

DR13.07: HVAC & Refrigeration Systems Using Advanced Refrigerants

ALTERNATIVE REFRIGERANT SOLUTIONS FOR REDUCING GLOBAL WARMING POTENTIAL AND ENERGY CONSUMPTION

Due to regulatory bodies moving to reduce the use of refrigerants with high global warming potential (GWP), the HVAC and refrigeration world is undergoing significant changes. In commercial and industrial applications, ammonia refrigerant is a common solution which has zero GWP, but its applicability is limited because of mild flammability and toxicity concerns. However, in recent years alternative technologies have been developed to decrease the flammability concern, through a combined approach using ammonia and carbon dioxide (CO₂). The developed system works by using ammonia as the primary fluid and CO₂ as a pumped volatile secondary fluid. This allows the ammonia charge to be much smaller than an equivalent all-ammonia system, while distributing only CO₂ into the building. In 2016, SCE installed this type of alternative system in a food production facility in Irvine, California and monitored it along with existing, baseline conventional-refrigerant equipment, to study

performance. The study focused on the differences in energy and power consumption as well as observations and learnings from the process of transitioning from a baseline system to a new, alternative-refrigerant approach.



Figure 1: Photograph of the NH₃/CO₂ Refrigeration Skid During Installation
(Photo Credit: CIMCO)

INTRODUCTION

What Is This Technology?

ALTERNATIVE REFRIGERATION SYSTEM: AMMONIA/CO₂

For this study, the Mayekawa Newton 3000, a newly packaged ammonia (NH₃)/carbon dioxide (CO₂) system was used. This system uses ammonia as the primary stage and pumped, volatile CO₂ as the secondary stage. The main ammonia circuit has a two-stage, screw compressor. The discharge of the screw compressor goes to a water-cooled condenser. From there, the refrigerant goes to an intercooler which separates liquid from vapor. The vapor goes to the compressor, mixing and cooling inlet refrigerant to the second stage of compression. The liquid goes to an economizer. The economizer works similarly, as vapor refrigerant goes to an economizer port in the first stage of compression, and liquid goes to the evaporator. The evaporator is an ammonia-to-carbon dioxide heat exchanger, which cools carbon dioxide. The CO₂ is in a liquid tank, from which sub-cooled liquid CO₂ is pumped to the process evaporators.

INTRODUCTION

EQUIPMENT SPECIFICATIONS

Newton 3000

Manufacturer: Mayekawa

Manufacturer provided the following specifications:

CO₂ Supply Temperature: -25.6 °F

Cooling Capacity (with cooling water at 89.6 °F): 26.9 TR

Motor Power: 45 kW

Ammonia Charge: 55.1 lbs.

Power Source:

AC 400/440V @ 50/60Hz for motor; AC 200/220V @ 50/60 Hz for controls

Compressor: Semi-hermetic, compound screw, VFD driven with IPM motor

Outer Dimensions: L 9ft 2in; W 6ft 5in; H 7ft 11in (excludes cooling tower)

The manufacturer also uses an interior permanent magnet (IPM) synchronous motor for the compressor; these motors have higher efficiency than conventional induction motors, and maintain high efficiency even at low compressor speed.

What We Did

FIELD TESTING AT A FOOD PROCESSING FACILITY

The system was installed in a food production facility in Irvine, California and is monitored along with existing, baseline conventional refrigerant equipment, to study performance. The new refrigeration system was installed to provide cooling for an existing a 2,100 square-foot, -20 °F drive-in freezer. The existing refrigeration equipment, part of a R507A system, was left in place but shut off. 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 approach for this evaluation is field-monitoring of equipment under normal operation, with periodic baseline testing which is performed by disabling the system under test, and turning on the baseline equipment. This was done several times during the test period, in an effort to get data across a range of weather conditions while respecting the scheduling/availability of on-site personnel to make and monitor the changes. Demand response tests were performed similarly, with several days of testing during which on-site personnel executed changes to the equipment set-points to simulate a demand response event.

TEST OVERVIEW

The testing was performed over the course of 2016 starting after the installation was complete. To generally sort data, the days are filtered into:

- › **Baseline** - the R507A system is the only one cooling the space
- › **New Equipment** - the NH₃/CO₂ system is the only one cooling the space
- › **Transition** - the day is split, usually because of a mid-day switch between baseline and new equipment, but also possibly including some limited maintenance which was not identified
- › **Other** - days where on-site maintenance was taking place, demand response testing was performed, or other known aberrations from the test schedule

The days tagged as “other” are identified by communication with the host site manager. In initial data processing, each day is flagged as “baseline” if the baseline compressor uses >100 kWh and the Newton uses <75 kWh. A day is flagged as “New Equipment” if the Newton uses >100 kWh and the baseline compressor uses <75 kWh. “Transition” and “Other” days are removed from the bulk data analysis.



ENERGY CONSUMPTION IS CONSIDERABLY LOWER USING THE NEW NH₃/CO₂ SYSTEM:

The energy consumption was significantly less with the new equipment vs. baseline equipment, in the range of approximately 200-300 kWh per day lower in typical conditions.

DAILY ENERGY CONSUMPTION VS. AVERAGE OUTDOOR TEMPERATURE FOR BASELINE AND NEW EQUIPMENT

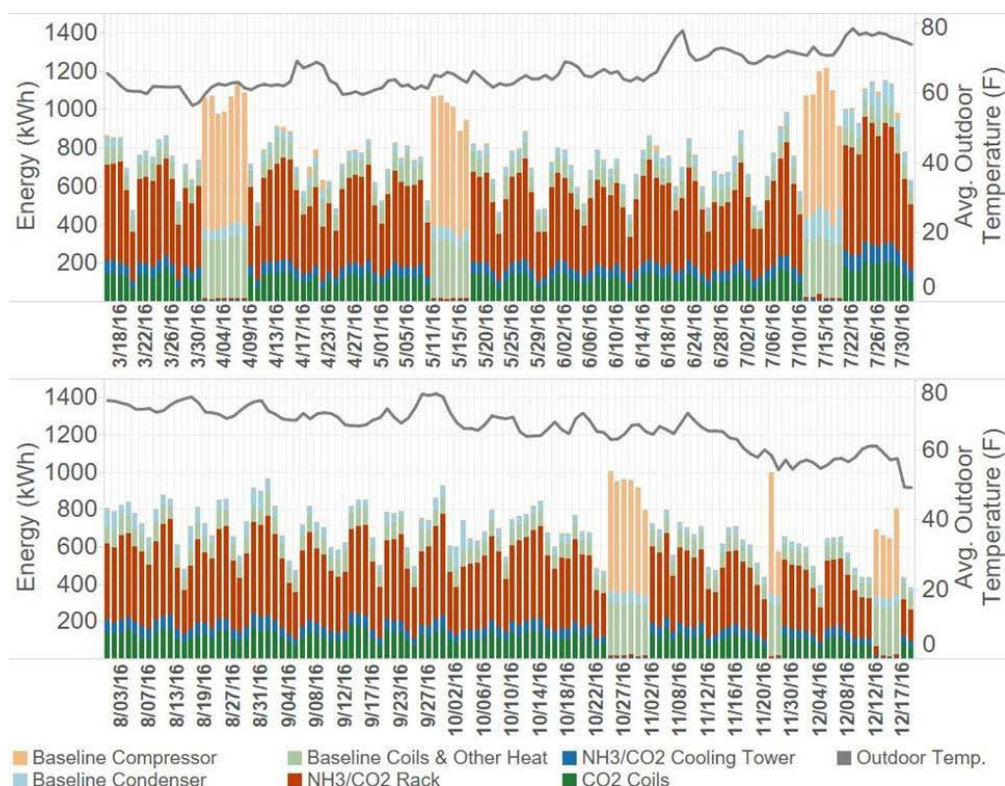


Figure 2: Stacked-Bar Chart of the Daily Energy Consumption for All Refrigeration Equipment



DEMAND RESPONSE SHED IS EFFECTIVE: The simulated demand response testing performed shows that a pre-cool and shed can be performed with this equipment. Due to the system's control functionality, where CO₂ is maintained at a fixed condition and pumped on-demand to the freezer, the ability to over-cool is limited. The ability to provide simple "on/off" load shedding is as much a function of the load itself as the equipment. The system under test was mostly able to fully power off during the shed for extended periods, with limited cycling to keep temperatures in the adjusted set-point range. This allowed reductions of average hourly power up to 21 kW, without requiring a large rebound or drastically altering the freezer condition. These shedding patterns could have significant financial impact, depending on the utility rate structure and incentives.



BELOW SET-POINT TEMPERATURE LIMITATIONS: The ability to drop temperature below set-point may be limited by the temperature of the CO₂ being supplied. This is due to the method of operation: the CO₂ reservoir is held as a liquid at a fixed pressure, which is maintained by the ammonia system. The controls of the Newton serve to maintain the condition of the CO₂, meaning that the supply of CO₂ is at a roughly fixed temperature and pressure. The thermostat of the freezer only turns the CO₂ coils on and off. So, the temperature of air that can be reached with the coils is limited by the CO₂ temperature, and achieving much lower temperature in a reasonable timeframe would require adjusting the CO₂ conditions. This would be possible with integration of advanced controls to the system. The pre-cool still serves a purpose by ensuring that the freezer is at the low end of the temperature range, and by holding the temperature lower, the temperature of the product in the freezer is likely lowered, which will in effect store some thermal energy. This effect was not directly measured, as product simulators were not installed.

CONCLUSIONS

What We Concluded

ENERGY CONSUMPTION

The energy consumption was significantly lower with the new equipment vs. standard baseline equipment. Each system also maintained a similar average freezer temperature in the early part of the study. The freezer temperature deviated higher during defrost with the new equipment, for which both defrost heaters ran simultaneously, than for the baseline equipment which defrosted typically one coil at a time, leading to more frequent temperature changes but of smaller magnitude. The new system was noted to be considerably oversized for the existing load, so although it has a variable-speed compressor, it often ran in cyclic operation, particularly during low-load hours. The host expects to double the freezer capacity by adding an additional, near-identical freezer, and anticipates only CO₂ coils connected to the new system will be used for the new freezer.

DEMAND RESPONSE

Since the NH₃/CO₂ system's operation calls for maintaining CO₂ at a fixed condition, and pumping liquid to the freezer, it was determined that pre-cool capability was limited since the instantaneous capacity at the evaporator coil is essentially fixed; to modify this, the CO₂ set-point conditions could be changed, but this could not be implemented in time to include in this evaluation. However, testing was performed by adjusting the freezer temperature set-point. The testing showed an ability to increase load during the pre-cool period, and to shed load by increasing the temperature set-point. The shed, which was executed with a simple 5°F increase in set-point temperature, resulted in average hourly power in the range of 14-21 kW for the first hour of load shed. Generally, the system did cycle on and run later in the shed event, but run times were shorter than in typical cycling. Also, defrost operation interrupted the demand response events (particularly the pre-cool) several times. The defrost heaters were not controlled as part of the demand response study.

These Findings are based on the reports "Ammonia/CO₂ Refrigeration System Evaluation at a Food Processing Facility," which is available from the ETCC program website, <https://www.etcc-ca.com/reports>

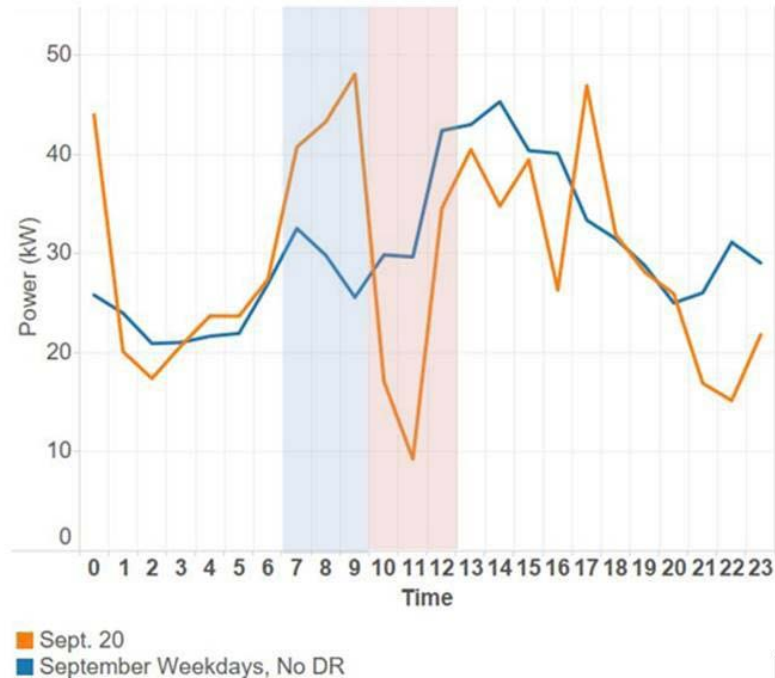


Figure 3: September 20 DR Event Compared with September Non-DR Weekday

Lessons Learned

The overall performance of advanced refrigeration systems for demand response purposes would be improved by increased control capability through the ability to shift defrost forward or back in time, and the ability to adjust the CO₂ conditions to facilitate a more effective pre-cooling mode. By having these additional control and automation capabilities in place, these systems would potentially offer a greater resource for demand response.