Over the last decade, the cold storage industry has seen massive changes in the key elements that either drive or have significant influence on the business. In no particular order these elements are: globalization, technology, regulation, environmental/community stewardship and industry consolidation.

There is little or no evidence that the changes effected by these elements are going to subside and it is reasonable to assume that the pace of change is only going to accelerate. As the title of this feature implies, refrigeration plays an enormous role in the cold storage industry and, while there are a modest number of facilities that do not utilize ammonia as the refrigerant of choice, most of the cold storage facilities in North America rely heavily on it as a refrigerant. Today, low ammonia charge is becoming a topic of increasing interest and importance. For decades, refrigeration was regarded by many as simply the cost of doing business and the dictum was often, “just make sure it’s cold.” With this perspective as a backdrop, both facilities and refrigeration systems grew dramatically in size.

Regulatory agencies
Accompanying the growth of the refrigeration system was a consequent growth in the ammonia charge of the facility. This increase in ammonia charge has not been without its consequences. There are three federal agencies which all have their eyes on the cold storage industry, at least where it relates to ammonia refrigeration, in general, and, specifically, ammonia charge. These agencies and their charters follow:

U.S. Environmental Protection Agency (EPA)
   → Chemical Accident Prevention—Risk Management Program (RMP) developed under Section 112(r) of the Clean Air Act (42 U.S.C. 7401-7671). This has resulted in the development of the Chemical Accident Prevention regulations (40 CFR 68) which includes ammonia when the quantity exceeds the 10,000-lb threshold (this is known as TQ for threshold quantity).
   → SARA Title III, Community-Right-To-Know—Chemical Inventory Reports. SARA is an acronym for Superfund Amendments and Reauthorization Act. SARA Title III establishes requirements for federal, state and local governments and industry regarding emergency planning and reporting on hazardous and toxic chemicals and issues a requirement for all facilities that hold an ammonia inventory of 500 lb or more to file a Tier 1 or Tier 2 report on an annual basis.
   → Emergency Release Notifications—There are two different federal acts which drive this requirement, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) and the Emergency Planning and Community Right-To-Know Act (EPCRA). In this case, the threshold for an ammonia release, the Reportable Quantity (RQ) is 100 lb in a 24-hour period and must be reported within one hour of the release. While this is the rule that most companies follow, there is some confusion in the wording that suggests that any release meeting or exceeding the RQ must be reported immediately.

U.S. Department of Homeland Security (DHS)
The DHS has been directed to identify, assess and ensure effective security at high-risk chemical facilities throughout the country. A program has been instituted under the Chemical Facility Anti-Terrorism Standard (CFATS) rule to assess certain chemical facilities to register with DHS and conduct security vulnerability assessments using DHS standards. While it is unlikely that few, if any, cold storage facilities will fall under this scrutiny, it is well within the realm of possibility. As with the EPA program and OSHA’s PSM program, the screening threshold quantity (STQ) of ammonia is set at 10,000 lb. However, the method of calculation is both different and more encompassing.

U.S. Occupational Safety and Health Administration (OSHA)
While fines assessed under various EPA violations have probably been the most severe, OSHA rules and violations have
usually been the most visible. The rule most familiar to those whose facilities which exceed the 10,000-lb threshold is that of the Process Safety Management program (PSM) administered under 29 CFR 1910.119. There are 13 critical components to this rule. It should be noted, however, that even those facilities that do not fall under the auspices of PSM are still expected to adhere the basic tenets of Recognized and Generally Accepted Good Engineering Practice (RAGAGEP).

**California Accidental Release Prevention (CALARP)**

Although it is not the intention of this feature to address all of the specific state-mandated ammonia programs, most people would agree that what starts in California eventually moves throughout the U.S., so the state has a special place of prominence in the regulatory arena for a number of reasons:

→ The state TQ limit for anhydrous ammonia is 500 lb compared to 10,000 lb at the federal level.

→ CALARP facilities are required to be inspected by the Administrative Agency once every three years in order to prove compliance with the facility's RMP.

→ An updated RMP must be submitted to the Administrative Agency at least once every five years.

→ The facility must do a compliance audit at least once every five years to verify that the RMP is still valid and no new processes have been added.

→ The RMP is expected to contain two release scenarios: worst case and most likely to occur.

While hindsight is 20/20, the trends in the industry over the last several decades have put the industry on a collision course with all of the aforementioned federal oversight and/or state mandates. Figure 1 illustrates the tendency over the past decade to move to larger and larger facilities. What is not evident in Figure 1 is that the decrease in the number of facilities 500,000 cu ft or less has only led to a decrease of about 25,000,000 cu ft in total volume, whereas the increase in facilities larger than 5,000,000 cu ft has led to an increase of over 800,000,000 cu ft in total volume. Using the same “time tested” technology and design philosophies, the growth in the size of the facility would, logically, lead to continuing growth in the size of the refrigerant charge.

Ammonia has been and continues to be the predominant refrigerant used in the cold storage and food processing industry. However, as a result of industrial accidents, the potential as a terrorist target, drug trafficking, and growing local concerns, its use has come under increased scrutiny over the past decade.

From a purely technical and environmental perspective, the benefits of ammonia as a refrigerant are unparalleled. It is a natural refrigerant with no global-warming or ozone-depletion potential. Its heat transfer characteristics are among the best...
substances known to man. It is inexpensive, and its use for more than 100 years has led to a base of experience unlike any other refrigerant in this industry. However, in the hands of untrained or careless individuals or in poorly maintained facilities, ammonia can be a highly dangerous chemical. Because of this, the actual size of the ammonia charge in any given facility has come under a large and expansive examination by regulatory authorities, communities and insurance providers. Over the past decade, a number of public refrigerated warehouse (PRW) owners have recognized the need to take action in reducing the ammonia system charge in their facilities. This recognition has broadened over the past few years and the PRW community has reached out to engineers, contractors, and equipment suppliers to find new and innovative ways to minimize their ammonia system charges.

Reducing ammonia charge
It is not an objective of this feature to delve into the history and reasons behind the relatively high ammonia charges seen in today’s cold storage facilities. What has allowed these dramatic improvements to be made in system design is worth noting, however, including:

- Advanced controls: Providing precise liquid metering for liquid feed and direct expansion systems.
- Advanced heat-transfer technology: Providing dramatically higher heat-transfer coefficients, more consistent and reliable latent heat transfer and optimized heat exchanger designs.
- Advanced manufacturing technology: Providing higher pressure components, enhanced tube surfaces, small cost-effective screw compressors.
- Advanced auxiliary components: Providing expansion valves which “mate” perfectly with the advanced control systems, versatile flow-control valves, unique liquid-distribution techniques, high-pressure pumps.

The various means of reducing ammonia charge can be categorized into one or more of the following approaches:

- Eliminating all but the most essential ammonia charge.
- Maximizing the heat-transfer from the ammonia residing within the system to the air or secondary fluid.
- Substituting other heat-transfer fluids for ammonia wherever practical and economically viable.
- Rejecting the “more is better” philosophy when it comes to ammonia charge.

All of the system designs under consideration will fall into one of three general categories. Those categories and the drivers behind their development are:

1. Central systems: Minimize or eliminate unused ammonia charge.
2. Hybrid systems: Isolate ammonia charge to the machine room and use a second coolant in the cold rooms in the facility. These systems would still be considered Central Systems.
3. Packaged systems: Eliminate the central system approach and all of the interconnecting piping and corresponding ammonia inventory by moving to numerous, smaller self-contained systems.

The cost of reducing ammonia charge
There is an old saying that states, “there is no such thing as a free lunch” and it would be a legitimate concern to
many that by reducing the refrigerant charge in the systems reviewed in this feature series some other important variable in the overall operation will suffer. While the primary objective of this feature is to examine different ways of reducing ammonia charge, an important additional objective will be to quantify, as best possible, the impact of these newer technologies on energy efficiency, installed cost and maintenance cost.

Energy efficiency—the logical progression of the technology review is to move from systems most similar to a hypothetical typical cold storage refrigeration system to the system most dramatically different. One objective of this document is to report energy consumption for each system on the basis of KW/TR, where KW = power required for all of the motors needed to drive compressors, fans and pumps; and TR = tons of refrigeration.

This objective has proven to be one of the more challenging elements in terms of calculating a credible value for the various systems under review. There are two ways to obtain the values: from the design perspective and from actual operations data. On the design side, the ratio is, essentially, the total kilowatts consumed by the various motors (compressors, fans, pumps) at the design conditions divided by the design loads of the rooms. The problem with this approach is that it is difficult to account for all of the parasitic losses in the system, especially for central systems.

On the operating side, if one had the time, money, and resolve to actually measure amps, voltages, operating hours, and true loads, it can be done but it is a long, arduous, and expensive process to do so. Fortunately, a research project was undertaken by VaCom Technologies on behalf of PG&E a number of years ago on an actual CO$_2$/NH$_3$ cascade refrigeration facility with design characteristics quite similar to the baseline system. In their overall assessment, VaCom also performed a comprehensive analysis of the expected energy consumption of a comparable pumped recirculated liquid system along with a comparison of the calculated CO$_2$/NH$_3$ system with that of the measured results for the same system. This study represents one of the few undertakings which provide actual performance data with that of theoretical results. Those results will be reported in this paper. Finally, due to the complexity of the topic, part-load energy-efficiency values will not be taken into account in this feature. It must be emphasized, however, that part-load energy consumption is an extremely important variable in that most systems operate in a part load mode most of the year.

Installed costs—In an effort to present a legitimate degree of relevance, another objective was to address the projected installed refrigeration system costs for the various systems under study. Installed costs will vary significantly by the type of system (central or packaged), local labor costs, and local codes and regulations. The only truly meaningful way to make a fundamentally sound comparison is to collect a large amount of actual cost data from across the country for all of these different systems. Unfortunately, because this feature is focused primarily on new technology, a large pool of data simply does not exist. Fortunately, some cost data was made available and all of the contributors to this document have developed their own cost analyses. For the purpose of reviewing installed costs, this feature will focus on the refrigeration system and any structural/building requirements that exist solely for the refrigeration equipment. In the case of a central system, this would include the machine room and, if valve stations are mounted on the roof of the building or in a mezzanine, any additional costs required to do so. For packaged systems, the cost would obviously include the structural housing of the unit itself as well as any additional building support required if the package is to be roof-mounted. In all cases, equipment transportation and rigging are expected to be included in these costs.

Maintenance cost—Most of the systems under review vary significantly in design and construction from each other. As will be reasoned, each system will have its strengths and weaknesses when it comes to maintenance. For example, as the reader will likely note, the packaged systems have a significant increase in the amount of rotating machinery to be maintained at each facility. However, at the same time, these systems almost completely eliminate the most critical mechanical integrity issues and isolate the few that remain to areas easy to service and, open, away from occupied rooms. Maintenance requirements are a key consideration when determining what type of system works best within the owner's constraints. At the same time, with little history to lean on, it is extremely difficult to quantify the gains and the losses for this operational expense.

Parts 2 and 3 of this feature will bring to light real-world examples of the ammonia systems mentioned here in an attempt to provide a broad overview of new and emerging technology that holds the potential for significant reductions in ammonia refrigerant charge.

References
1 USDA, National Agricultural Statistics Service, “Capacity of Refrigerated Warehouses 2013 (January 2014).”

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