CO2 Technical Committee:

Release Events Guidance

NORTH AMERICAN
Sustainable
Refrigeration
Council

1 Introduction

This guidance document outlines design options and mitigation strategies to reduce CO2 (R744) refrigerant releases during standstill conditions, when refrigerant flow stops and trapped refrigerant warms toward ambient temperature, causing pressure to rise. In CO2 systems, these events can occur during power outages, control failures, or other conditions that isolate portions of the system and allow pressures to exceed relief settings, resulting in refrigerant loss, downtime, and potential restart challenges.

The document focuses on the sections of a CO2 transcritical system that require pressure relief and on the design considerations and mitigation approaches for systems with pressure ratings below 80 barg (1160 psig) and at or above 80 barg (1160 psig). Recent industry data and modeling indicate that lower-pressure systems generally reach pressure relief setpoints faster during standstill, increasing both the likelihood and magnitude of refrigerant release events, while higher-pressure designs provide longer standstill tolerance.

This resource is intended to help food retailers and other refrigeration stakeholders evaluate pressure design choices, understand standstill pressure behavior, and engage effectively with OEMs and engineering consultants to reduce release events. It is a guidance document, not a substitute for project-specific engineering, because actual performance depends on factors such as climate, system configuration, charge level, component selection, operating practices, budget, and applicable codes.

2 Definitions

CO2 transcritical systems can be separated into 4 main sections.

High side: As indicated in the name, the high side of a refrigeration system denotes the highest design pressures in the system. Generally, the high side starts at the discharge point inside the compressor and includes the discharge line, the gas cooler/condenser, the gas cooler outlet pipe or condenser "drain line", and all valves installed on or in between any of those components, up to the High-Pressure Valve. In a CO2 system, the refrigerant can be in a vapor, liquid, or supercritical state with a max design pressure rating of 120 barg - 130 barg (1740 psig - 1885 psig)[1].

Flash Tank/Liquid line: These items can also be referred to as the intermediate system pressure. Generally, the Flash Tank/Liquid line pressure starts at the outlet of the High-Pressure Valve and ends at inlet to the Flash Gas Bypass Valve and at the inlet to the system metering devices (EEV for CO2). The components at Flash Tank/Liquid line pressure are the Flash Tank itself, the liquid lines running to the case and walk-in coils, all valves and components located therein. The refrigerant in the Flash Tank is a saturated mixture of vapor and liquid. The outlet of the flash tank through the liquid line should be 100% liquid. In typical designs, flash tank design pressure ranges from 60 barg to 90 barg (870 psig - 1305 psig) and Liquid line ranges design max pressure rating of 45 barg (653 psig) to 90 barg (1305 psig) with each having advantages and disadvantages. The maximum operating pressure ranges from the low end of 45 barg to 90 barg (653 psig - 1305 psig) on more resilient systems and typically under normal operation functions between 34 barg - 40 barg (493 psig - 580 psig).

MT Evaporator/Suction: Starts at the outlet of the Medium Temperature metering device (EEV for CO2) and/or outlet of Low Temperature compressors and ends at the outlet of the Flash Gas Bypass Valve and/or inlet to the Medium Temperature compressor(s). This section includes the outlet piping from the Flash Gas Bypass Valve, usually heat exchanger(s) used to maintain proper superheat, the medium temperature evaporators, and all valves and components located therein. The refrigerant in the MT Evaporator/Suction section is entirely vapor except for a saturated mixture condition that exists in the Medium Temperature evaporators. The MT Evaporator/Suction section typically has a design max pressure rating of 45 barg (653 psig) and up to 90 barg (1305 psig) on more resilient systems and typically functions under normal operation functions between 24 barg - 35 barg (348 psig - 508 psig).

LT Evaporator/Suction: Starts at the outlet of the Low Temperature metering device (EEV for CO2) and ends at the inlet to the Low Temperature compressors. This section includes the low temperature evaporator, piping from the outlet of the Low Temperature evaporator to the Low Temperature compressor, and all valves and components located between those two points. It will in many designs include various heat exchangers to maintain superheat or improve liquid quality. The LT Evaporator/Suction section typically has a design max pressure rating of 0 barg (435 psig) and up to 90 barg (1305 psig) on more resilient systems and typically functions under normal operation between 11 barg - 18 barg (160 psig - 261 psig).

1 Any reference to 'barg' in this document refers to gauge pressure and not absolute pressure.

3 Design Considerations

The following are design considerations recommended based on the lowest pressure relief valve (PRV) set point in the CO2 Transcritical systems.

80 BARG OR ABOVE

Piping

- The same piping can be used throughout the entire system (e.g. XHP, ANSI number C19400, or Stainless Steel), at all pressure levels, to have one consistent pipe material avoiding multiple materials through the system. However, it is not necessary. There are multiple options available for the low side of the system that meet 80 barg (1160 psig) rating (e.g. HP90, ASTMB290).
- 80 barg (1160 psig) or higher pressure pipes are currently limited to only a few manufacturers and are more expensive.
- 90 barg (1305 psig) pipes weigh more than 45 barg (653 psig) copper pipes and requires additional support (pipe hangers, roof support etc.) and it is more difficult to handle during installation.
- Either C19400 or HP90 pipes can be used but all the fittings must be C19400. Currently, there are no HP90 fittings available in the market/industry.

Compressors

- There are fewer compressor models available with a 90 barg (1305 psig) rating. Higher pressure rated compressors are more robust and more expensive.

Walk-ins

- There are more options to select from for lower pressure rated coils (<80 barg). Feasibly, each coil could have suction and liquid side pressure relief valve connections to allow for installation in an otherwise high pressure rating (80 barg or greater) system. Design must allow for relief of high-pressure refrigerant and isolation as system-specific relief pressure set points.
- 90 barg (1305 psig) Evaporators can be more expensive than standard 45 barg (653 psig) evaporators.

Cases

- There are fewer cases models rated at 90 barg (1305 psig) or greater than 45 barg (653 psig). Specialty cases do not always have a 90 barg (1305 psig) option, e.g., service, self-service, cheese islands, blast chillers, operations desires may not be available.
- 90 barg (1305 psig) cases can be more expensive than 45 barg (653 psig) cases

BELOW 80 BARG (30/45/60)

Piping

- Designer should account for the different pipe types, diameters, and associated pressure ratings. E.g., type K copper carries different pressure ratings at different pipe diameters (smaller pipe diameters have higher pressure ratings).
- Multiple pressure rated system must provide connections to appropriate locations for the pressure relief valves (for each pressure rating). Each of the four system sections must be equipped with method for pressure relief, regardless of pressure rating.
- Multiple types of pipes are typically specified with 30 to 60 barg rated systems - Type K copper, XHP, HP90, stainless steel, or other. Must have call outs and identifier for each pipe type, commissioning or punch list to verify during construction correct pipe used in all applications.

3 Design Considerations *(cont.)*

- Fittings must meet pressure rating.
- Pipe types should be labeled with pipe type. This is applicable to XHP or HP 90. Not specific to low K or L type copper.
- Lower pressure rated pipe cost less than higher pressure rated pipe.
- Lower pressure rated pipe is easier to handle and therefore install due to weight.
- Verify line selection tools and calculations are using the correct internal diameter. This is applicable to all pipes.
- Call out where joining dissimilar metals (different pressure rated pipe). Specify techniques for properly joining dissimilar metals. This is applicable to K, L, HP90 and XHP pipes. Not just for pipes rated less than 80 barg (1160 psig).

Compressors

- There are more selection options for 30/45 barg Low Temperature compressors
- Medium temperature separates the high side pressure relief from lower side relief.

Relief Valves

- Each section with different pressure rating requires Pressure Relief "valve station" designed for that sections pressure rating. This requires additional PRV's at various pressure ratings. For <80 barg (1160 psig) systems, there are 4 sections in the system that require 4 different relief valves.

Valves

- Valves must be rated for the pressure relief. Must isolate the Lower Pressure Relief sections of the refrigeration system from the higher-pressure relief sections; all shut off valves must have "path" to appropriate pressure relief device that does not route through Higher Pressure rated section.

Loss of CO2 (30/45 barg)

- Data from multiple operating CO2 refrigeration systems indicates that refrigerant is lost through pressure relief devices. Lower rated pressure rated systems have much shorter duration of standstill before CO2 internal pressure becomes greater than pressure relief valve.

Oil System (30/45 barg)

- Oil system and oil reservoir relief at low temperature pressure relief rating. Must design for isolation and relief to same rated section of the system.
- 2-stage compression oil systems are more complicated than single stage. Additional solenoids and shut off must be provided to separate the lower pressure sections from the higher pressure relief sections. Potential for solenoid failure and/or improper programing/ control should be anticipated and checked during commissioning and preventative maintenance checks.
- 30/45 oil system oil components are rated at higher pressure (typically 130 barg minimum), but the system operates at lower pressure and is protected by the relief valves in the system. The Discharge oil separator (DOS) is protected by the high side pressure relief valve. The oil reservoir and oil lines are protected by the Flash tank relief valve. No additional relief valves are required for oil system.

Standstill Pressure Management

- Systems will lose charge under standstill conditions without means to maintain charge when the power is lost or sections of the system are isolated. When power is lost or sections of the system are isolated, the CO2 gains energy from the surrounding environment and that energy manifests into increased pressure whereby the pressure exceeds the pressure relief valve. Refrigeration systems with higher pressure relief design can remain in standstill for a longer period of time giving the system a chance to move back into steady state operation once power/refrigerant flow is restored.

4 Mitigation Strategies

The following mitigation strategies are designed to reduce or eliminate the release of CO2 refrigerant under a standstill pressure condition. No strategy will guarantee that no unintended PRV releases happen, but when applied correctly and thoroughly will lessen the amount of refrigerant released.

80 BARG OR ABOVE

- System design pressure is a passive mitigation with no active mitigation required to avoid charge loss in almost all US ambient environments.
- PRVs must be set at the correct relief set points to allow pressure buildup in system up to allowable limits.

BELOW 80 BARG (30/45/60)

There are several PRV release mitigation techniques for CO2 refrigeration systems with pressure ratings less than 80 barg (1160 psig). These techniques require each of the release zones lower than 80 barg (1160 psig) to "isolate" such that they can properly relieve refrigerant once the pressure builds higher than design.

Mitigation Strategy: Section Isolation

The main refrigeration rack controller should be connected to an Uninterruptible Power Supply (UPS) and during a power outage the main rack refrigeration controller, or other means of control, closes the high-pressure valve and flash gas bypass valve and thereby isolating the High Side of the refrigeration system. The EEV's at the evaporator coils should either close automatically or should utilize an additional normally closed solenoid valve that automatically closes during a power outage. This allows the system charge to be isolated into four quadrants or sections; Low Temperature suction, Medium Temperature suction, liquid (in the flash tank/receiver as well as liquid lines up to expansion valves) and high side (from MT compressor discharge to the high-pressure valve before the flash tank, including the gas cooler). The isolation of the different sections of the system prevents the migration of CO2 from higher pressure piping sections to lower pressure piping sections.

This control method does delay the release of CO2 charge during a power outage and should be utilized as a baseline mitigation strategy. However, if the system remains offline for an extended period, pressures in the system can exceed their respective pressure relief valve thresholds and at that point CO2 will discharge from relief valves as needed to keep the pressure under design limits. Once the pressure limits are restored, the PRV is designed to close and thereby stop venting of CO2. The CO2 pressure relief valves open to allow the pressure to drop until it is below the valve closing point. When this occurs the release of CO2 reduces the temperature and pressure of the CO2 in the

4 Mitigation Strategies *(cont.)*

system and the spring inside the pressure relief valve will cause the valve to close until the pressure again builds beyond the pressure relief setting. If this cycle is allowed to continue, enough CO2 may be discharged from the system that when the power is restored, the system may have an insufficient amount of CO2 to restart and operate as intended, leading to a potential loss of refrigerated product.

This pressure relief system requires the spring in the pressure relieve valve to fully "re-seat" to stop the flow/loss of CO2 refrigerant; experience indicates that the pressure relief valves do not always fully reseat. If the valve fails to reseat, CO2 will continue to be vented.

Mitigation Strategy 1: Auxiliary Condensing unit

To overcome the complete loss of CO2 refrigerant charge from the system during a power outage, an auxiliary condensing unit and heat exchanger can be added to prevent the loss of CO2. The Auxiliary Condensing units are typically installed on the liquid side of the system as it contains the largest amount of CO2 and is most critical to restart the system.

Power for the auxiliary condensing unit must be fed from either a battery or a backup generator. The condensing unit should only run when the power is out and cycles on and off based on the receiver or flash tank pressure to maintain that zone's pressure lower than the PRV setting. It

Maintains the flash tank pressure below the PRV setting by cooling the CO2 in the flash tank to offset the energy absorbed from its surroundings. Any mitigation strategy that relies on this auxiliary unit requires a separate backup power source, e.g., generator or battery, that have additional periodic maintenance/testing, servicing needs, and fuel requirements. Consult the local jurisdiction having code authority for additional air quality, fuel type, and emissions testing/reporting when using a back-up generator.

Limitation/Disadvantage: This design protects the system's liquid charge (flash tank to expansion valves), but the LT and MT suction sides of the system may still release CO2 through pressure relief valves as they are not protected by the Auxiliary CDU. Also, the Auxiliary CDU typically uses a different refrigerant than CO2. If the Auxiliary CDU uses an A2L refrigerant, there may be additional design requirements to account for the mildly flammable nature of the A2Ls. Some manufacturers offer proprietary auxiliary solutions that don't require the use of another type of refrigerant.

5 Supporting Analysis

The following are examples of retailer-based data demonstrating the effectiveness of 80+ barg (1160 psig) systems at mitigating CO2 release events.

MODELING EXAMPLE

A major national retailer and team of consultants led a modeling analysis to apply a dynamic 15-minute-resolution isochoric pressure-rise model to a Transcritical Booster System based on that retailer's prototypical system. **Results are not meant to indicate performance for all similar systems; however, do directionally provide guidance related to orders of magnitude of time to pressure rise to different thresholds.**

Five (5) climate profiles were simulated (Minneapolis, Kansas City, Bentonville, Montgomery, Death Valley) under two (2) outage scenarios:

1. Midnight power loss (cooler ambient at start)
2. Morning outage during ambient temperature rise (~07:00–08:00)

Outputs: time-to-relief-valve setpoints (45 / 60 / 80 / 90 barg), peak section pressures and temperatures, and (for TC) mass transfer between discharge, intermediate and suction sections.

KEY TAKEAWAY

In the hottest U.S. climates a CO2 supermarket system can exceed 60 barg relief limits within one to three hours of a power outage. Up-rating critical sections to 80 barg (1160 psig) or higher offers robust, largely passive protection against CO2 charge loss and vented emissions.

5.4.2 Valves Fail Open (mass-transfer equalization)

With EEV Mass Transfer Link

Start Midnight

Location	High Side	Intermediate (hrs)				Suction (hrs)			
		45bar(g)	60bar(g)	80bar(g)	90bar(g)	45bar(g)	60bar(g)	80bar(g)	90bar(g)
Minneapolis	Loses heat, loses mass to intermediate. Pressure reduces.	0.75	12	Not hit	Not hit	0.5	12.25	Not hit	Not hit
Kansas City		0.75	11.25	Not hit	Not hit	0.5	11.25	Not hit	Not hit
Bentonville		0.75	14	Not hit	Not hit	0.5	14	Not hit	Not hit
Montgomery		0.5	3	Not hit	Not hit	0.5	3	Not hit	Not hit
Death Valley		0.5	1.25	9.75	Not hit	0.5	1.5	10	Not hit

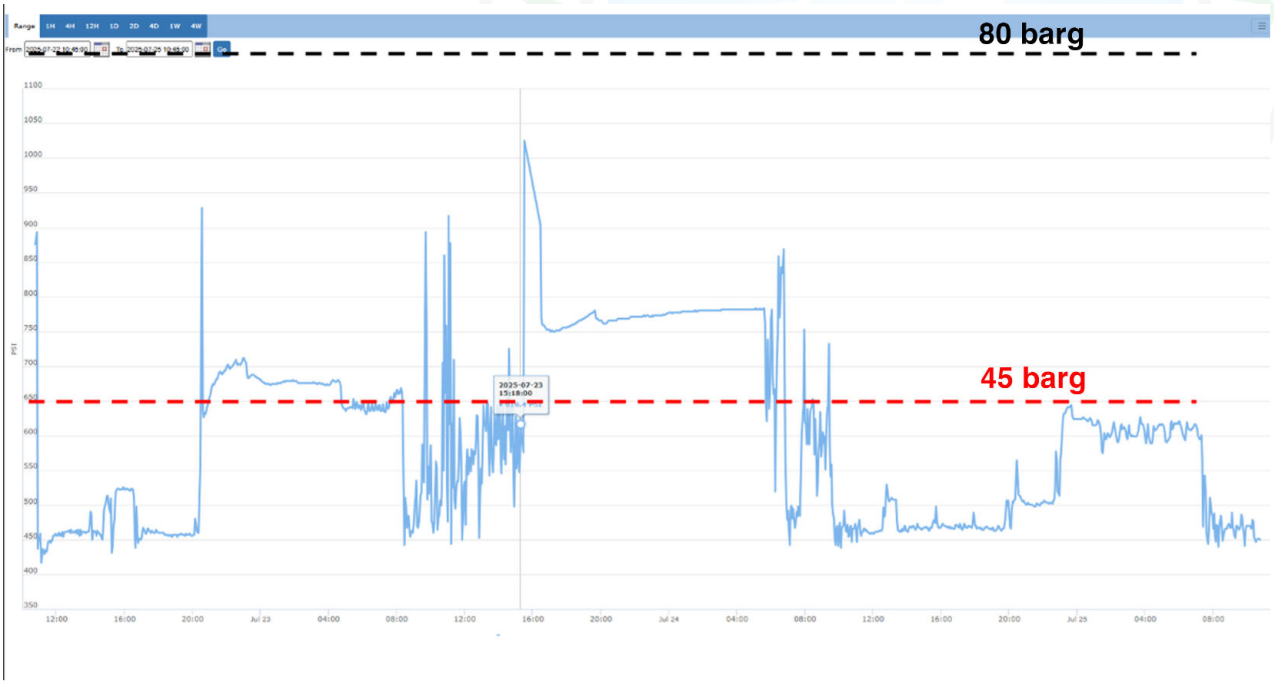
Start Ambient Rise Aligned

Location	High Side	Intermediate (hrs)				Suction (hrs)			
		45bar(g)	60bar(g)	80bar(g)	90bar(g)	45bar(g)	60bar(g)	80bar(g)	90bar(g)
Minneapolis	Loses heat, loses mass to intermediate. Pressure reduces.	0.75	4.75	Not hit	Not hit	0.5	4.75	Not hit	Not hit
Kansas City		0.75	4.5	Not hit	Not hit	0.5	4.5	Not hit	Not hit
Bentonville		0.5	2.25	Not hit	Not hit	0.5	2.25	Not hit	Not hit
Montgomery		0.5	1.75	Not hit	Not hit	0.5	1.75	Not hit	Not hit
Death Valley		0.5	1.25	4.5	Not hit	0.5	1.25	4.5	Not hit

5 Supporting Analysis *(cont.)*

EMPIRICAL EXAMPLE

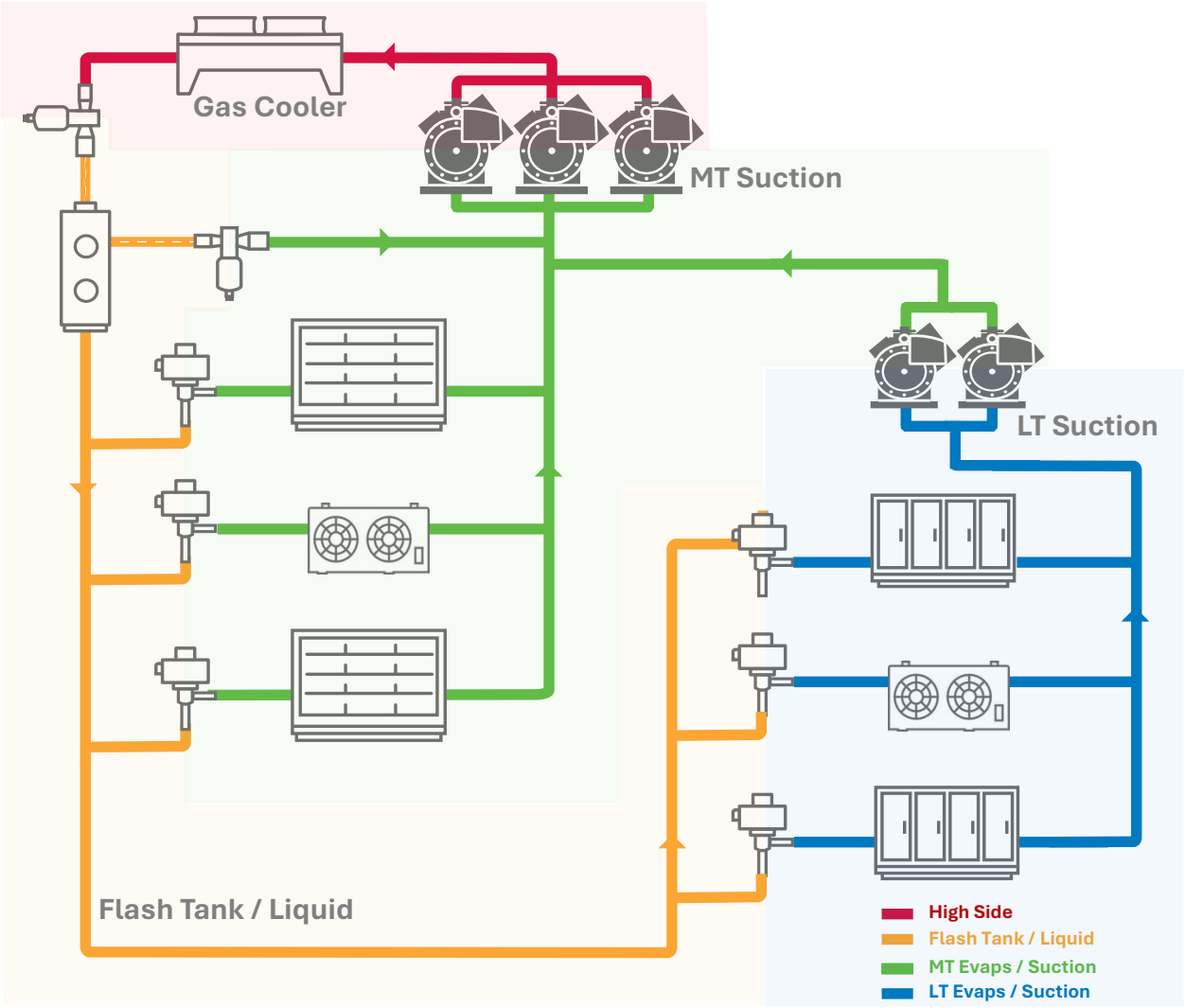
The figure below shows the flash tank pressure at a retailer CO2 Transcritical Booster system start up. The system shut down several times during the start-up process and did not vent due to the higher-pressure rated system (80+ barg (1160 psig)).



CONCLUSION

CO2 refrigeration systems should be engineered to minimize standstill pressure risks and unintended refrigerant loss, recognizing that repeated charge loss can quickly translate into product shrink, revenue impacts, and additional service costs for re-charging the system with CO2. To mitigate these risks, project teams should carefully weigh first cost and life-cycle cost against system downtime and failure risks when selecting design pressures, standstill mitigation strategies, and supporting components. In most supermarket applications, this will mean either specifying low-side design pressures of at least 80 barg (1160 psig) with high-side pressures of 120 barg - 130 barg (1740 psig - 1885 psig) or incorporating an auxiliary condensing unit or equivalent means of removing energy from the CO2 charge during standstill conditions. Site-specific engineering analysis remains essential, and end users should work closely with their engineering design firm and OEM to validate appropriate standstill pressure management strategies for each project.

CO2 Transcritical Booster System



CO2 Transcritical Booster System Separated into four Main Sections

1. High Side
2. Flash Tank / Liquid Line
3. MT Evaporator / Suction
4. LT Evaporators / Suction

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