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CO2 Is Keeping Supermarkets Cool

A Danfoss Case Study Examines A Cascade System Using CO2 and R-404A.

In two recent articles, the background and attributes of carbon dioxide (CO2, R-744) as a refrigerant and its application in cascade systems for industrial refrigeration were discussed. (See “CO2 in Refrigeration Applications,” Oct. 6, 2003, and “CO2 in Industrial Refrigeration,” Nov. 3, 2003.) The following article presents a case study of a cascade system in a commercial application where every evaporator operates with CO2. This system has been in operation for two years in a 21,500-square-foot supermarket in suburban Copenhagen.

Bitzer Octagon-K compressors are used for the CO2 cycle, the low stage in the cascade.

The store has 18 low- and 36 medium- and high-temperature fixtures. There are now 10 such installations in Europe, all circuits operating with subcritical CO2 cycles. There are an additional 10 to 12 stores with CO2 used for low-temperature fixtures and R-404A used for medium- and high-temperature fixtures.

The store’s inside ambient temperature is controlled to 69.8 degrees F (21 degrees C) during daytime open hours, and to 64.4 degrees F (18 degrees C) at night. Outdoor ambient temperature ranges during the year from 14 degrees to 86 degrees F. Fresh air ventilation is completely sufficient for cooling during the summer months, and in winter the store is warmed entirely by heat reclaim, although in some other similar installations where winter ambients are low, auxiliary heat must be used because of the CO2 system’s high efficiency.

In Europe, meeting the requirements of the Kyoto Protocol has become increasingly important. CO2 has absolutely zero ozone depletion effect, and its global warming potential is negligible in the amounts used for industrial and commercial refrigeration. There is a decided trend away from HFC refrigerants.

HFCs are being used, but in restricted amounts. Heavy taxes on HFCs, equivalent to $35 to $59 per 2.2 pounds, add considerable urgency to the trend toward natural refrigerants. Natural refrigerants like CO2 (and the hydrocarbons), with no environmental consequences, are tax free, and they are increasingly being looked upon as a long-term solution.

Because CO2 is a high-pressure refrigerant, normal commercial refrigeration systems have to be of a cascade design, with another refrigerant being used in the high stage. Hydrocarbons have been evaluated for use as the high-stage refrigerant, but they are not currently being used in large supermarket installations.

Because of the taxes on HFCs and the lower cost of CO2 installations, an increasing number of smaller markets and supermarkets are being installed using natural refrigerants in Germany, Luxembourg, Denmark, and other European countries.

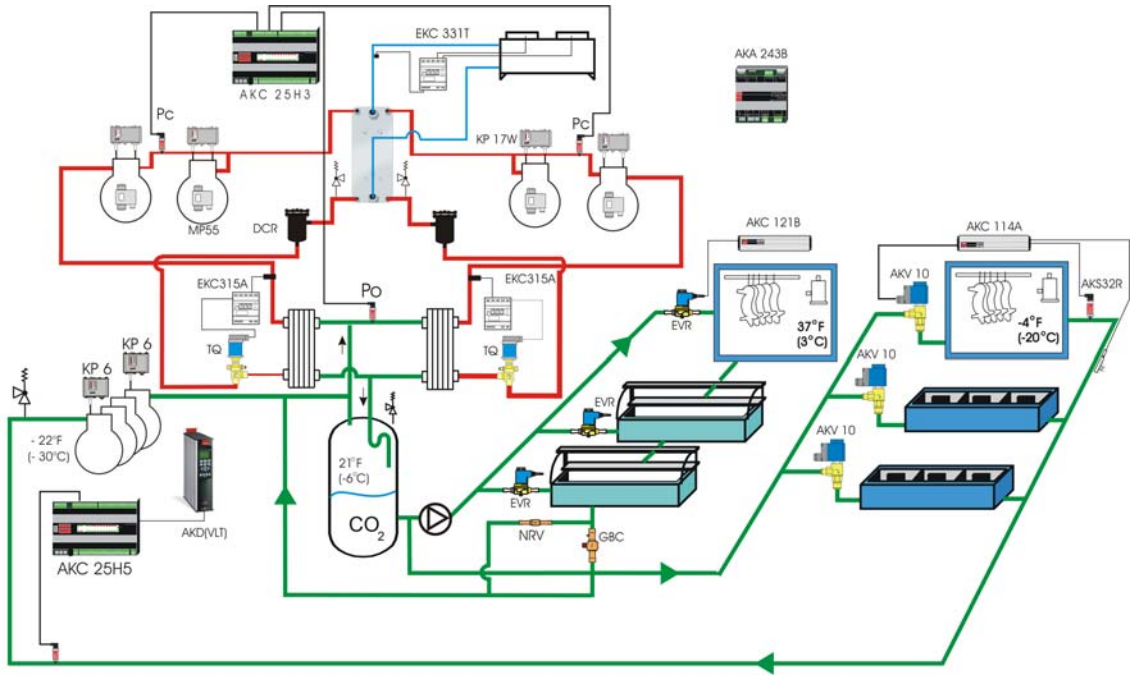

Fig 1. A detailed representation of the cascade system, including the electronic and mechanical Danfoss controls used.

Benefits of CO2

Chief among the benefits of using CO2 are these:

- Small gas flow compared to HFC refrigerants because of CO2's very high efficiency. As an example, the volumetric refrigeration capacity for CO2 is approximately 8 times that of an HFC, so CO2 compressors are considerably smaller.

- Piping is smaller, seldom larger than 7/8 inches. Therefore, standard copper pipe can be installed.
- Evaporators are smaller and more efficient.
- A relatively small amount of CO2 is needed (551 pounds), and the cost of CO2 is much lower than that of HFC refrigerant. CO2 of "welding quality" is used, which is 99.9 percent pure. Dryness is essential to eliminate the potential for ice formation. The cost of suitable CO2 for such a system in North America would be less than $200. The R-404A charge in this system (the high part of the cascade) is 80 pounds.

System Design

The layout of the system is given in Figure 1.

There are effectively two R-404A systems in the high stage, each with a group of compressors. Two systems ensure that if one fails or is being serviced, refrigeration continues and there is no risk of the CO2 in the lower stage reaching too high temperature and pressure. The cost of two systems is only slightly more than for a single system because with the double-system design the compressors and other components are smaller. Each R-404 loop is connected to an evaporator plate heat exchanger. The other side of these heat exchangers is the condenser for the CO2 stage.

Heat rejection for the R-404A stage is accomplished by connecting discharge to a double-circuit condenser plate heat exchanger. There are two circuits on the HFC side. The single circuit on the liquid side is connected to a liquid cooler so that the rejected heat can be used for heating. Excess heat is rejected to the atmosphere by a remote water-cooled unit with fans.

In the low stage of the cascade (CO2), a single group of compressors uses the two plate heat exchangers for condensation. Condensed CO2 liquid is returned to a comparatively large receiver that is also used as a pump vessel.

The suction side is connected to the low-temperature evaporator outlets. The low-temperature

evaporators are fed by liquid from the receiver by direct expansion using Danfoss AKV10 electronic expansion valves with Adap-Kool® electronic control. High- and medium-temperature evaporators are fed by a pump with liquid CO2 from the 106-gallon receiver, the CO2 acting as a brine in a liquid overfeed system. Control into the evaporators is by Danfoss EVR solenoid valves with Adap-Kool electronic control.

	High Stage R-404A	Lower Stage R-744 (CO_2)
Capacity	42.86 TR	11.43 TR
Load	CO_2 compressor capacity + motor work + CO_2 condenser capacity	Dependent upon fixtures
Evaporating Temp	21°F	-22°F
Condensing Temp	86° to 97°F	21°F
Charge	2 x 40 pounds	551 pounds

Table 1. Summary of system specifics.

Compressors

Compressors used in this, as in most European CO2 supermarket installations, are Bitzer type Octagon-K, developed for subcritical CO2 installations. The R-404A compressors in this installation were also supplied by Bitzer. The machine room equipment, supplied by York International, is shown in Figure 3.

Figure 3. The central refrigeration plant. *(Photo courtesy of York Refrigeration, York International.)*

Display fixtures were supplied by Arneg (Italy). All of the fixtures, including boxes and prep rooms, have evaporators by ECO (Italy). Plate heat exchangers were supplied by SWEP (Sweden).

Electric defrost is used in the low-temperature fixtures and natural defrost in the high- and medium-temperature fixtures.

Danfoss Adap-Kool electronic and mechanical controls were used throughout the installation, as were Danfoss line components. The AKC 25H controller used for the CO2 compressors is a single-rack step controller that also offers capacity control for one compressor by means of an AKD variable-frequency drive.

Low-temperature fixtures are controlled by Adap-Kool superheat controllers with adaptive algorithms controlling liquid injection by AKV electronic expansion valves. Adap-Kool brine controllers type AKC 121B control the high- and medium-temperature circuits with adaptive pulse width modulation and type EVR solenoid valves. Both types control temperature, anti-sweat heaters, fans, defrost, and night setback, and have alarm capability. It is possible to connect the Adap-Kool controls to a gateway so that re-mote monitoring, troubleshooting, and alarming are possible.

(Note: Further information on the controls and control strategies is available from Danfoss and will be the subject of a future article.)

Economy

The initial cost of each of the first several similar installations was higher than for a normal HFC installation, but the increase was partly compensated by the great savings on refrigerant. More recent installations have about the same installation cost as a traditional HFC installation.

In the event of a refrigerant loss, the replacement cost is much reduced compared to HFC. The Technical University of Denmark is currently engaged in a controlled study funded by the Danish government in which two HFC supermarkets are being compared with two CO2 supermarkets. Preliminary results indicate that the running costs are lower for the CO2 installation. The results of the study, when complete, will be included in a future article.

The Bitzer R-404A compressors are pictured here. There are two complete systems.

In the low stage of the cascade (CO2), a single group of compressors uses the two plate heat exchangers for condensation. Condensed CO2 liquid is returned to a comparatively large receiver that is also used as a pump vessel.

From our experience with a number of CO2 supermarket installations, it is clear that this natural refrigerant is a viable alternative to HFC installations in both regulatory and economic aspects.

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