PART 6:

CO_2 as a Refrigerant—

Installation, Commissioning & Services

The sixth and final article in this series covers key considerations when systems are commissioned and operating, as well as service and maintenance issues.

BY ANDRE PATENAUDE

Images courtesy of Emerson Climate Technologies, Canada.

Part 5 of this series detailed design considerations applicable to R-744 cascade, transcritical booster and secondary systems. The sixth and final article in this series covers key points for commissioned and operating CO_2 systems, plus important service and maintenance issues. Know that this is not a complete guide to commissioning and service.

Key points for safe handling of R-744 include:

→High system and cylinder pressures, e.g., approximately 50 bar (725 psi) at 15°C (59°F).

→R-744 is an asphyxiant (the practical limit in EN378 is 0.1 kg/m³).

→High risk of freeze burns (liquid or solid R-744).

→High risk of excessive pressure with trapped liquid; 1°C (1.8°F) increase in temperature produces a 10-bar (145-psi) increase in pressure.

→Risk of solid R-744 formation when venting liquid or charging liquid into an evacuated system.

→R-744 (refrigerant-grade CO_2) must be used to ensure low moisture levels.

→Appropriate personal protective equipment, including gloves and goggles, must be worn.

→R-744 cylinders are heavy, and must be secured when handling.

→Correct cylinder adaptors must be used—connections must not be bodged.

→R-744-rated equipment for charging and venting must be used; standard gauge manifold hoses must not be used.

→Proper case and plant isolation procedures must be followed to avoid trapping liquid in service lines, pipe work or components.

→Systems must not be brazed or welded with R-744 still in the system/part of system.

Good installation practice

Sufficient time should be provided so systems can be fully pressure-tested for strength and leak tightness prior to being put into service. This minimizes future reliability issues.

Pipe work—Pipe work should be routed in accordance with good refrigeration practice to minimize pressure drop and allow oil return to the compressor. It is important that pipe work is correctly supported and fixed as outlined in Part 3 of this series "CO_2 as a Refrigerant—System Design, Commissioning, Operation & Service" featured in the May 2015 issue of *RSES Journal*.

Vent lines from pressure-relief valves should discharge to a safe place. This is typically an unoccupied area outside a building or plant enclosure where the refrigerant can disperse without asphyxiation risk. PRV vent lines should be of sufficient diameter to prevent R-744 solidifying (see Table 1).

The most reliable method of jointing pipe work is to braze or weld to a nationally recognized standard. Special attention should

Copper Pipe OD (in.)	Maximum Support Spacing (ft)	Steel Pipe Nominal Bore (in.)	Maximum Support Spacing (ft)
3/8 to 3/4	3.28	1/2 to 1	3.28
7/8 to 1/8	6.56	1 1/4 to 2	9.84
5/8 to 1/8	9.84	2 1/2 to 3	11.48
		4 to 7	13.12

Table 1 **Pipe diameters for copper and steel pipes.**

›› Figure 1 **Example of R-744 charging equipment.**

be made to the hazard category of the joint and the required levels of competency and certification to carry out the work.

Pressure testing—The completed installation should be pressure tested for strength and leak tightness in accordance with the relevant standard. This is typically:

- →Strength test at 1.1 x maximum allowable pressure (PS) for most pipe work (i.e., joints that are hazard category 1 or lower, as defined in EN378-2, annex B).
- →Strength test at 1.43 x PS for the high side of transcritical systems where the hazard category is 2 or higher. Alternatively, 1.1 x PS can be used, in which case 10% of the joints must be nondestructively tested.
- →Leak tightness test at 1.0 x PS.

The relevant standard must be referred to for specific pressure-testing requirements. Pressure-relief valves should be isolated during pressure testing. Best practices include:

- →Equipment, including the nitrogen regulator, should be rated for the pressure.
- →Evacuation of anyone not directly involved in the pressure testing.
- →Oxygen-free nitrogen should be charged slowly into the system and an initial check carried out at approximately 5 bar (72.5 psi).
- →Strength test pressure should be held for a minimum of 15 minutes.
- →Nitrogen used for leak testing should be vented to a well-ventilated area, ideally outside.
- →Pressure should be reduced to the tightness test pressure and each joint checked with leak-detection spray, or the pressure held and monitored over at least 24 hours.

Evacuation—Non-condensable gases and moisture must be thoroughly evacuated. Both have an adverse impact on R-744 systems.

Non-condensable gases (e.g., air and nitrogen) tend to accumulate in the condenser or gas cooler, where they increase pressure. This leads to reduced capacity, efficiency and reliability of the system. The effect of non-condensable gases in an R-744 system is greater compared to HFC systems, especially transcritical systems.

R-744 State	Temperature	Maximum Moisture (ppm)
Liquid	-40°F	130
	14°F	405
Vapor	-40°F	7
	14°F	33

^ Table 2 **Pipe diameters for copper and steel pipes.**

High moisture will cause system failures, e.g., water and carbon dioxide produce carbonic acid. If moisture content is above the maximum ppm as shown in Table 2, there will be free moisture that can freeze. This is most likely in the superheated vapor between the exit of the evaporator and compressor suction, especially with low-temperature (LT) evaporators. Moisture accumulation in static parts of the system can freeze and expand, causing pipe failure.

Great care should be taken during service to minimize the ingress of air and moisture to avoid these problems.

Charging R-744

R-744 is available in bulk or in cylinders with either a liquid take-off or a gas take-off valve. The cylinders are heavier and generally less stable than other refrigerant cylinders, so care is needed when handling them. Equipment used to connect the cylinder to the system must be rated for the pressure. For example, EN378 specifies that equipment must be rated for at least 90 bar (1,305 psi). Typically a hydraulic or braided-steel hose is used (see example in Figure 1).

The cylinder connection fitting must be correct for the cylinder valve—standard adaptors for HFC cylinders must not be used. Charging lines should be evacuated or purged prior to charging to reduce the ingress of air and moisture into the system.

To prevent dry-ice formation, evacuated systems should be charged with R-744 vapor to a pressure above the triple point (4.2 bar [60.9 psi]). The whole system must be above the triple point—this is likely to be the case if all the gauges show a pressure of 10 bar (145 psi). When this is achieved the system can then be charged with liquid.

Care must be taken when charging R-744 systems to prevent pressure-relief valves from discharging. R-744 cylinder pressure will be greater than some or all PRV relief pressures, especially those on the low stage of cascade systems and the low and intermediate sides of transcritical booster systems. To avoid PRV discharge, the refrigerant should be charged slowly to allow system pressure to equalize, especially during initial bulk charging ("bomb" charging) of the system.

Charging the low stage of cascade systems—Before the low stage of a cascade system is charged, the high stage must be available to run, i.e., the high stage must be charged and commissioned first.

Charging a transcritical booster system—It is unlikely that all of the refrigerant can be charged without running the system, which should not be topped up by charging into the suction. Systems with an intermediate pressure higher than cylinder pressure should be pumped down or intermediate pressure reduced to enable refrigerant charging. Cylinder pressure can also be increased by heating the cylinder with a thermostatically controlled heater.

High-stage compressors must be available to operate before the low-stage compressors can be started.

System checks

Before a system runs for the first time, the following should be checked on all systems:

- →Visual inspection;
- →Documentation for the system and its marking, especially pressure equipment;
- →Installation of safety devices;
- →Control tests to ensure all controls function correctly, including any manual backup system;
- →Set pressure of all safety devices and other pressure cutouts;
- →Set pressure of the gas cooler pressure regulating valve;
- →Compressor and oil reservoir oil levels;
- →Cores fitted in filter-driers;
- →Pressure test records; and
- →All valves open/closed as required for operation.

During initial operation, the following should also be checked:

- →Phase rotation of scroll compressors;
- →Fan rotation; check before starting compressors—turn fans on manually;
- →Refrigerant level;
- →Oil level in compressors and reservoir;
- →Expansion valve superheat;
- →Pressure and temperature of cascade heat exchanger;
- →Regulating valve in both subcritical and transcritical modes;
- →Operating pressure of receiver pressure regulating valve; and
- →Operation of any auxiliary cooling unit.

Charge Size (lb CO_2)	Frequency of Leak Detection
Up to 66	1/year
66 to 661	2/year
More than 661	4/year

[1]Regulation 842/2006 on certain fluorinated greenhouse gases

Table 3 F-gas regulation leak check.

Service

General—Work should take place in a well-ventilated area. If there is no operational permanent leak detection, technicians should use personal R-744 detectors for safety. Personal protective equipment should include gloves, safety glasses and ear protectors. Tools and equipment should be rated for the pressure of the system, R-744 cylinders and nitrogen cylinders (where used).

Technicians should be familiar with the system and understand safe isolation of all sections, including the effects of closing valves and the potential for trapping liquid R-744.

Leak detection—Leak detection is critical because of the higher pressures and smaller molecule size of R-744, especially in retail central plant systems with many joints. Leak-detection methods include:

- →Visual inspection (many leaks cause oil stains);
- →Leak-detection spray, although this is difficult on insulated joints and sections of the installation below 0°C (32°F);
- →Hand-held electronic leak detectors suitable for R-744, typically infrared; and
- →Ultrasonic leak detectors.

The entire system must be checked and leaks repaired as soon as possible after detection. For efficiency, retail R-744 systems should be checked for leaks following, at a minimum, the same regimen as specified in the European Fluorinated Gas Regulation[1] for HFC refrigerants, as shown in Table 3.

Disposal of R-744—R-744 is usually vented, not recovered. This should be done in a well-ventilated area, ideally outside a building (R-744 is a low-toxicity asphyxiant).

Dry ice can form in the vent line or system as pressure drops through the triple point (4.2 bar [60.9 psi]) to atmospheric pressure. This can give a false indication that the system is devoid of refrigerant—if dry ice forms, the refrigerant pressure

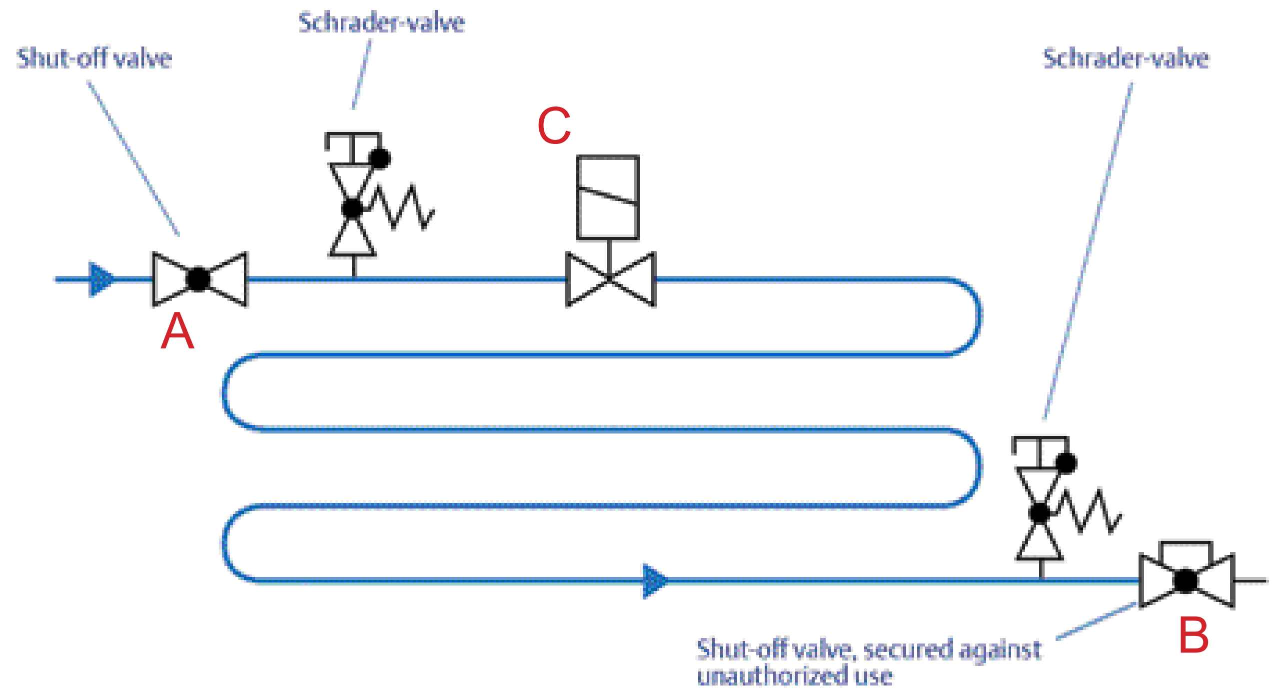

Figure 2 **Isolation of components for service.**

will drop to 0 bar (0 psi). When the dry ice sublimes the pressure will increase, e.g., to 56 bar (812 psi) if the temperature is 20°C (68°F).

If R-744 is recovered, the recovery machine, cylinder and associated equipment must be rated for the maximum pressure. This would be 70 bar (1,015 psi) at 30°C (86°F) for example, but could be significantly higher if the ambient is greater. Most recovery machines and cylinders are not rated for the required pressure.

Component isolation—When isolating components for service, avoid trapping R-744 liquid between closed valves in unprotected parts of the system. Control valves should not be used as isolation valves. Welding or brazing should not be carried out on the system until the R-744 has been removed. When removing flanges, ensure all R-744 has been removed and that pressure is as low as possible:

→All bolts should be slackened; and
→The flange should be loosened with at least two bolts still in place.

Methods of removing R-744 include:

→Venting (as described above);
→Transferring to another part of the system; or
→Evaporating (see below).

The following procedure is an example for isolating the evaporator in a cabinet and is from *The British Refrigeration Association's Code of Practice for Isolation of a Display Cabinet Evaporator from a Carbon Dioxide (R-744) System*. The example in Figure 2 shows a typical arrangement of isolation valves.

1. Mount a gauge to the access port on the ball valve (B).
2. Isolate the inlet ball valve (A) while the control valve (C) is open. Ensure the control valve is open using a permanent magnet.
3. Allow the coil to pump out for 15 minutes. *Note: An estimated time of 15 minutes would ensure a reasonably frost-free coil with the fan running.*
4. Isolate the evaporator coil outlet ball valve (B).
5. Immediately proceed to vent refrigerant from access port A while the pressure is being observed on the gauge.
6. Monitor pressure at the coil outlet through service valve B. This is essential to be sure the refrigerant has been fully removed and that the service valve ahead of liquid control valve C has not become blocked with solid carbon dioxide (R-744).

Isolation of filter-drier for service—The following procedure is an example for isolating the filter-drier in the liquid line of a cascade system. The example in Figure 3 shows a typical arrangement of isolation and bypass valves.

Dry ice will probably form in the dryer housing because it is usually not possible to remove all liquid from the housing (see example in Figure 4). It will deposit to solid when pressure is reduced during venting. It will have a surface temperature of approximately -78.5°C (-109.3°F), so it should be carefully handled. Because of the low temperature, moisture will condense on the inside of the housing (see Figure 5)—removing this is essential to avoid moisture-related problems outlined earlier.

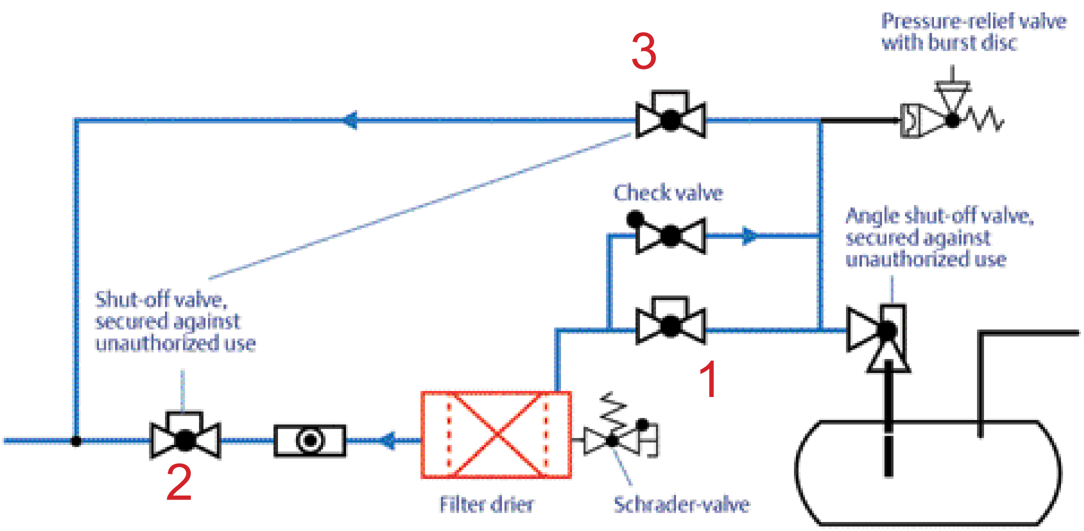

Figure 3 Isolation of filter-drier for service. Valve 1 is closed. After approximately 15 minutes, valve 2 is closed and valve 3 opened. A suitable gauge manifold set is fitted to the drier core housing. The remaining R-744 is carefully vented via the gauge manifold.

Figure 4 Example of dry ice formation in a drier.

The drier should be evacuated before returning to service. To avoid dry-ice formation, gas should be charged into the drier housing to above the triple-point pressure before opening it up to the liquid line. Gas can be taken from an R-744 off-take cylinder or from the suction of the system.

Charging compressor oil—Any oil added to the system must be the correct type; oils of different makes or viscosity should not be mixed. Avoid moisture and air ingress when adding oil, which should be pumped, not poured into the system. Oil should not be charged from a previously opened container.

Taking the system temporarily out of service

When a system is switched off, standstill pressure can be higher than the discharge pressure of some or all pressure-relief valves. An auxiliary cooling system can sometimes be used to keep the pressure below the PRV discharge pressures for short periods of time if there is no load on the system. Otherwise, the refrigerant should either be:

- →Vented from the system; or
- →Pumped down into the high side of the system of the receiver if large enough and if the pressure will not cause high-side PRVs to discharge. In transcritical systems, the receiver-outlet valve (liquid-line solenoid valve) and the receiver pressure-regulating valve should be closed to achieve a pump down.

Maintenance

R-744 system maintenance should follow good refrigeration practices, including:

- →A general check of system condition;
- →Check oil level;
- →Check refrigerant level;
- →Inspect and test safety cutouts, transducers and sensors;
- →Change oil filters and filter-driers, as required;
- →Carry out an acid test on a sample of oil;
- →Check R-744 detectors and alarms;
- →Check control valve operation in line with manufacturers' guidance; and
- →Check plant room ventilation.

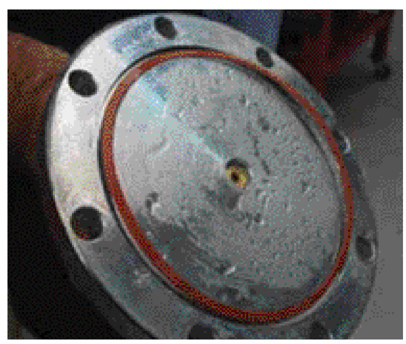

Figure 5 Example of dry ice formation in a drier.

Conclusion

CO_2 offers significant advantages over traditional technologies, but requires technicians trained in the pressure and phase-change properties of R-744. Developing a CO_2-competent team has the potential to give any organization a competitive edge, driving up industry standards and leading to more end user proficiency.

[*Note: The content presented in this article first appeared in "Commercial CO_2 Refrigeration Systems: Guide for Subcritical and Transcritical CO_2 Applications." Go to www.emersonclimate.com to download the complete CO_2 Guide.*]

Andre Patenaude is the Director of Marketing with Emerson Climate Technologies, Canada. He leads market strategy, planning and implementation of programs for Emerson Canada's refrigeration and A/C business. Patenaude is a certified Mechanical Engineering Technologist and has worked for Emerson since 1984 in a variety of technical and marketing positions, allowing him to gain a deep understanding of customers' needs. For more information, email andre.patenaude@emerson.com or visit www.emersonclimate.com.