuit; should be simple, relatively fool proof, and easy to operate; and above all, should be perfectly safe for comfort cooling in spaces which would be crowded with people.

THE EARLIEST RECORD

Carrier must surely have had these ideas very much in mind, but apparently it took several years of mulling to develop a specific concept--or at least to put it in writing.

The earliest record consists of a memo of about 3500 words on the subject of "Development Possibilities for Improvement in Refrigeration." Unfortunately, it was not dated; but it is known to have been written prior to June 16, 1920 as that is the date on which General Manager J. I. Lyle transmitted copies of it to several Carrier Engineering Corporation people--with a letter instructing them to read it carefully, to protect it carefully, and to return it when the reading was finished.

AN IDEAL MACHINE

In this memo, Carrier described the ideal machine as one which would embody six major features:

(1) The compressor should be rotary and, if possible, adapted to direct connection to standard motors or turbines.

(2) The compressor should be non-positive in effect--with this effect to be obtained indirectly by means of a special by-pass relief or directly by means of a centrifugal type.

(3) A refrigerant with suitable characteristics and commercial availability should be found.

(4) The refrigerant should have no corrosive effect on non-ferrous metals, such as brass, copper, or solder.

(5) The design of the condenser should be similar to the design of standard steam condensers.

(6) The water cooler should be of the closed-circuit type and similar to the condenser or a feed water heater.

A PLAN OF ACTION

He then proceeded to discuss the pros and cons of each; to evaluate various ways and means of putting them into effect; and then went on to lay down a plan of action calling for the development of two machines: one was to use a Nash "Hydro-Compressor" and to have a capacity of 25 tons or less; the other was to use a centrifugal compressor with a capacity of 50 tons or more.

Each was to be developed for some new refrigerant which would be almost the exact opposite of anything previously used for that purpose: The volume of vapor should be great instead of small; the vapor pressure should be very low and the difference between condensing pressure and evaporating pressure should be very small; and, for the centrifugal especially, the molecular weight should be quite high.

It would be these features of the new and then unknown refrigerant that would determine the size and design of the first experimental machines.

IV THE SMALL MACHINE

Early Research
An About-Face

The development of the small machine was to come first. It should have a capacity of 5 to 15 tons--as, in that range, it would be suitable for small air conditioning, would cost less, and would pave the way for the development of the larger machine.

EARLY RESEARCH

The Company's "Department of Research and Development" which had been organized by Alfred E. Stacey, Jr. in July of 1919 was called in and given some of its earliest assignments: it was to initiate a search for a refrigerant; to obtain and test a compressor; and to help devise an evaporator--all according to Carrier's instructions.

The search for a chemical compound which would meet his specifications for a refrigerant began with an examination of chemical dictionaries, catalogs, and similar publications--and was carried on by correspondence with various chemical manufacturers at home and abroad. This led to the consideration of various compounds and, incidentally, uncovered the first traces of Dielene as one of the possibilities. Then, as one or another showed promise, samples were obtained and tested for certain physical properties--which were usually unknown because none of them had ever been used as a refrigerant.

A Nash Hydro-Compressor was obtained and tested. Carbon tetrachloride was used inasmuch as it was immediately available and had properties quite similar to those of Dielene. This work was begun in the Fall of 1919, and some but not much preliminary work was done on the evaporator.

AN ABOUT-FACE

Then for reasons that have dimmed out of memories, the project was abandoned. A complete machine was never built. And, although the start was a false one, the tests which were made and the knowledge which was gained did much to speed the development of the larger machine.

V DEVELOPMENT OF THE LARGE MACHINE

Carrier Goes to Europe
Finds a Refrigerant
Finds and Modifies a Compressor

The shift of effort from the small machine to the large one must have been speedy since the two main problems were essentially the same. Carrier had to find a refrigerant that was suitable for centrifugal compression and a manufacturer from whom compressors could be obtained.

A canvass of domestic manufacturers revealed two potential sources, but both promptly disqualified themselves: One stated bluntly that it was not interested, and the other wanted $10,000 for a compressor that was soon to be purchased for less than $900. Carrier could have applied his past experience to the design of one, and the Company could have built one as it did eventually--but unfortunately, it was decided that such a move should be postponed indefinitely. The other component parts of the machine would present so many strange problems that not enough time or money would be left for work on a compressor.

CARRIER GOES TO EUROPE

Since previous correspondence on both of these matters pointed toward Europe, Carrier sailed on April 10, 1921--ostensibly for a vacation. He went to Switzerland first and promptly made two discoveries: first, that centrifugal compressors had been developed and were in use for compressing various gases including ammonia; and second, that the Swiss were much too interested in why he wanted one and what he was going to do with it.

This was fortunate because it speeded his move into Germany and brought an end to the search for both refrigerant and compressor. Through a follow-up of correspondence, he found that Dielene (Dichloroethylene $C_2H_2Cl_2$) was being manufactured there and in quantity for, of all things, a solvent for dry cleaning clothing; also that the C. H. Jaeger Company of Leipsig was manufacturing a suitable line of compressors, and was willing to co-operate without a disturbing inquisitiveness about end uses.

FINDS A REFRIGERANT

Carrier put the two together and decided to proceed. The availability of Dielene seemed to be well assured by its own local market. It had never been used as a refrigerant, but the meager data that was available indicated that it would meet his specifications. The volume of the vapor and the ratio of compression were suitable for centrifugal compression; molecular weight was favorably high; boiling point was suitably low; and it was non-toxic and sufficiently nonflammable to be safe. Enough was known about its properties to enable him to make a fairly good guess at the size and type of compressor.

FINDS AND MODIFIES A COMPRESSOR

Dielene was indeed a low pressure refrigerant: So low, in fact, that the pressure throughout the entire cycle would be considerably below atmospheric---and this, in itself, presented a new requirement: the inward leakage of air around a shaft turning at 3500 to 4000 rpm would have to be reduced to an absolute minimum.

Carrier's solution was to make arrangements with the Jaeger Company for three modifications in their standard: One was the simple matter of enlarging the casing of the compressor so that the outboard bearing would be completely enclosed; the second was the substitution of a special seal for the standard stuffing box; the third was a forced-feed lubricating system to supply oil to the seal and to the enclosed bearing.

These alterations were planned by Carrier with the help of Jaeger's Engineering Department during the several months which he spent in Germany. Then with blueprints of the compressor and specimens of Dielene, he returned to ~~this country~~ to undertake the design of the other components of the experimental machine.

VI THE FIRST CENTRIFUGAL MACHINE

Unveiled on May 22, 1922
After Twenty-Six Years of Service
A Decision---To Manufacture or to License
The First Commercial Model

But before that could be done, one more step was necessary. He knew how much vapor the compressor would handle, but had only an approximate idea of its latent heat---and, without that, he could not be reasonably sure of what its refrigerating capacity would be---and, consequently, how much heat transfer surface to put in the condenser and the evaporator.

Accordingly, his first step was to determine the latent heat of Dielene. And, to make assurance doubly sure, he and Stacey made independent tests, each employing a somewhat different technique. The idea was a good one; but in the end, their results had to be reconciled by a compromise, and the machine designed on an approximation.

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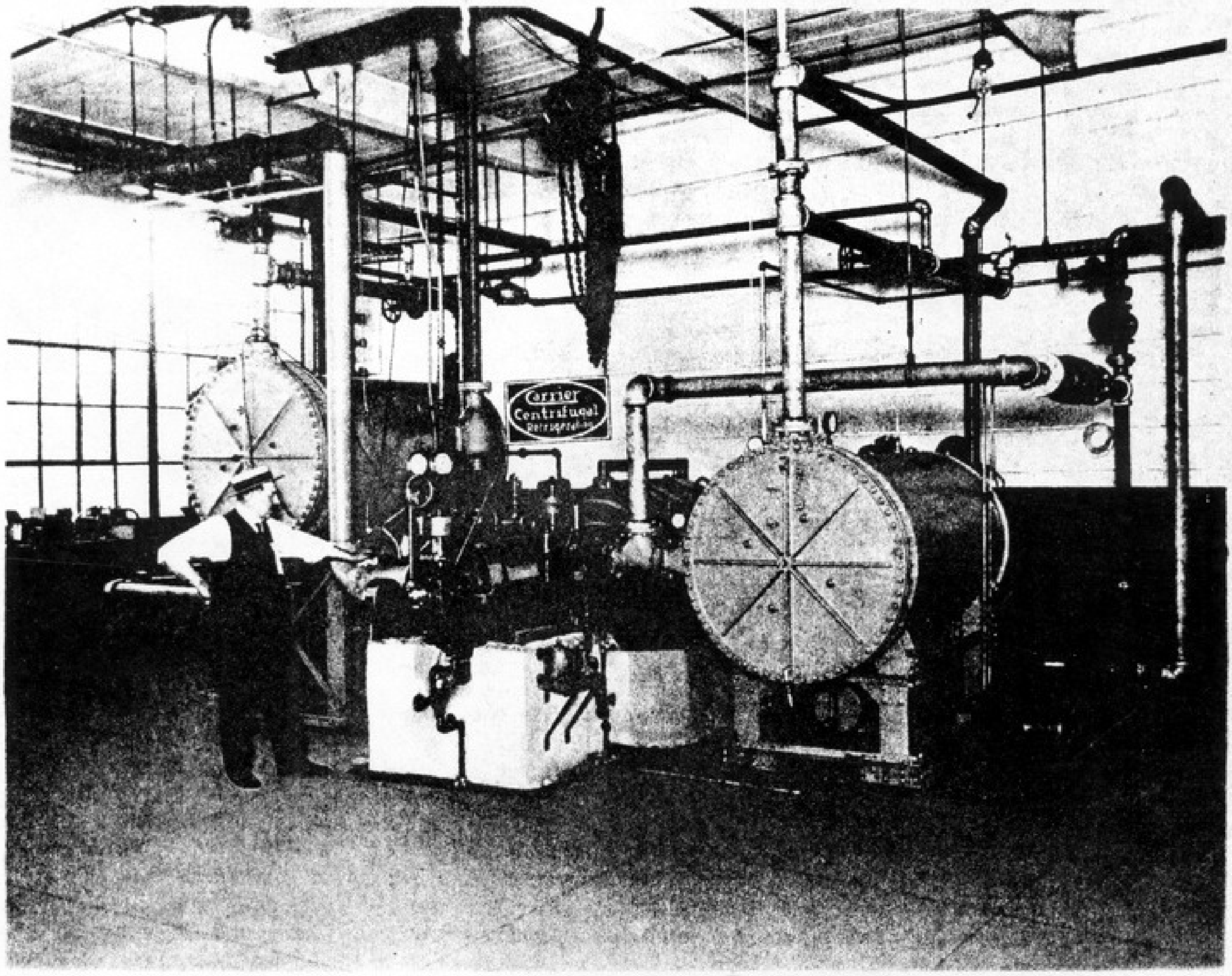

FIG. 3. THE NUMBER ONE OR EXPERIMENTAL MODEL CIRCA MAY 22, 1922. Cooler on left, condenser on right, and compressor in rear center. Harry Moor faces the turbine drive. Photograph taken before insulation was applied.

This machine was unveiled on May 22, 1922, used for experiment and demonstration for about two years, and then sold to the Onondaga Pottery Company in 1924--where it gave 26 years of regular service in air conditioning their Syracuse China Plant.

This is an incomplete version of Lewis's draft script