



CGA G-6.4—2023 SAFE TRANSFER OF LIQUID CARBON DIOXIDE IN INSULATED CARGO TANKS, TANK CARS, AND PORTABLE CONTAINERS

FIFTH EDITION

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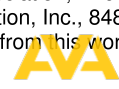
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1 Introduction

Liquid carbon dioxide is transported in insulated tank cars, cargo tanks, and portable tanks. Shipping this product requires transferring it from production plant storage to a variety of shipping containers and subsequent transfer to storage containers at consumer sites. Accidents that occur during transfer operations are usually attributed to failure to follow established safe procedures.

2 Scope

The information contained in this publication is provided for personnel involved in the safe transfer of liquid carbon dioxide.

General procedures recommended for the safe loading and unloading of the different types of carbon dioxide containers are presented. The special hazards of liquid carbon dioxide associated with product transfer are explained so personnel can be properly trained for product handling.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Approved

Acceptable to the authorities having jurisdiction (AHJ).

3.2.2 Appurtenances

All system components (excluding the container) such as pressure relief devices (PRDs), liquid level gauges, valves, pressure gauges, vaporizers, refrigeration systems, pumps, control equipment, and regulators.

3.2.3 Authorities having jurisdiction (AHJ)

Federal, state, provincial, territorial, local, or other bodies having regulatory authority over the equipment being installed or used.

3.2.4 Blow-down valve

Valve used to depressurize lines or systems.

3.2.5 Capacity

Maximum weight of carbon dioxide a container will hold when filled to the proper level.

3.2.6 Carbon dioxide

Chemical compound consisting of one atom of carbon bonded to two atoms of oxygen expressed by the chemical formula CO₂.

NOTE—The shipping name for carbon dioxide in uninsulated cylinders in the United States and Canada is “Carbon Dioxide.”

3.2.7 Carbon dioxide, refrigerated liquid

Shipping name for liquid carbon dioxide in insulated containers.

3.2.8 Cargo tanks

Tank trucks and trailers that comply with U.S. Department of Transportation (DOT) specifications MC-330 and MC-331. In Canada, these are defined as highway tanks under specification TC-331 in CSA B620, *Highway Tanks and Portable Tanks for the Transportation of Dangerous Goods* [1].¹

3.2.9 Container

Insulated pressure vessel designed and constructed to Section VIII, Division I of the American Society of Mechanical Engineers *Boiler & Pressure Vessel Code* (ASME Code) for the storage of liquid carbon dioxide [2].

3.2.10 Crossover line

Interconnecting piping system that utilizes available carbon dioxide vapor to safely purge liquid carbon dioxide from the hose and piping to the atmosphere.

3.2.11 Design pressure

Most severe condition of coincident pressure and temperature expected in normal operation.

NOTE—This considers the maximum allowable working pressure (MAWP), static head of the product, and the vacuum if vacuum jacketed.

3.2.12 Dry ice

Common name for solid carbon dioxide.

NOTE—Its temperature is –109.3 °F (–78.5 °C) at atmospheric pressure.

3.2.13 Hose whip

Hazardous, uncontrolled movement/action of an energized hose.

3.2.14 Liquid carbon dioxide

Carbon dioxide can exist as a liquid only at pressures between 75.1 psia and 1070.6 psia (518 kPa, abs and 7382 kPa, abs) and temperatures between –69.9 °F and 87.9 °F (56.6 °C and 31.1 °C).²

3.2.15 Liquid full

Container condition in which thermal expansion of the liquid has displaced all the vapor space causing any additional liquid expansion to increase the pressure hydrostatically instead of pneumatically.

3.2.16 Maximum allowable working pressure (MAWP)

Maximum gauge pressure permissible at the top of a container within its operating temperature range.

3.2.17 Minimum design metal temperature (MDMT)

Lowest temperature at which a container is designed to operate.

3.2.18 Mobile storage container

Carbon dioxide storage container built to ASME Code and permanently mounted in a wheeled chassis not to be transported containing product at pressures greater than 25.3 psi (174.4 kPa) [2].

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

² psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif, and kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline on Metric Practice in the Compressed Gas Industry* [3].

3.2.19 Operating pressure

Pressure at which the system normally operates, as distinguished from design pressure.

3.2.20 Portable container

Container complying with specification Transport Canada (TC)/DOT-51 or TC-51 with water capacity in excess of 1000 lb (454 kg) or 120 gal (454 L).

3.2.21 Purging

Procedure for displacing air, moisture, and other foreign materials by using carbon dioxide vapor.

3.2.22 Single-hose fill

Transferring from a supply container to a receiving container without returning vapor to the supply container.

3.2.23 Small, stationary, insulated carbon dioxide system

Assembly of equipment consisting of one or more insulated carbon dioxide containers, interconnecting piping, and appurtenances.

NOTE—The capacity of each container is 1000 lb (454 kg) or less.

3.2.24 Sublimation

Process of changing from the solid phase directly to the gas phase without passing through the liquid phase.

3.2.25 Tank car

Container built to DOT-, TC-, or CTC-105A500 and/or DOT-, TC-, or CTC-105A500W specifications and mounted on a railcar chassis.

3.2.26 Triple point

Temperature and pressure at which a material exists simultaneously as a solid, liquid, and gas.

NOTE—For carbon dioxide it is -69.9°F (-56.6°C) and 75.1 psia (518 kPa, abs).

3.2.27 Vapor balance

Tank connection that is used to prevent overfilling and overpressurization. The vapor balance line is open to the vapor space of the tank at the maximum fill level.

NOTE—This connection may also be known as vapor fill line, vapor equalizing line, or vapor return line.

4 Hazards

Although all hazards shown in CGA G-6, Carbon Dioxide are applicable to these installations, dry ice blocking/plugging and trapped liquid are hazards more prevalent with the transfer of liquid carbon dioxide in insulated cargo tanks, tank cars, and portable containers. For information on these and all hazards of carbon dioxide, see CGA G-6 [4].

4.1 Dry ice blocking

Liquid carbon dioxide in a hose or pipe flows like water. However, when the pressure is reduced less than 75.1 psia (518 kPa, abs) the liquid changes into a mixture of vapor and solid carbon dioxide. Solid carbon dioxide, when formed in a pipe or hose, as a result of improper purge, leaking valve, or inadequate design can create a dry ice plug. This can result in overpressurization and/or forceful ejection of the plug creating a safety hazard.

The pressure behind or within a plug can increase as the dry ice sublimates until the plug is forcibly ejected or the hose or pipe ruptures. A dry ice plug can be ejected from any open end of a hose or pipe with enough force to cause serious injury to personnel, from the impact of the dry ice plug and/or the sudden whip of the hose or pipe as the plug ejects. To prevent dry ice blockage, the liquid carbon dioxide shall be purged from the hose or pipe before reducing the pressure less than 75.1 psia (518 kPa, abs). This can be done by supplying carbon dioxide vapor to one end of the hose or piping system to maintain the pressure greater than the triple point while removing the liquid from the other end. This can be done by use of a crossover line.

Flexing elastomer hoses containing residual dry ice inside can lead to fracturing of the inner liner, which can lead to catastrophic failure.

4.2 Trapped liquid

When liquid carbon dioxide is forced to occupy a fixed volume such as between two closed valves or within a valve, the pressure will increase as the carbon dioxide warms and expands. As long as there is a vapor space in the valve or pipe, the pressure rises about 5 psi per °F (62 kPa per °C). When the pipe or valve becomes liquid full, the hydrostatic pressure rises at the rate of 80 psi per °F (990 kPa per °C). As the temperature continues to increase, the pressure of the trapped liquid can exceed what the piping and hoses can withstand. This will cause rupture of the hose or piping with possible injury and property damage.

To prevent trapped liquid from becoming a hazard, all liquid carbon dioxide piping and transfer lines shall be equipped with PRDs located in all parts of the system in which liquid can be trapped such as between valves, check valves, and pumps. These PRDs shall be set to discharge within the design pressure of the part of the system they protect and should discharge into a well-ventilated area. For further information, see CGA G-6.5, *Standard for Small Stationary Insulated Carbon Dioxide Supply Systems* [5].

To prevent trapped liquid from becoming a hazard in ball- and gate-type valves, they shall be adequately designed to prevent liquid carbon dioxide from being trapped within the valve.

4.3 Personnel overexposure

See CGA G-6 for information on personnel overexposure [4].

4.4 Low temperature effects on materials

See CGA G-6 for information on low temperature effect on materials [4].

4.5 Overfilling containers

When liquid carbon dioxide is stored in a container with little or no product withdrawal, heat leak causes the temperature and pressure to increase and the liquid to expand. As long as there is vapor space in the container, the pressure increases approximately 5 psi per °F (62 kPa per °C). When the container becomes liquid full, the hydrostatic pressure increases at the rate of 80 psi per °F (990 kPa per °C). Table 1 and Figure 1 illustrate this phenomenon with data for pressure increase in a container originally filled to 92.6% with -20°F (-28.9°C) liquid carbon dioxide.

Liquid carbon dioxide storage containers should not be filled to a level that allows them to reach a liquid full condition before reaching the PRD setting, which is generally 350 psi (2410 kPa). This prevents oversteering of the containers and nuisance cycling of the PRD with subsequent product loss.

The safe filling level depends on the temperature of the liquid being transferred into the container. The colder the liquid, the more vapor space required for liquid expansion. Figure 1 shows safe filling levels for a range of liquid temperatures. Filling greater than 92.6% leads to an overfilled condition.

4.5.1 Symptoms of overfilling

Typical symptoms of overfilling are:

- Activation of a high pressure alarm, if the container is so equipped;
- Erratic operation of the level gauge;
- Excessive frost on piping connected to the vapor space;
- Refrigeration unit operating, but not decreasing pressure (heat transfer is greatly diminished when liquid is around the refrigeration coils); and
- Venting from a back pressure control valve.

4.5.2 Test for overfilling

To maintain a safely operating container, the level of the liquid carbon dioxide in the storage unit should be kept no higher than the bottom of the vapor balance line. If overfilling is suspected, the vapor balance valve should be opened slightly to observe the discharge of carbon dioxide into the atmosphere. If the discharge is clear or only slightly foggy, the tank is at an acceptable level. If the discharge is a dense, white cloud containing particles of dry ice, the liquid level in the tank might be too high. In this event the slow discharge should be continued until the dense, white fog discharge changes to a clear or blue fog discharge. Contact the supplier or the equipment manufacturer if overfilling is suspected.

CAUTION: This procedure should only be performed by properly trained and authorized personnel with proper ventilation and personal protective equipment (PPE).

Table 1—Volume expansion upon warming of liquid carbon dioxide saturated at 200 psi (1380 kPa) for an insulated container with a 350 psi (2410 kPa) MAWP

Pressure		Temperature		Maximum allowable volume occupied by liquid carbon dioxide ¹⁾
psi	kPa	°F	°C	%
200	1380	−20.1	−28.9	92.6
210	1450	−17.6	−27.5	93.1
220	1520	−15.2	−26.2	93.5
230	1590	−12.9	−24.9	94.1
240	1660	−10.6	−23.7	94.6
250	1720	−8.4	−22.4	95.1
260	1790	−6.3	−21.3	95.6
270	1860	−4.2	−20.1	96.1
280	1930	−2.2	−19.0	96.6
290	2000	0.2	−17.9	97.1
300	2070	1.7	−16.8	97.6
310	2140	3.6	−15.8	98.1
320	2210	5.4	−14.8	98.6
330	2280	7.2	−13.8	99.0
340	2340	9.0	−12.8	99.5
350	2410	10.7	−11.8	100.0

¹⁾ The percent liquid full is the percent of total container volume and should not be confused with the liquid level gauge reading.

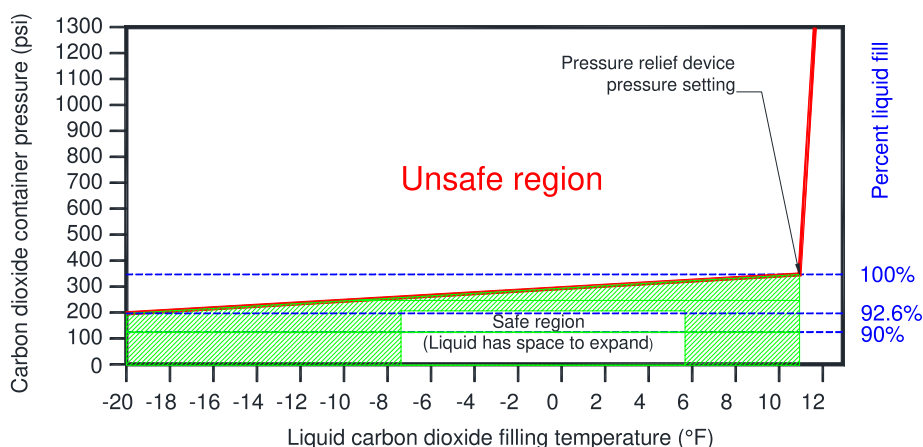


Figure 1—Safe filling volumes for 350 psi (2410 kPa) carbon dioxide containers

4.6 Thrust from discharge to atmosphere

The thrust from carbon dioxide vapor at the open end of any piping system, including rigid metallic piping, can cause quick movement of the open end with the potential to strike personnel or equipment and cause injury or death. All open ends on pipes shall be mechanically restrained from excess movement, including the possibility of rotation. For liquid depressurization situations, the designer should consider the dynamic load of moving ice plugs analogous to water hammer. Hard pipe vent lines shall be restrained (e.g., by u-bolts, pipe supports, or other rigid restraint) and fastened to solid fixtures, particularly when mechanical joints are used. Mechanical joints such as threaded connections, grooved end mechanical couplings, and hammer unions can be subject to violent rotation, if not properly constrained.

5 Physiological effects of carbon dioxide

See CGA G-6 for information on the physiological effects of carbon dioxide [4].

6 Regulations

6.1 Regulatory agencies

In the United States, the transportation of liquid carbon dioxide in interstate commerce by rail, highway, air, and water is governed by regulations of DOT in Title 49 of the U.S. *Code of Federal Regulations* (49 CFR) [6]. In Canada, the *Transport of Dangerous Goods Act* and the *Transportation of Dangerous Goods (TDG) Regulations* promulgated under the act cover the movement of liquid carbon dioxide [7]. For a partial listing of DOT regulations pertaining to carbon dioxide, see Table 2.

Table 2—DOT regulations pertaining to carbon dioxide [6]

General			
Table of hazardous materials		Part 172, Subpart B	
Shipping papers		Part 172, Subpart C	
Marking		Part 172, Subpart D	
Labeling		Part 172, Subpart E	
Placarding		Part 172, Subpart F	
Definitions and abbreviations		Section 171.8	
Notice of hazardous materials incidents		Sections 171.15 and 171.16	
Compressed gases—preparation and packaging		Section 173.300	
Rail		Sections 174.201 and 174.204	
Highway		Sections 177.834 and 177.840	
Containers			
	Cargo tanks ¹⁾	Portable tanks	Tank cars ^{2), 3)}
Construction specifications	Section 178.337 (MC-331)	Section 178.245 (DOT 51)	Sections 179.100 and 179.102-1
Qualifications and maintenance	Part 180, Subpart E		Part 180, Subpart F
Use of containers	Section 173.33	Section 173.32	Section 173.31
Requirements for shipment	Section 173.315	Section 173.315	Section 173.314
¹⁾ In Canada, the requirements for cargo and portable tanks are outlined in CSA B620 and CSA B622, <i>Selection and Use of Highway Tanks, Multi-Unit Tank Car Tanks, and Portable Tanks for the Transportation of Dangerous Goods, Class 2, by Road</i> [1, 8].			
²⁾ Canadian tank car requirements for the transportation of dangerous good by rail are specified in Transport Canada Standard TP 14877, <i>Containers for Transport of Dangerous Good by Rail</i> [9].			
³⁾ Marking for tank cars is detailed in the Association of American Railroads (AAR) <i>Manual of Standards and Recommended Practices</i> , Section C Part III, Specification for Tank Cars (M-1002) [10].			

6.2 Product classification

Liquid carbon dioxide is classified by DOT and TC as a nonflammable, compressed gas and shall be shipped only in containers authorized for such shipments.

6.3 Container specifications

The container specifications of these regulatory authorities require that the materials used for liquid carbon dioxide containers shall meet certain chemical and physical requirements, shall pass specified hydrostatic pressure tests and visual inspection at prescribed intervals, and shall be protected by adequate PRDs.

7 Transfer facility design

7.1 General

Final approval of the design, equipment, appurtenances, and installation rests with the authorities having jurisdiction (AHJ).

The transfer site area shall be free of obstructions to enable the cargo tank to maneuver easily and safely into position, and to give personnel a safe area in which to work.

Piping, valves, pumps, hoses, and fittings used at a transfer site shall be made of materials suitable for use with carbon dioxide and designed for the pressure and temperature to which they can be subjected in transfer operations. See Table 3 and Table 4 for material specifications.

Table 3—Piping materials commonly used for carbon dioxide transfer facilities

Material	Sch	Grade	Type	Joint type
Carbon steel above –20 °F (–28.9 °C) ¹⁾	40	A53 Types E and S A106 Type E and S A333 Type S ²⁾	Grade A and B Grade A or B Grade 6	Butt or socket weld (No threaded connections)
	80	A53 Types E and S A106 Types E and S A333 Type S ²⁾	Grade A and B Grade A or B Grade 6	Threaded, butt, or socket weld
Stainless steel	10	A312 welded or seamless	304 and 316	Butt weld only (no threaded connections)
	40	A312 welded or seamless	304 and 316	Threaded, butt, or socket weld
	80	A312 welded or seamless	304 and 316	Threaded, butt, or socket weld
Red brass	40	B43	Seamless	Brazed only
	80	B43	Seamless	Threaded, brazed
¹⁾ Unless an engineering analysis allows a lower MDMT.				
²⁾ This type is appropriate for service temperatures above –50 °F (–45.6 °C).				

Table 4—Fittings

Material	Grade	Type	Connection type
Carbon steel <u>above</u> <u>−20 °F (−28.9 °C)</u> ¹⁾	A 105 A 234 A 105	Class 2000 or 3000 forged <u>Sch 40 min</u> Class 2000 or 3000 forged	Threaded (<u>for ≤ 2 in nominal pipe size [NPS]</u>) Butt weld Socket weld
Carbon steel <u>above</u> <u>−50 °F (−45.6 °C)</u>	<u>A 420</u> <u>A 350</u>	<u>Sch 40 min</u> <u>Class 2000 or class 3000</u>	<u>Butt weld</u> <u>Threaded (for ≤ 2 in NPS)</u> <u>Socket weld</u>
Stainless steel	A 182 A 403 A 182	Class 2000 or 3000 <u>Sch 40 min</u> Class 2000 or 3000	Threaded (<u>≤ 2 in NPS</u>) Butt weld Socket weld
Copper ²⁾	ANSI B16.22	Wrought	Brazed Flare or Compression (<1/2 in outside diameter [OD])
Brass	Forged bar stock		Threaded (<u>≤ 2 in NPS</u>) Brazed Flare (<1/4 in OD) Compression (bite type) (<1/2 in OD)
NOTES 1 Plastic pipe is suitable only for warm carbon dioxide vapor service less than 100 psi (791 kPa). Properly sized and rated PRDs are required to prevent pressure buildup due to failure of pressure-reducing regulators. Low temperatures caused by gas expansion through pressure-reducing regulators, vaporizer malfunction, excessive withdrawal, etc., can cause piping temperatures to decline to unsafe levels. Cold plastic piping can become brittle and can fail catastrophically. Plastic piping can also fail from overheating at much lower temperatures than metallic piping. Plastic piping in carbon dioxide service should be used with extreme caution. 2 Pipe unions of a minimum 2000 class rating may be used on pipe sizes up to 2 in (5.1 cm). ANSI Class 300 flanges are recommended for use on pipe sizes larger than 2 in (5.1 cm). 3 For more information refer to CGA G-6.1, <i>Standard for Insulated Liquid Carbon Dioxide Systems at Consumer Sites</i> [11]. 1) <u>Unless an engineering analysis allows a lower MDMT</u> 2) <u>Copper fitting pressure rating shall be compatible with system requirements and minimum pressure rating of 400 psi (2757 Kpa).</u>			

7.2 Unacceptable materials of construction for pipe and fittings

The following types of pipe and fittings are not acceptable for carbon dioxide service:

- A-120 galvanized steel pipe (A-106 galvanized is acceptable);
- Cadmium plating for food service;
- Carbon steel tubing (limited by external corrosion).
- Cast iron or malleable iron fittings and pipe;
- Grade F furnace brazed steel pipe; and
- Plastic pipe and fittings.

NOTE—For more information, refer to CGA G-6.1 [11]