

Brief History of Centrifugal Chillers

By *Mark H. Huston*

My father retired recently from the HVAC business after more than 45 years. He spent one career at Carrier, and a second at Siemens. At his retirement party, there were a group of industry friends, some with experience stretching back to the very early days of the industry. One of these old friends had been a mechanic for the last 60 years, mostly working on centrifugal chillers. They both had a great time reminiscing about the old days.

After his retirement, I helped Dad clean out the basement. In 45+ years, you can accumulate a lot of stuff, and Dad seldom throws anything away.

About the Author

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The basement had mounds of old technical literature, mostly on centrifugal chillers. Most of the machines listed in the manuals have been removed from service over the last 10 or 15 years. (“Dad, they haven’t made one of those machines for 50 years. It is probably okay to

throw the manual away!”)

It occurred to me as I went through the literature that an era was passing, and I knew very little about the history of one of the most important advances of the 20th century — the centrifugal chiller.

Centrifugal chillers and the entire refrigeration industry were moved forward by the desire of many other industries to do something better, or faster, or cheaper.

In 1901, the Buffalo Forge Company in New York hired a 24-year-old engineer from Cornell University named Willis Carrier to work on the installation and design of heating systems. Within a year, he was placed in charge of the experimental engineering group. This group was the core of the team that would form the Carrier Engineering Company. It was here in 1902 that he was credited with the first air-conditioning project at Sackett-Williams Lithography and

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Photograph 1: Carrier Engineering Corporation of America founders. Front row (from left): L.L. Lewis, Willis Carrier, L.I. Lisle and E.T. Murphy. Back row (from left): E.P. Heckel, E.T. Lyle and A.E. Stacey Jr. Photo credit: Carrier Corporation.

Publishing Company in Brooklyn, N.Y., which has been identified by many as the first true consolidated air-conditioning project. (The definition of air conditioning considered as the control of both temperature and humidity.) He received his first patent in 1906 for “Apparatus for Treating Air.”

The term air conditioning actually was coined by Stuart H. Cramer. He used the phrase in a 1906 patent application for a device that added water vapor to the air in textile plants. He used the air to condition the yarns.

To understand where the chiller originated, we need to understand the state of engineering at that time. At the turn of the last century, air handlers did not exist. The concept of finned tube coils had not been developed yet. Fans were little more than motor-powered windmills. Ammonia was the most common refrigerant (none of the new fluorocarbon based refrigerants had been invented yet). No vendors sourced components for a refrigeration machine. Everything was custom-made.

Buffalo Forge had created the Carrier Air Conditioning Company as a division of Buffalo Forge. The management of Buffalo Forge named the new subsidiary after the young engineer, instead of putting its own name on the division. They felt if this new field turned out to be a dead end, or suffered a tremendous failure, it was less likely to fall back to the company. At the outbreak of World War I, Buffalo Forge made the business decision to no longer pursue the new air-conditioning market. The group left and formed the Carrier Engineering Corporation of America (Photograph 1).

This group was responsible for many of the HVAC

engineering breakthroughs we take for granted today. The concept of humidity relative to temperature was not well understood. At that time, they knew that if you sprayed cold water directly into a hot, humid airstream, the result was that it both cooled and dehumidified the air. Exactly why that happened, and how much, was unknown. A lot of basic research was needed.

Many pioneers other than Carrier and his team were responsible for the early building blocks of refrigeration and air conditioning. Although Carrier is credited with the invention of air conditioning in 1902, others had concurrent patents for the treatment and cooling of air at that time. Many engineers and amateurs were working in the field. Cramer had been working on cooling and humidifying cotton mills for several years. However, the credit belongs primarily to this group of engineers for the practical centrifugal chiller.

Technical innovation usually cannot be pinpointed to a single moment. When Alexander Graham Bell invented the telephone, and he called out his famous, “Watson come here!” between two rooms, there were many people involved. Without batteries, wire, magnets, the telegraph and cones for the speaker and microphone, Bell could never have uttered those words. His discovery evolved from a concept, and then to a hypothesis, and then experimentation and collaboration, until all of the pieces finally came together, and the telephone actually worked. He built on existing technology for his new invention. The same is true for the centrifugal chiller.

Design

Carrier and his team did not invent the centrifugal compressor, but it was a new technology in the early 1910s. The first patents for centrifugal compressors were already in place when Carrier and his team began to work on the refrigeration application. Multistage blowers already were made by several manufacturers. Of course, centrifugal pumps were common by then.

Between 1910 and 1915, Maurice LeBlanc, working in France, had experimented with refrigeration and his design of centrifugal compressor. He was using carbon tetrachloride in one experiment, and water vapor in another. The carbon tetrachloride broke down and ruined the compressor, while the water vapor could not be used because of required impeller speeds. The technology was not available to build and operate a lightweight high-speed impeller for water vapor. However, he was the first person to use the centrifugal compressor for a refrigeration application. LeBlanc also had issues with shaft sealing. This was a common early problem, even for Carrier.

According to an October 1942 paper by Walter A. Grant (a Carrier employee), Willis Carrier’s concept of a

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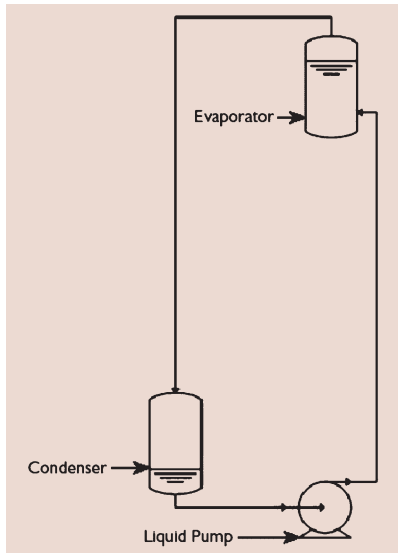


Figure 1: Condensing by means of static head, based on the height of the condenser gas column, was one concept that led to the development of the centrifugal chiller.

The concept was that the refrigerant could condense under its own weight with little mechanical help except for a pump — similar to the air entrained in the water with the Taylor compressor. It was an idea that eventually morphed into their chiller, substituting a centrifugal compressor for the static head concept.

In his important February 1926 paper, “Centrifugal Compression as Applied to Refrigeration,” Willis Carrier discusses the static head concept and credits this as an example for understanding the process where compression is produced by a gravitational column (Figure 1). In this diagram, the pump pushes the theoretical liquid refrigerant to the evaporator. It changes state to a vapor in the evaporator, and condenses in the bottom of the system due to static head.

Obviously, this is not a practical system. However, the concept was easy to grasp, and it is intuitive as to how the compressor can substitute for the static head.

The concept and theory were easy. The hard part is making it work in the real world. Two major components were required: the compressor and the refrigerant. At that time, no suitable refrigerants were available. Some were promising, but all had drawbacks regarding toxicity or flammability. Propane was once marketed as the safe alternative to the then-current refrigerants!

Various refrigerants, or “volatile fluids,” to use the terminology of the day, were exactly that. Highly volatile. Vapor compression refrigeration had been ongoing since the 1830s in one experimental form or another. The list of compounds to choose from was extensive, and after

exhaustive testing, a compound called dielene was chosen by Carrier as the best.

He found a manufacturer in Germany that would make what was essentially a cleaning fluid in some quantity. Further research showed it to be composed of two different isomers, and the product was more fully refined for stable and predictable performance. However, it was highly flammable. The vapors would travel like gasoline vapors to a source of ignition, and, if ignited, it would produce deadly by-products. Today, it would probably be rated as a B3 refrigerant based on ANSI/ASHRAE Standard 34-2001, *Designation and Safety Classification of Refrigerants*. This would be the most toxic and flammable rating. It was the best technology available then, despite obvious drawbacks.

Carrier and his team then began a study of static head, gravity, and pressures, and the theoretical concept of having the evaporator far above the condenser.

Carrier at the time did not have the manufacturing capability to develop its own compressor, so the search was on for suitable vendors. Air compressors of this type were not uncommon, and four possible European vendors were evaluated. The vendor chosen was the C.H. Jaeger Company of Leipzig, Germany. Post-WWI Germany was a fertile ground for cost-effective manufacturing capability, and it appears that Carrier and his team took advantage of it.

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C.H. Jaeger Company had begun operation in 1898 as a foundry. The company had begun building turboblowers in 1905 and supplied its first centrifugal compressor in 1910. They continued to build compressors for Europe and then for the German war effort in WWII. Jaeger continued operations in East Germany until reunification, when it was re-privatized. Jaeger continues to manufacture centrifugal compressors today as part of PGW Turbo, for the water treatment and industrial markets.

Many modifications were required for the compressor when it arrived at the Carrier workshop in New Jersey in 1920 or 1921. New lubricating systems that could operate in a dielene environment were needed, and the shaft seal was a real problem.

The shaft seal was solved by the application of a unique bellows seal. When the compressor was shut down, springs held the seal face tight to the seat. When operating, the bellows would pressurize, lift the seal face from the seat, and pressurize that area with oil from the lubricating pump. An effective seal solved a vexing problem.

Carrier patented the centrifugal refrigeration machine in 1921. The actual development progressed to a point where a product introduction could occur in May 1922. The chiller was unveiled at a meeting of the American Society of Refrigerating Engineers (ASRE), one of the forerunners of ASHRAE. Many team members also

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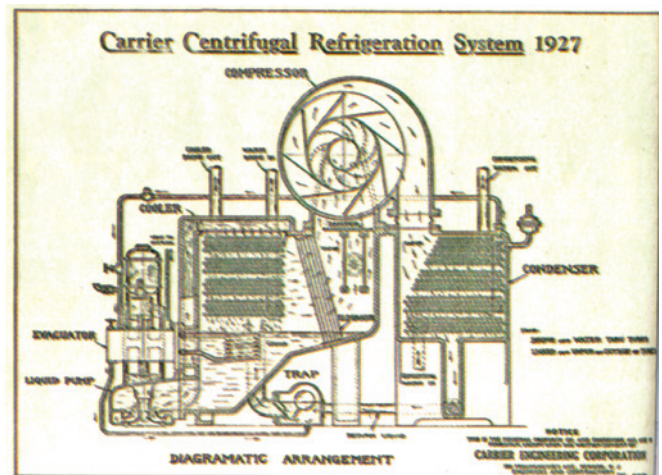
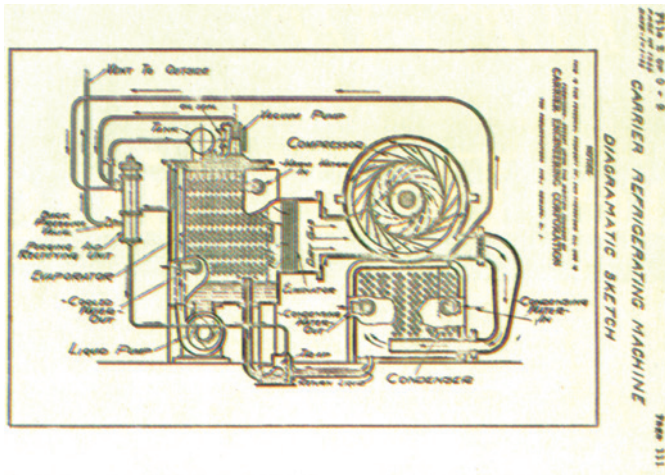


Figure 2 (left) : Early chiller layout, with compressor mounted on condenser and horizontal suction/discharge. Credit Carrier Corporation. Figure 3 (right) : Later chiller layout. These machines were installed with methylene chloride and added an inlet damper. Credit Carrier Corporation.

belonged to the professional association. Four of the original seven founding engineers from the Buffalo Forge team were either ASRE or the American Society of Heating and Ventilating Engineers society presidents over the years.

The unveiling was to be with 300 engineers at the meeting in Carrier’s New Jersey shop. To enhance the experience (and to ensure attendance), a boxing match was scheduled. In the buildup to the unveiling, Carrier was speaking to the audience. He later related this tale of what happened while he was at the podium. The chiller was set up in an adjacent room when suddenly a loud noise came through the wall that sounded much like a rotating piece of machinery grinding to an unplanned and unpleasant stop.

“It was terrible when I heard that long, loud rumbling slowly diminishing b-r-r-r. I visualized the rotor of the compressor tearing itself to pieces. Beads of perspiration came out on my forehead, and my hands were soaking wet. But I kept right on talking, trying to act as if nothing had happened. Irvine (Lyle, from the Buffalo Forge days) sitting near the back casually left with an air of calmness I know he did not feel. Directly he came back and signaled me that all was okay. Later he told me the cause of the noise. In arranging the space for the boxing matches, one of our men pulled a large metal dining table across a rough concrete floor. No sound effect.... could have any better imitated the disintegration of a rotative machine.”

The compressor itself was a horizontal split-case configuration, and all of the early Jaeger compressors had a horizontal suction and discharge. Many were driven by 3,600 rpm direct connected squirrel cage motors with no gear. Some, as the prototype, were turbine drive. As production increased, they were made in four, five and six stages and five different sizes (Figure 2).

Most of the production machines were what they called the subbase type, in which the compressor was mounted on a short low condenser, and the evaporator was elevated. The evaporator was not flooded as today, but used a pan to distribute a flow of liquid over the tubes. The construction of the evaporator would be roughly recognized today.

It was multipass with removable heads and 5/8 in. (16 mm) diameter tubes. The shell was cast-iron with ribbed reinforcement. Any permanent joints were made with lead, and asbestos containing gaskets were used throughout. The tubes and the tube sheets were made of Admiralty bronze, annealed to the temperature rating that the design required. Subassemblies were hydrostatically tested, vacuum tested and pressure tested prior to shipping. Condensers were essentially identical. Machines were field-erected.

The lubrication system was simple, but highly effective. It consisted of a typical gear drive oil pump, sump, and brass tube oil cooler. There was a simple strainer for oil filtration before the oil flowed to the shaft seal. Bearings were not pressure lubricated, but were equipped with babbitted oil slingers or rings. Bearings were split and had removable shells. On later models of the 1925 compressors, the drive end bearing was moved out of the refrigerant atmosphere, but by 1926 they were back inboard in the configuration that would last for many years of production in future compressors.

The liquor pump is not seen today. This pump was used to circulate liquid refrigerant in the evaporator, and generally had complex multilayer packing and a glycerin seal. This pump flowed liquid refrigerant from the bottom to the top of the evaporator into a distribution pan. From the pan, the refrigerant flowed down across the tubes

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creating the chilled water flowing through the tubes. There was also an “evacuator” on the evaporator that served as a purge system to remove non-condensable gas (air). Several different types of evacuators were developed as the designs evolved. An acceptable leak rate was 1 in. (249 Pa) of vacuum loss in 24 hours!

The first installation of a production machine was in an industrial application. Industry drove the development of the chiller, not the office building market. The new machine could be applied to many conditions with impeller combinations and size configurations.

The technology grew quickly. The first production centrifugal chiller went to Stephen F. Whitman and Sons of Philadelphia, a candy manufacturer. The second went to a candy maker as well, William F. Schrafft and Sons of Boston, the next month. The prototype also was sold to a pottery company in Syracuse, N.Y.

By 1925, the next line of refined compressors was introduced, called the “R” type. These were still made by C.H. Jaeger and were similar except for a vertical suction and discharge (*Figure 3*).

Carrier’s design offered flexibility. The basic structure could be applied to a comfort cooling application or to a low-temperature brine operation. The combinations of impellers, stages, and shells gave the company a wide array of potential customers. It was an impressive engineering accomplishment.

The company grew rapidly as large-scale delivery of temperature-controlled water and brine was offered to industries as diverse as paper mills and refineries; candy plants and steel manufacturing. Other engineering companies took immediate notice, and competition began.



Photograph 2: Rivoli Theater in New York, 1925. This was an early centrifugal chiller installation, cooled by “refrigeration plant” as evidenced on the marquee. *Photo credit: Carrier Corporation.*

In Europe, Brown-Boveri had a centrifugal chiller operating as early as 1925 on ammonia and, in 1932, another test refrigerant, ethyl bromide.

By 1924, the centrifugal chiller began to make its presence known to the general public, with the air conditioning of department stores, movie theaters, and office buildings. Other theaters and buildings had been cooled by refrigeration for several years, but the centrifugal chiller was simpler, more efficient and more reliable. No more of the theater owners dragging in ice to cool their theaters. By 1930, 300 Carrier centrifugal chillers were in theaters (*Photograph 2*).

Advantages existed for this chiller over the competition. Most systems that used chilled water required a separate refrigeration plant with ammonia or CO₂ as the refrigerant. The chilled water generally was made in a baudelot cooler. This type of cooler used an open container that had the refrigerant piping or plates inside. Water was then pumped across the piping. Many applications required an insulated room for the baudelot cooler. This builtup system was large, unwieldy, prone to freezing, and required expert operation. Valves were manual, including the expansion device. Oil coating of the heat exchange surface was a typical issue, but due to the solvent nature of the dielene, this was not as great of a problem as with the early centrifugals.

Development

The early centrifugal chiller provided many of the same advantages that it provides to designers and engineers today: a smaller footprint, reliable long-term operation, ease of installation, competitive pricing, simple operation, and energy efficiency.

The problem of refrigerant continued. While dielene could be reasonably used in a chemical plant, other applications were more difficult. So research continued, and methylene chloride was used for the first time in 1926. Dielene only lasted for four years.

Methylene chloride (R-30), while an improvement, is listed as a B2 refrigerant, somewhat better than dielene. Not great, but at least it isn’t highly flammable. Carrier’s team named this new refrigerant Carrene-1. It was still dangerous and difficult to work with, requiring special care and handling. Technicians working at the time remembered that it was extremely irritating and could be absorbed through the skin. It became clear that for the refrigeration industry to thrive, new refrigerants were needed.

Little or no competition existed for the next several years, and the company weathered the Great Depression, even introducing a new compressor in 1933. This was a compressor of its own manufacture, and it was no longer sourced from Germany. The “Z” series was opti-

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mized for the new refrigerant R-11. This system also was able to incorporate an economizer for the first time to increase cycle efficiency. And, in the first series of centrifugal chiller refrigerant retrofits, R-11 was placed into most of the old dielene and methyl chloride (Carrene-1, R-30) machines. The system had the same basic configurations as the earlier machines, and still used the spray deck cooler.

In 1935, Ingersoll-Rand developed an interesting centrifugal chiller that used water as the refrigerant. This eliminated the need for a chilled water heat exchanger. The impeller speeds and number of impellers obviously were impressive at the time. The amount of market penetration or the success of the design is unknown.

In 1936, Carrier Engineering teamed up with General Electric and produced a single-stage, high-speed centrifugal compressor. They called this the “G” type. This was unique in that the small sizes used a hermetically sealed motor. It was not highly successful.

Trane Turbovac

Alfred E. Stacey was head of research at Carrier Engineering starting in 1919 until he took the position of vice president in charge of research in 1928 and then in 1931 as vice president of engineering. Without a doubt, he had an impact on the early formation of the centrifugal chiller.

However, in 1935, he left Carrier Engineering and started his own business as a contractor/manufacturer in New York. The company was called Buensod-Stacey. Along with other markets, they

manufactured and installed air washers and other conditioning equipment to the tobacco and textile industries in the southeast. While there, they developed a uniquely designed hermetic chiller but lacked the manufacturing and development faculties to produce the chiller.

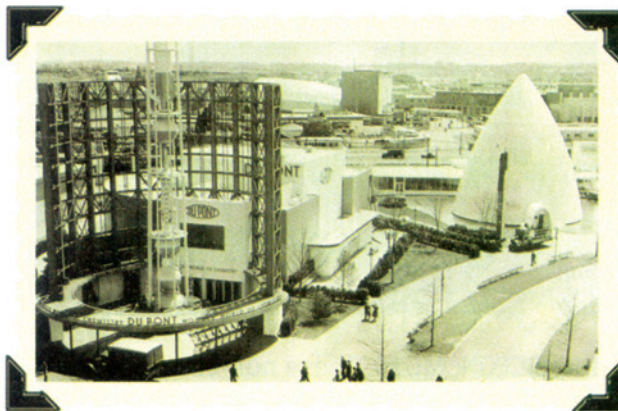
At the same time, Trane in LaCrosse, Wis., was producing a successful line of fan coils and “Climate Changers.” They had also authored the important “Trane Air-Conditioning Manual.” This was to become the industry standard reference for many years. They did not have a chiller product and were in the process of design. Buensod-Stacey and Trane teamed up in 1937 to produce the first practical hermetic centrifugal suitable for wide distribution. Trane engineers developed the chiller through 1938 and unveiled it in 1939.

This machine used the new R-113 refrigerant, and its unique design offered features that the competition did not have. It was smaller, easier to operate and install, and quiet. The chiller had two barrels, a condenser above and a cooler below. Located in the end of the cooler was a motor with a two-stage centrifugal compressor, which discharged to the suction of the two stage centrifugal compressor located in the condenser barrel. While acceptance of the design was slow, with only three units sold in the first year, the machine became the start of the product line. Originally offered in 65 to 80 tons (229 to 281 kW)

capacity, the Turbovac (Photograph 3) was the foundation for rapid growth in the coming years.



Photograph 3 : Reuben Trane, left, and associates look at the prototype Turbovac. This was the cover of the 1939 sales catalog, listing some early installations.



Photograph 4 : The Carrier “igloo” at the 1939 World’s Fair in New York had a pair of 45 ft. (12.2 m) tall thermometers showing the indoor and outdoor temperatures.

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Competition

In 1936, a project was begun by Carrier engineers to develop a new compressor and chiller configuration to take advantage of the new R-12 and R-11 refrigerants. That machine was unveiled in 1939 as the 17M series. It had the typical configuration that we still see today, using shell and tube heat exchangers, now with steel and copper construction (special heat exchangers could be specially built for process applications). The compressor sat alongside the chiller and condenser bundle, with a motor and gear drive, or turbine. The compressor was manufactured until a few years ago.

Carrier had an exhibit at the 1939 World's Fair in New York that was in the shape of an igloo, with 40 ft (12.2 m) tall thermometers showing the interior and outdoor temperatures at the exhibit. It was appropriately adjacent to the DuPont pavilion. Without the production of Freon™, beginning in 1931, the refrigeration and air-conditioning industry would not have been able to grow (*Photograph 4*).

It was also the year that real competition developed in the form of open drive industrial quality machines from York and Worthington, both operating on R-11. Carrier was no longer the only game in town for industrial centrifugal chillers. Future research is needed to tell the story of these other early machines.

What happened to that first prototype compressor that was built in Carrier's New Jersey shop? After operating for years at a ceramics company in New York, it was donated to the Smithsonian in Washington D.C. And in the late-1960s, Dad took us to the nation's Capitol to see the sights. We made a special trip to the Smithsonian to track down the compressor, so Dad could have his picture taken in front of it.

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