Understanding CO₂’s unique properties and system operation

BY DON GILLIS

For most refrigeration contractors and service technicians in the U.S., working with CO₂-based refrigeration is still largely an abstract concept. Most know that CO₂ has higher pressures, unique performance characteristics and architectures that are vastly different from traditional systems. But very few technicians have ever worked with a CO₂ system. That will likely change soon.

CO₂ refrigeration is on the rise in the U.S. for a variety of reasons, including: environmental regulations requiring transitioning to lower GWP refrigerants, helping operators comply with corporate sustainability objectives, and the fact that some European grocers have brought their preferred CO₂ refrigeration architectures to the U.S.

From an environmental standpoint, traditional hydrofluorocarbon (HFC) systems used in large supermarkets have become a global target for regulators. With larger refrigerant charges that increase the chance of leaking, these systems have known global warming impacts. To help put this into context, R-404A has a global warming potential (GWP) of 3,922; CO₂ has a GWP of 1.

CO₂, also known as R-744, is considered a natural refrigerant that is non-flammable and presents no threat to the ozone layer. In fact, it is the refrigerant by which the GWP of other refrigerants are measured. So, in terms of GWP, one pound of R-404A emissions is the equivalent of 3,922 lbs of CO₂ emissions.

A variety of lower-GWP alternatives exist across the full spectrum of GWP ratings, but CO₂ is often considered to be a refrigerant of the future as it satisfies current and known future regulatory requirements. As a result, manufacturers continue to perfect CO₂ refrigeration technology to support supermarket owners and operators making the transition to environmentally friendly refrigeration.

High pressure and heavier than air — CO₂ refrigerant peculiarities

CO₂’s characteristics are different than traditional HFC refrigerants in many ways. Contractors must be aware of the differences to prepare themselves to properly service CO₂ systems. For starters, CO₂ has a much lower temperature at atmospheric pressure than HFCs, and has a lower saturation point, as well as higher operating and standstill pressures. Understanding how these factors impact servicing requirements and system performance is essential.

Low critical point (pressure and temperature) — Compared to HFCs, CO₂ has a very low critical point (at 1,056°F or 623°C) and a very low critical pressure (at 1260 psig). This means that CO₂ can be used in a wider range of applications, including in places with extreme temperatures or pressure conditions.

Basic properties of R-744 compared to HFC refrigerants commonly used within the retail sector.
psig or 87.8 °F) which, unlike HFCs, is within normal temperature ranges in a number of places on earth. As a result, this determines its modes of operation. In subcritical mode, where systems operate below 87.8°F, the system has similar pressures to one charged with R-410A. Above critical point, systems operate in transcritical mode, as is the case in warmer regions or during summer heat levels.

In transcritical mode, CO₂ transforms into a supercritical fluid (no longer a liquid or a vapor) and pressures can rise to 1,400 psig.

High triple point (potential dry ice formation) — At 61 psig, CO₂’s triple point where the refrigerant’s solid, liquid and vapor phases coexist — is also very high. If system pressures reach the triple point, the refrigerant will turn to dry ice (an unusable solid state that’s neither a vapor nor a liquid). This can occur during maintenance when the system is exposed to air. In this case, the system would need to be dried out to remove any moisture prior to recharging.

Unlike traditional HFCs, the relationship between CO₂’s pressure and temperature occur very close to each other. Due to CO₂’s low critical point and high triple point, both occur above atmospheric pressures of 14.7 psi. From its state as a solid (dry ice), CO₂ expands 845 times and sublimes back into a gas. Put another way, one liter of dry ice will produce 845 liters of gas. It’s important to keep this in mind for safety purposes when transporting CO₂ in a vehicle or in a confined area where it could become an asphyxiation threat.

CO₂ also has a relative density versus oxygen of 1.52, which means it’s heavier than air and could potentially collect in low lying areas if leaked. For this reason, leak detection devices should typically be installed within 18 inches of ground level.

Rapid pressure rise (power outage strategies) — During power outages, CO₂ pressures typically can rise quickly within a system. That’s why systems are designed with appropriate pressure-relief valves that release the refrigerant charge when it exceeds acceptable pressures — which would typically also require the system to be recharged. Obviously, this can affect cooling capabilities, which presents the potential risk of losing product.

To prevent having to evacuate the system charge during a power outage, CO₂ systems are often designed with a backup generator connected to a stand-by condensing unit. When the power goes out, the generator powers a condensing unit that has a loop within the flash tank (i.e., receiver) designed to cool the liquid within the tank and keep pressures down.

Vapor to liquid charging — Unlike normal refrigerants that are shipped in a tank as a liquid, CO₂ is shipped in tanks in liquid and vapor — both of which are typically needed to charge a system. To prevent the potential formation of dry ice, it’s important to understand that you should not charge the system with the liquid state CO₂ until the system reaches pressures above triple point. The most common practice is to charge a CO₂ system
Common Pressures Referred to for CO₂ Systems

90 bar g
1305 psig

120 bar g
1740 psig

35 bar g
500 psig

40 bar
580 psi
43°F

60 bar g
870 psig

43°F

PFV

Transcritical CO₂ booster system architecture is designed to manage pressures at each stage of the refrigeration cycle.

with vapor until it reaches 100 psig — which is well beyond triple point and provides a safe margin of error — and then finish the charging process with liquid.

A look inside a transcritical CO₂ booster system
Once you understand the peculiarities of CO₂, you can see how system architectures are designed to manage pressures and maximize its full potential. Operators of large supermarkets seeking all-natural refrigeration options are evaluating transcritical CO₂ booster systems, which provide both medium- and low-temperature cooling.

A transcritical booster system is designed to operate above the critical point of 87.8°F. In the system diagram, the red lines indicate the highest system pressures in transcritical mode. At point 1, pressures are very high at 1,740 psig, so technicians typically rely on special gauges, which may even be built into the system. To handle these pressures, piping needs to either be stainless steel or extra high pressure (XHP) copper with a thicker wall.

The condenser at point 2 is referred to as a gas cooler. Since the refrigerant technically cannot condense above critical point, its purpose is to cool the liquid in a transcritical state. At point 3, a high-pressure (HP) valve (or metering device) serves as a hold-back valve that manages the refrigerant and prevents excess pressures from releasing into the system below.

Note the presence of high-pressure electronic controllers, which are typically needed to assist in this process and help maximize the coefficient of performance (COP). CO₂ systems typically require the use of high-pressure controllers, electronic expansion valves, pressure transducers and temperature sensors to optimize pressures in the system and regulate refrigerant quality to the cases.

The flash tank at point 4 is similar to a receiver and is designed with thick walls to withstand the higher pressures. The HP valve (at point 3) meters the refrigerant and flashes it off as a saturated liquid or vapor into the flash tank. A bypass valve (points 9 and 10) helps keep...
the temperature stabilized in the event that outside ambient temperatures rise.

The properly cooled and pressurized liquid refrigerant at the bottom of the flash tank then feeds the medium- and low-temperature portions of the system. Electronic expansion valves control the flow of refrigerant into both suction groups (see points 5, 6 and 8).

Another unique characteristic of this architecture is that there are three different types of refrigerant pressures feeding into one suction header: from the bypass valve and the medium- and low-temperature suction groups (see point 12). From there, the refrigerant flows into the medium-temperature compressors, and the refrigeration cycle repeats.

Educate yourself and seek professional training

From a service technician’s perspective, CO₂ refrigeration represents a sharp contrast when compared to working with traditional HFC systems. While the adoption of CO₂ systems in the U.S. is still relatively small, industry trends point to the potential for more operators to begin making the transition to CO₂ in greater numbers soon.

With its peculiarities and unique performance characteristics, CO₂ greatly impacts servicing and requires specific system design strategies to manage its high pressures. If you’re adding CO₂ servicing to your list of qualifications, it’s critically important to be prepared and fully understand proper handling procedures.

To help with this learning curve, many equipment manufacturers are supporting their customers by offering CO₂ training courses. Emerson’s Educational Services are dedicated to help contracting businesses educate their service technicians by providing a comprehensive CO₂ training curriculum. Contact our certified CO₂ training professionals to help your technicians prepare for using this refrigerant in adapting to the future of refrigeration.

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