Reaching Near-Zero GWP

With Packaged Ammonia/Carbon Dioxide Systems

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Changing rules around the use of high global warming potential (GWP) refrigerants have been one of the hottest topics in the HVAC&R industry in the last few years. Following the phaseout of ozone-depleting refrigerants starting in the 1990s, the U.S. EPA, acting under the Significant New Alternatives Policy (SNAP) program, has recently changed the status of certain high GWP refrigerants. In the next several years, refrigerants such as R-404A, R-507A, R-134a, and others will be prohibited for use in some types of new or retrofit commercial refrigeration installations.[1]

Changes are happening at a local level, too: California's Air Resources Board has recently issued a strategy document proposing aggressive changes, which could include GWP limits as low as 150 for stationary refrigeration and 750 for stationary air conditioning.[2] These limits are challenging to reach with today's most commonly used refrigerants, some of which are highlighted in *Table 1*.

Increasingly, natural refrigerants* such as ammonia (R-717), carbon dioxide (R-744), and hydrocarbons (such as R-290 and R-1270) are being used to meet the demand for very low GWP refrigeration equipment. Hydrocarbons seem to be the long-term solution for systems such as stand-alone refrigeration applications, where the charge level of flammable refrigerant is small and efficiency is very good. For larger industrial applications, ammonia has long been the refrigerant of choice, but due to toxicity and flammability, its use in large quantities near highly populated areas brings risks that must be accounted for and may add cost.

Carbon dioxide is gaining traction for supermarket refrigeration in the U.S., and current research and development efforts are focused on overcoming efficiency hurdles under transcritical operation, which is a particular challenge in warm climates. Solutions that can use these refrigerants while minimizing the technical and safety challenges associated with their use could open new possibilities in significantly increasing the efficiency of the national refrigeration fleet.

* Natural refrigerants are substances that can be found naturally occurring in the environment. Natural refrigerants include ammonia, carbon dioxide, hydrocarbons, water, and air.

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Ammonia is itself subject to restrictions on the federal, state, and local levels. In particular, the U.S. EPA has different regulations applying for site inventory thresholds of 500 lb (227 kg) and 10,000 lb (4536 kg) and requires emergency release notification in the event of leaks exceeding 100 lb (45 kg) in a 24-hour period. Similarly, OSHA requirements apply to ammonia facilities, with additional requirements when exceeding the 10,000 lb (4536 kg) threshold. State level programs are common, too. Most notable (and relevant to the field study discussed here) is California, where the quantity for increased scrutiny is 500 lb (227 kg). Inspections and reporting are required at regular intervals, and compliance audits must also be undertaken at regular intervals.[4]

Further restrictions may be applied at the local level, particularly considering ammonia systems in highly populated areas. For these reasons, ammonia charge quantity reduction is becoming an increasingly hot topic in the industry. Most ammonia regulations were intended to deal with large-charge systems. A number of efforts are currently under way to develop regulations specifically for low-charge ammonia systems that can take advantage of ammonia's high efficiency while minimizing the risk of harm due to leaks.

For some applications, a combined approach using ammonia and carbon dioxide may provide beneficial performance while limiting risk factors and operational issues. Many readers are likely familiar with the cascade cycle, a type of two-stage cooling cycle where a high-stage fluid (ammonia in this case) is paired with a low-stage fluid (CO_2); heat rejection from the low stage is absorbed by the evaporating high-stage refrigerant. Cascade systems are useful, particularly with a large temperature difference, and can offer good efficiency. However, they can be expensive, and the cost and complexity is not needed for moderate cold storage and freezing temperature applications.

Another increasingly popular approach is to use CO_2 as a volatile secondary fluid, pumped to the evaporators where it partially evaporates before returning to be condensed in a chiller. This can be achieved using ammonia as the primary working fluid. Compared with the common approach of using water/glycol as a secondary fluid, pumping power for volatile CO_2 is drastically lower, about 5% of the power required to pump water or glycol, as pointed out by Pearson in a 2012 *ASHRAE Journal* article.[5]

TABLE 1 Atmospheric and safety details for some prominent refrigerants.[3]

REFRIGERANT	GLOBAL WARMING POTENTIAL (GWP)	OZONE DEPLETION POTENTIAL (ODP)	ASHRAE SAFETY CLASSIFICATION
R-22	1,810	0.040	A1
R-404A	3,922	0	A1
R-507A	3,985	0	A1
R-407A	2,107	0	A1
R-410A	2,088	0	A1
R-407F	1,825	0	A1
R-1270	3	0	A3
R-290 (Propane)	3	0	A3
R-744 (Carbon Dioxide)	1	0	A1
R-717 (Ammonia)	<1	0	B2L

Project Overview

This article provides a case study of an installation of a small, packaged ammonia/CO_2 system that has been installed in a food manufacturing facility in Irvine, Calif. Funding for the project comes from the electric ratepayers of California under the state's Emerging Technologies Program.[6] The installation has provided data on energy savings as well as lessons learned from the design, installation, and commissioning of the system.

The new system was installed in an existing freezer as a partial replacement of the facility's existing R-507A system, but the R-507A system was left in place to allow periodic baseline comparison testing. The owner of this site is anticipating expansion of the freezer, doubling its square footage, once this project is complete. Data collection through the end of 2016 will be followed by an upcoming technical report.

At the facility studied in this test, Japanese-style mochi (rice paste) snacks are produced, then stored in a 2,100 ft^2 (195 m^2), –20°F (–6.7°C) drive-in freezer. The refrigeration load, approximately 12.2 tons of refrigeration (42.9 kW), was met with a single R-507A reciprocating compressor installed in 2010. Three additional R-507A compressors for various other refrigerated spaces all share an evaporative condenser. The production line typically operates 12-hour shifts five days per week. The freezer, shown in *Photo 1*, is used for short-term product storage before shipping.

PHOTO 1 Freezer under investigation.

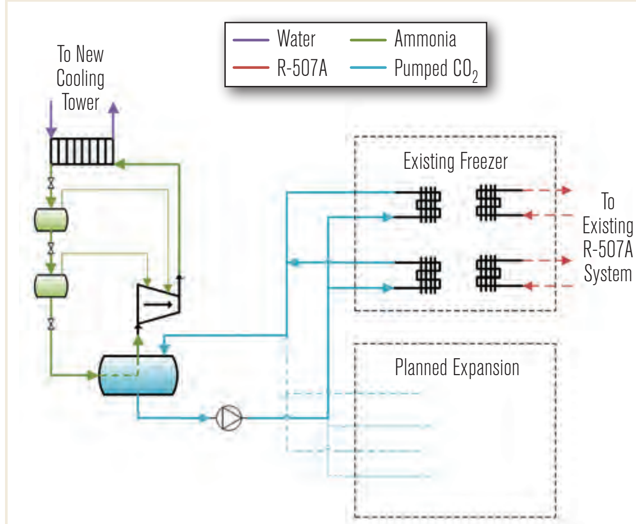

FIGURE 1 Configuration of new ammonia/CO_2 refrigeration system.

The facility is situated in a busy, mixed-use area in Irvine, Calif., in close proximity to retail and residential areas. For this reason, a large ammonia system would not be feasible. The owner, aware of environmental and regulatory concerns around R-507A and other high GWP HFC refrigerants, chose to pursue a natural refrigerant solution for the expansion.

System Overview

A new packaged ammonia/carbon dioxide system was installed to provide cooling for the freezer space. A schematic is shown in *Figure 1*. The new system is a modular skid-mounted configuration (shown in *Photo 2*) with a nominal capacity of 25.6 tons (90 kW) and an ammonia charge of 55 lb (25 kg). A dual-economized two-stage screw compressor with variable frequency drive control is used. A new dedicated cooling tower was also installed. All ammonia-containing portions of the system are located outside the building. The existing system uses electric resistance defrost, as does the new system.

Installation and Monitoring

Instrumentation equipment was installed, including power meters on the new compressor rack, new evaporator coils and new cooling tower, as well as on the existing compressor, evaporator coils, and condenser to capture performance of the existing and new systems. Power metering was done at the breaker panel, so defrost heaters, underfloor heaters and other auxiliary loads are also captured. After start-up and commissioning of the new system, periodic baseline data is gathered by disabling the new system (which maintains standby power to periodically cool the CO_2 reservoir) and turning the existing R-507A compressor back on.

PHOTO 2 Installation. (Credit: CIMCO Refrigeration)

Power meters were installed on six circuits:

- Ammonia/CO_2 system skid (includes compressor, liquid CO_2 pump, controls and sensors, etc.);
- Ammonia/CO_2 system cooling tower;
- CO_2 evaporator coils (includes electric resistance defrost heaters);

- Baseline (R-507A) compressor;
- Baseline (R-507A) condenser (serves total of four R-507A compressors); and
- Baseline (R-507A) evaporator coils (includes electric resistance defrost heaters for R-507A coils, and also an underfloor heater, which is also on during NH_3/CO_2 system operation).

Outdoor temperature and humidity were measured with a sensor mounted on an adjacent outdoor wall. Inside the freezer, temperature was measured in a central location as well as at the inlet and outlet of each coil. The refrigerant temperatures and pressures, as well as compressor speed and other operating data, were captured off the equipment's control board for the ammonia/CO_2 system.

PHOTO 3 Aesthetic fence around new system. (Credit: CIMCO Refrigeration)

The installation process took place over approximately four weeks in February and March 2016. The total time on site was reduced compared with a conventional installation because of the skid-mounted system. The installation was not without surprises. Satisfying the city permitting and inspection requirements led to several unanticipated additions to the site plan. A higher surrounding façade (for aesthetic purposes only) and additional ammonia leak containment measures (the addition of an ammonia diffusion tank for the vent discharge) were required. The surrounding façade is shown in *Photo 3*.

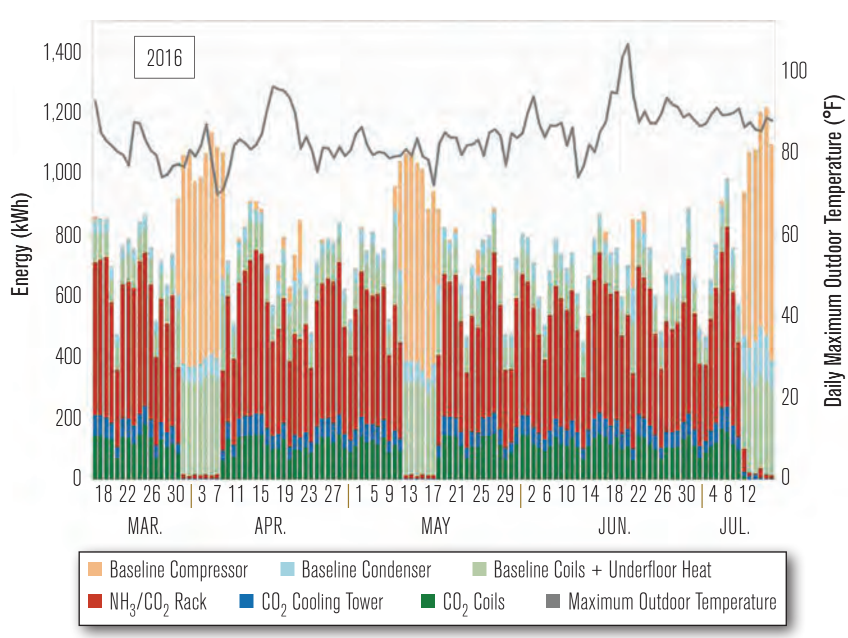

FIGURE 2 Daily energy consumption (excludes baseline/new system transition days and on-site inspection days).

Results

The energy consumption is shown in *Figure 2*, with transitional days between baseline/new system removed for clarity. The combined energy consumption of all monitored refrigerating equipment has been 1,046 kWh per day during baseline (R-507A system) days and 715 kWh per day during new system (ammonia/CO_2) days. The use is lower on weekends. Considering weekdays only, the consumption is 1,066 kWh/day with the baseline and 770 kWh/day with the new system. The energy savings is observed most prominently at lower outdoor temperatures.

Since there is some overlap in power consumption (such as the underfloor heaters and the R-507A condenser, which both operate regardless of which compressor system is running), the energy for each measured circuit is included for all days. The reader may note, for example, that the baseline coil and underfloor heat circuit (light green) is significantly smaller, but not zero, during days with the ammonia/CO_2 system operating. This reflects the underfloor heat component of that circuit. Similarly, the baseline condenser (light blue) uses energy in both cases, so it must be considered in the analysis. The savings observed here are attributable to a combination of effects, including new efficient components and controls, and not only the result of the efficient use of ammonia and CO_2.

In the initial period of installation, and during some of the inspector visits, the ammonia/CO_2 system was periodically shut down for short periods and the baseline system turned on; otherwise, the new system ran unless the system was switched to "baseline," which was done three times in the period shown (starting on April 1, May 11, and July 12).

Figure 3 shows a typical day's power consumption with the new system. The overnight power consumption was typical low-duty-cycle operation, with the system running approximately 20 minutes of every hour; defrost induced the variable speed compressor to run above minimum threshold to restore temperature, and during the hottest part of the day the compressor ran more continuously.

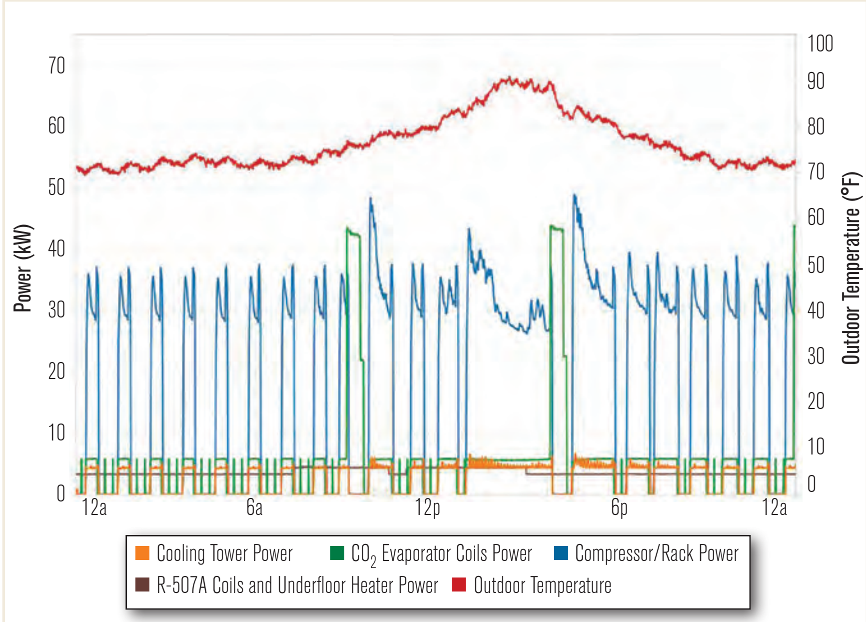

FIGURE 3 One-minute data showing power and outdoor temperature for the ammonia/carbon dioxide refrigeration system.

However, the system ran below maximum compressor speed for the whole day (except for 5 to 15 minutes immediately following defrost), typically at about 55% to 75% of the maximum compressor speed. The outdoor temperature sensor was affected by proximity to the system, and registered a 1°F to 2°F (0.6°C to 1.1°C) temperature increase when the system was running. Note that the power underfloor heaters are also shown in this graph, as measured on the circuit including the R-507A coils (themselves off during this period).

The CO_2 receiver pressure was maintained at about 168 psig, or –28.6°F saturation (1158 kPa, or –33.7°C) while running; during shutdown periods, the compressor ran periodically to maintain pressure below about 230 psig (1600 kPa). It is important with CO_2 refrigeration systems to provide adequate standby/backup cooling during shutdown periods and plan for safe relief discharge in the event of prolonged shutdown, as even in mild conditions the standby pressure can reach hazardous levels. A blow-off valve is present to release pressure if needed.

Both systems satisfy the cooling requirements of the space; the new system has a larger defrost heater in the new coils, so the temperature swing is larger in magnitude, but the temperature is maintained at the same setpoint and remains within satisfactory bounds for both systems. The facility manager reports no observed functional difference between baseline and new system days.

Conclusions and Lessons

The system under test is providing energy savings and has ample capacity to provide cooling for the facility's planned freezer expansion project. It is anticipated that the new expansion will not be connected to the R-507A system, and the old R-507A coils in the existing freezer space will eventually be decommissioned. It is expected that the additional expansion will be considerably easier, as no changes to the outdoor infrastructure, the ammonia charge, or the outdoor safety infrastructure will be needed.

Other potential applications that could benefit from this approach include cold storage facilities, institutional kitchens, food processing facilities and breweries. In potential new installations of this technology, the engineers and installing contractors should plan to contact the local inspecting agency early and often to address any specific concerns that may arise from a still-novel deployment of ammonia refrigerant in nonconventional applications, particularly in densely occupied areas. This should become less of a concern as familiarity grows.

Also, for this project, having manufacturer engagement with the installing contractor throughout the process was found to be helpful; the manufacturer was involved in the bid, design, installation, and commissioning. This will be less necessary as familiarity grows. Finally, the packaged rack configuration can be helpful in facilitating a faster installation, and the integrated control package should facilitate smooth commissioning. However, the host and any unfamiliar maintenance personnel and technicians may require new training or instruction for how to properly handle the new controls. Again, manufacturer engagement and training will be key to ensuring a smooth deployment.

The price premium for the refrigerating hardware used here is approximately 30%; the installation costs are estimated to be approximately the same. One potential avenue to offset the upfront cost of installing such equipment is to target utility incentives. Many electric utility companies are investigating new low or near zero GWP refrigerant solutions as they eye legislative changes and subsequent changes to the HVAC&R industry.

Utility load shapes are heavily influenced by HVAC&R equipment, especially in summer-peaking locations like southern California, and it is in the utility's interest to identify equipment that will not exacerbate high peak demand from HVAC&R loads. While utilities generally will not go as far as to incentivize one refrigerant or another, utilities are usually willing to offer incentives for efficient systems and systems that may help reduce peak demand.

Generally, larger projects like those discussed here are not part of prescriptive rebate programs, but rather are treated as custom incentives. Some utilities are willing to consider enhanced incentives for lesser-known emerging technologies, but the application is always helped by the availability of reliable estimates of energy savings and thorough documentation. From this perspective, the more data from real field sites is made available the better.

Acknowledgments

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