Abstract:

For the average individual, when someone mentions ammonia, more than likely their first thought is that ammonia is a good household cleaning agent. In fact, ammonia has been used for more than a century as a refrigerant in mechanical industrial refrigeration systems. Many of the modern conveniences we have today can be traced back to ammonia refrigeration. Food preservation and storage, commercial ice production, recreational ice skating arenas, carbonated soft drink production, and some industrial chemical applications rely upon ammonia refrigeration systems as a utility.

According to the International Institute of Ammonia Refrigeration (IIAR), ammonia was first used as a refrigerant in the 1850s in France and was applied in the United States in the 1860s for artificial ice production.[1] With its long history of being used as a refrigerant, the available and evolving mechanical technology has enabled ammonia to be utilized as an efficient alternative refrigerant. Ammonia was first synthesized in 1823 by reacting air and hydrogen, and the first commercial production of synthetic ammonia began in 1913. Presently, there are an estimated two billion metric tons of ammonia present in the world. Of this amount, approximately five percent is man-made. Approximately 18 million metric tons of ammonia are produced annually in North America alone, and of this amount, less than two percent is used for refrigeration.[2]

Ammonia is an outstanding refrigerant alternative, given its good cycle efficiency and low cost, as compared to other commercially available halocarbon refrigerants. Furthermore, ammonia's benefits also come from its benign effect on the environment. Ammonia has zero Ozone Depletion Potential (ODP) and zero Global Warming Potential (GWP). As we face growing legislation to protect the environment, as well as increasing awareness of man's impact on the environment, ammonia is well positioned as a natural alternative refrigerant.

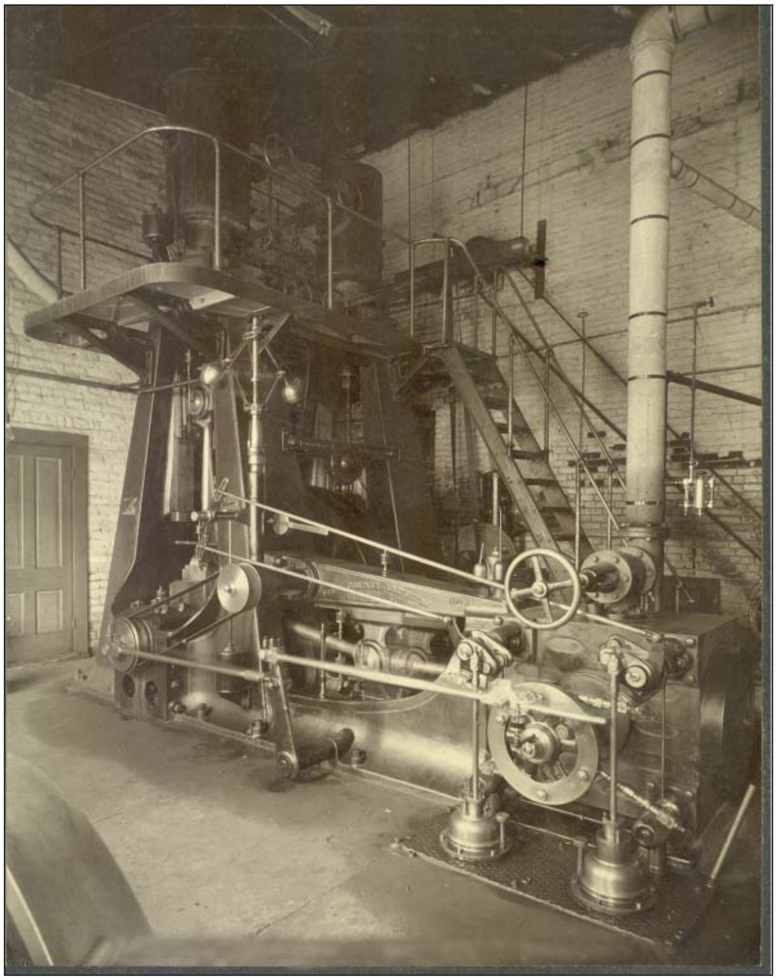


Figure 1: Frick ammonia compressor built in 1886. Installed at Gipps Brewery, Peoria, IL. Operated until 1946.

[1] S.M. Miner, an Appraisal of Ammonia as an Alternative Refrigerant in Light of the CFC and GWP Situation (International Institute of Ammonia Refrigeration, Technical Paper T167, 1992), 1.
[2] International Institute of Ammonia Refrigeration, Ammonia: The Natural Refrigerant of Choice (An IIAR Green Paper).

Background:

Refrigerant grade ammonia (chemical symbol NH_3) is 99.98% pure and does not contain water, and therefore, is referred to as anhydrous ammonia. A typical industrial refrigeration system is either a flooded or pumped evaporator system with an externally mounted evaporative condenser. They also tend to be simple mechanical systems and easily understood by operators, given more than 100 years of application in industrial refrigeration. Plant utilities like this lend itself to be site constructed by an installing contractor due to the large footprint. An average cold storage warehouse could contain over 150,000 square feet of product storage space. The required cooling load of a building this size could be as much as 400 tons of refrigeration, with three different refrigeration retention temperatures of -10°F (-23°C), 35°F (1.7°C), and 40°F (4.4°C). In comparing ammonia to a halocarbon refrigerant (R-507), the initial capital cost for the ammonia system could be as much 15-20% more expensive. However, when comparing the two systems over a 20-year life cycle, it is estimated that the ammonia system will be at least 45% less expensive; including the initial acquisition costs.[3]

Unlike typical halocarbon refrigerants, ammonia is corrosive with "yellow metals," such as copper and brass. In a typical halocarbon refrigeration system, the evaporator is constructed of copper; thus yielding a compact, low weight solution, as compared to an ammonia system. Furthermore, enhanced surface copper heat exchangers have further reduced cost and size, as compared to a typical ammonia system. Because of its corrosive effect with copper, a typical ammonia evaporator is constructed of either steel or aluminum, depending upon the service environment or design conditions required.

In a typical cold storage warehouse, the evaporators can be spaced a significant distance apart from one another, in addition to being a long distance from the ammonia refrigeration equipment room. For that reason, some ammonia facilities pump refrigerant throughout the facility to each evaporator, in a multitude of cold rooms, providing a utility. For this reason, if the building is very large, the refrigeration system could contain a large quantity of refrigerant (charge).

Unlike halocarbons, ammonia is relatively inexpensive ($0.65/lb.), and therefore, not a significant cost driver if a large quantity of ammonia is required.

There are many positive attributes of ammonia refrigeration, such as: good cycle efficiency, zero Ozone Depletion Potential (ODP), zero Global Warming Potential (GWP), and the fact that it is well known and widely used globally. However, there are challenges to consider with ammonia, such as its chemical toxicity, mild flammability (16 to 27% concentration in air), and its incompatibility with copper.[4] Exposure to an ammonia leak can vary depending upon the concentration of ammonia in the air stream. Table 1 below outlines the effects of exposure depending upon ammonia concentration.

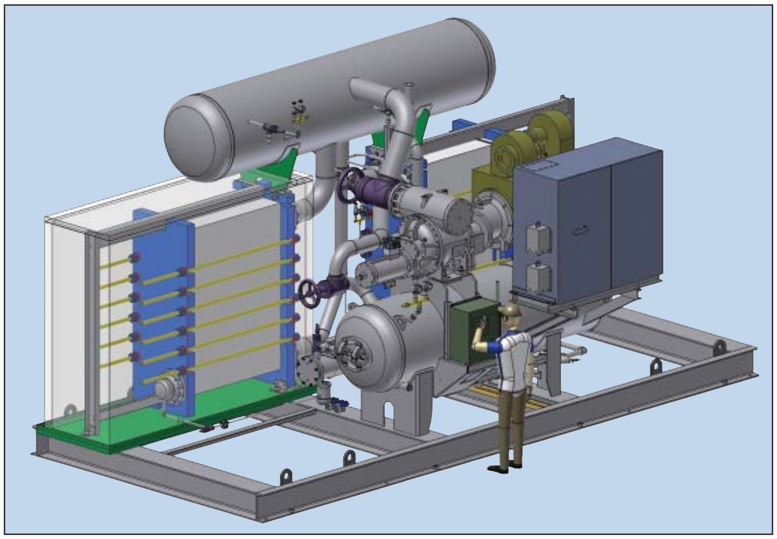
Exposure, ppm	Effects
0-5	Smell hardly detectable.
5-20	Human nose starts to detect.
25	TLV-TWA (Threshold limit value – time weighted average, 8 hr).
35	STEL (Short term exposure limit – 15 min.)
150-200	Eyes affected to limited extent after about 1 min exposure. Breathing not affected.
500	IDLH (Immediately Dangerous to Life and Health, per NIOSH).
600	Eyes streaming in about 30 second exposure.
700	Tears to eyes in seconds. Still breathable.
1,000	Eyes streamed instantly and vision impaired, but not lost. Breathing intolerable to most participants. Skin irritation to most participants.
1,500	Instant reaction is to get out.

Table 1: Ammonia Exposure: source, ***Cooling applications for ammonia refrigeration*** **by W.F. Stoecker, University of Illinois at Urbana and Atmospheric emissions and control,** ***Ammonia Plant Safety*** **by D.P. Wallace.**

[3] International Institute of Ammonia Refrigeration: Ammonia a Sustainable Refrigerant: A Comparison of Ammonia vs. Halocarbon Refrigerants.
[4] Expanding Ammonia Usage in Air-conditioning. J.W. Pillis, PE, ASHRAE / ANSI Refrigerants Conference- August 1993.

Development of Alternative:

One of the many applications that utilize ammonia is the commercial fishing industry. Large quantities of ice are required to chill and refrigerate the catch from the sea. In an attempt to reduce the time required to manufacture a fishing vessel, ammonia system manufacturers developed compact, factory-built, skidded ammonia plants in lieu of a typical site-erected system. This enabled the fishing vessel manufacturer to reduce the time required to build a vessel. The added benefit of purchasing a preconfigured ammonia plant was the reduction of site-related delays, along with an optimized design, that reduced welding in a compact footprint.



All the electronic controls, piping, and leak testing are completed in a factory and then delivered to the ship builder. The skidded plant or packaged ammonia chiller (PAC Chiller) include the major refrigeration system components. A PAC Chiller requires the distribution of a secondary refrigerant or brine solution, rather than a pumped ammonia system, to a remote evaporator. The benefit gained by pumping a secondary refrigerant or brine is the significant reduction in ammonia charge required. Furthermore, all the ammonia required to operate the system is contained in the PAC Chiller and not pumped throughout the facility. Furthermore, a PAC Chiller is built on a skid, and therefore, transportable. In the event the chiller ever needs to be relocated, it is much easier to relocate a PAC Chiller than a site-assembled system.

Figure 2: Concept drawing of 800 ton packaged ammonia chiller.

Bringing the alternative to market:

Beyond the traditional issues faced by a new product, PAC Chillers must be evaluated against the full cost of a site-assembled refrigeration plant. A PAC Chiller is constructed in a controlled factory environment with component locations optimized for a compact footprint. Optimized design and component location ensures reduced assembly time and lower cost. In addition, all of the electrical wiring and control devices are mounted and installed prior to shipment. A conventional site-assembled plant requires the mechanical and electrical trades to install their respective components, and therefore, the entire cost needs to be included in the product evaluation.

Each year several thousand halocarbon chillers are produced globally, and therefore, manufacturing economies of scale have reduced the cost of halocarbon chillers dramatically. In comparison, only several hundred PAC Chillers are produced globally each year. For an equivalent cooling capacity, halocarbon chillers can be two to three times less expensive than a comparable PAC Chiller. As PAC Chillers grow in acceptance, its cost should continue to decline; however, it will probably never be competitive with a halocarbon chiller due to manufacturing scale.

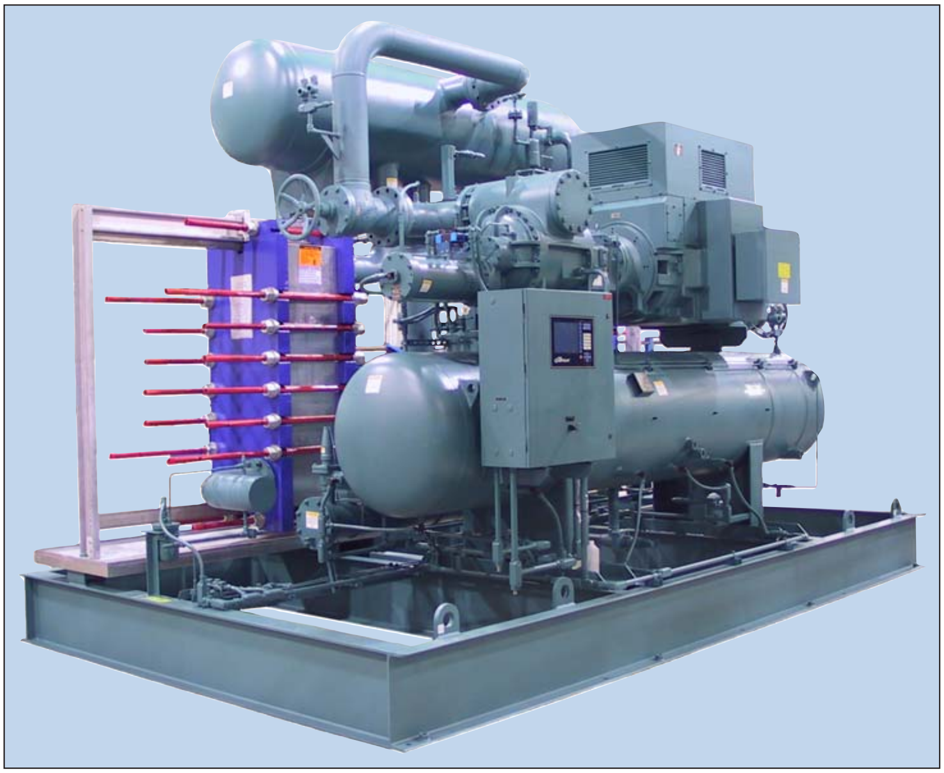
External factors can often require the more costly solution (PAC Chillers versus halocarbon chillers) to be an accepted alternative. Growing global legislation for environmentally-friendly solutions has allowed PAC Chillers to be an attractive solution. Global multi-national corporations that demonstrate environmental stewardship are promoting the use of environmentally-friendly alternatives, even though the first cost premium is significant. The beginning roots for PAC Chillers have emanated from Western Europe and Scandinavia. PAC Chillers have crossed over from being just a solution for industrial refrigeration to meeting the environmentally driven demands of many air-conditioning applications. The facility expansion at Heathrow Airport, Terminal 5, employs packaged ammonia chillers for use in air-conditioning. These four ammonia chillers provide nearly 8,000 tons of air-conditioning capacity.

Figure 3: One of four packaged ammonia chillers being installed at Heathrow Airport Terminal 5

Impacts of Switch to Alternative:

Ammonia chillers continue to grow in popularity, in addition to being applied in other low temperature applications. When ammonia chillers were first launched, the primary application was refrigeration. As the need for energy-efficient, green solutions for air-conditioning become apparent, ammonia chillers have been used. In several projects, ammonia chillers have been applied for dual purposes; in process cooling and air-conditioning.

Enhancements in controls and variable speed drive (VSD) technology have yielded further efficiency gains for ammonia chillers. In one instance, a food processing plant installed five 1,000 TR ammonia chillers. Each chiller was outfitted with a VSD. The amount of energy saved by using a VSD, in conjunction with the ammonia chiller, saved enough energy to power 120 homes for a year, or the equivalent reduction of 970 tons of green house gas emissions per year.



As more ammonia chillers are produced every year, improved manufacturing techniques will further reduce the cost per ton (cooling capacity). More than five years ago, the capital cost premium for an ammonia chiller was 8-10 times that of a conventional chiller. Today, that premium has reduced to just three times more of a premium.

Ammonia's good cycle efficiency, coupled with VSD technology, will further reduce ammonia chiller's low 20-year life cycle cost versus a conventional chiller. When considering halocarbon alternatives, ammonia chillers provide a track record of dependable, energy-efficient operation. Future product innovations will serve to make ammonia chillers the natural alternative to halocarbon chillers.

Figure 4: 800 TR dual purpose, packaged ammonia chiller

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