CARBON DIOXIDE

AIGA 068/20

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As part of a program of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has published AIGA 068, *Carbon Dioxide*, jointly produced by members of the International Harmonization Council and originally published as CGA G-6 by Compressed Gases Association (CGA) as *Carbon Dioxide*

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Note: Technical changes from the previous edition are underlined

1 Introduction

This publication is one of a series compiled to satisfy the demand for information relative to the production, storage, transportation, safe handling and use of compressed and liquefied gases, cryogenic liquids, and related products.

2 Scope and purpose

2.1 Scope

The scope includes the physical and chemical properties, physiology, toxicity, hazards, production, regulations, storage, handling, transportation, and applications of carbon dioxide.

2.2 Purpose

The purpose of this publication is to provide information on carbon dioxide. It should be useful to carbon dioxide users, producers, and distributors. Detailed information on the various aspects of carbon dioxide and its transportation and use can be found in sources listed in the reference section.

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 Carbon dioxide

Chemical compound consisting of one atom of carbon bonded to two atoms of oxygen expressed by the chemical formula CO_2.

3.2.2 Container

Insulated pressure vessel designed and constructed to Section VIII, Division I of the American Society of Mechanical Engineers (ASME) *Boiler & Pressure Vessel Code* for the storage of liquid carbon dioxide [1]. [1]

NOTE—Container is interchangeable with vessel or tank.

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

3.2.3 Critical point
Highest pressure and temperature for a pure gas at which the liquid and vapor phases can exist in equilibrium.

NOTE—For carbon dioxide, this occurs at a temperature of 87.9 °F (31.1 °C) and a pressure of 1070.6 psia (7381.8 kPa, abs).[2]

3.2.4 Critical pressure
Pressure that shall be exerted to produce liquefaction at the critical temperature.

NOTE—For carbon dioxide the critical pressure is 1070.6 psia (7381.8 kPa, abs).

3.2.5 Critical temperature
Temperature above which a pure gas cannot be liquefied regardless of the degree of compression.

NOTE—For carbon dioxide the critical temperature is 87.9 °F (31.1 °C).

3.2.6 Cylinder

3.2.6.1 Insulated cylinder
Insulated U.S. Department of Transportation (DOT)-approved pressure vessel with a water capacity not greater than 120 gal (454 L) or 1000 lb (454 kg) and a service pressure rating of less than 40 psi (276 kPa) but not greater than 500 psi (3448 kPa), or a Transport Canada (TC)-approved pressure vessel with a water capacity not greater than 119 gal (450 L) and a service pressure rating from 3 bar to 35 bar.

3.2.6.2 Uninsulated cylinder
Single walled DOT- or TC-approved pressure vessel having a circular cross section with a minimum rated service pressure of 1800 psi (124 bar) and a water capacity not greater than 120 gal (454 L).

NOTE—The minimum service pressure of 1800 psi (124 bar) is specific to carbon dioxide.

3.2.7 Dry ice
Common name for solid carbon dioxide.

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

3.2.8 Maximum allowable working pressure (MAWP)
Maximum gauge pressure permissible at the top of a container in its operating position for a designated temperature [1].

3.2.9 Qualified carbon dioxide technician
Person who by reason of education, training, and experience knows the properties of carbon dioxide; is familiar with the equipment used to store, transfer, and use carbon dioxide; and understands the precautions necessary to safely use carbon dioxide equipment.

3.2.10 Registered inspector
Person registered with the DOT in accordance with Title 49 of the U.S. *Code of Federal Regulations* (49 CFR) Part 107 Subpart F who has the knowledge and ability to determine whether a cargo tank conforms to the applicable DOT specification [3].

3.2.11 Small stationary insulated carbon dioxide container
Insulated ASME-approved pressure vessel with a carbon dioxide capacity of not greater than 1000 lb (454 kg).

3.2.12 Saturated
Condition at which the pressure and temperature of all existing physical states are at equilibrium.

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

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

3.2.14 Supercritical fluid

Substance that is at a pressure and a temperature equal to or greater than its critical point and has complete mutual solubility of the liquid and the gas.

3.2.15 Triple point

Temperature and pressure at which a material exists simultaneously as a solid, liquid, and gas. For carbon dioxide the triple point is –69.9 °F and 75.1 psia (–56.6 °C and 518 kPa, abs).

3.2.16 Upset condition

Any condition outside normal design parameters.

4 Carbon dioxide

4.1 Physical and chemical properties

Carbon dioxide is a colorless, odorless, slightly acidic gas that is approximately 50% heavier than air. It is nonflammable and will not support combustion. The physical constants of carbon dioxide are summarized in Table 1. Carbon dioxide can exist as a solid, liquid, gas, or supercritical fluid, depending upon conditions of temperature and pressure.

Carbon dioxide at its triple point exists simultaneously as a liquid, gas, and solid at –69.9 °F and 75.1 psia (–56.6 °C and 518 kPa, abs). Any change in pressure or temperature causes carbon dioxide to revert to a two-phase condition (see Figure 1).

Carbon dioxide at its critical point exists simultaneously as a liquid, gas, and supercritical fluid at 87.9 °F and 1070.6 psia (31.1 °C and 7381.8 kPa, abs). At pressures and temperatures greater than the critical point, carbon dioxide exists only as a supercritical fluid.

The solubility of carbon dioxide in water varies with temperature and pressure. See Table 2 for various temperature and pressure conditions [4].

See Tables 3 and 4 and Figures 2a and 2b for the thermodynamic and physical properties of carbon dioxide.

4.2 Manufacture

Large quantities of carbon dioxide for commercial use are primarily obtained from one of the following processes:

- acid neutralization;
- ammonia;
- coal gasification;
- combustion;
- ethylene oxide;
- fermentation;
- hydrogen;
- phosphate rock; and
- wells/geothermal.

Carbon dioxide is typically refined to the required purity by the following:

- adsorption/desorption;
- distillation;
- filtration;

- oxidation; and/or
- scrubbing.

For carbon dioxide purity specifications, see CGA G-6.2, *Commodity Specification for Carbon Dioxide* [5].

Carbon dioxide is generally liquefied by compression and refrigeration for storage or shipment. It is stored and shipped as a liquid at pressures and temperatures ranging from 200 psi and –20 °F to 350 psi and 11 °F (1380 kPa and –29 °C to 2410 kPa and –12 °C).

Solid carbon dioxide is manufactured by decreasing the pressure of the liquid below its triple point forming dry ice (snow) and cold vapor (see CGA G-6.9, *Dry Ice*) [6].

Solid carbon dioxide can be compressed into blocks of dry ice, cut or formed into slabs or slices, or extruded into pellets. Dry ice blocks are commercially available in 10-in (25.4-cm) nominal size cubes weighing 50 lb to 60 lb (23 kg to 27 kg) and having a density of approximately 94 lb/ft^3 (1500 kg/m^3). Slabs and slices are available in a variety of weights and dimensions, according to customer requirements. Extruded product is available in various sizes, see Figure 3.

Table 1—Physical constants of carbon dioxide

	U.S. Units	**SI Units**
Chemical formula	CO_2	CO_2
Molecular weight	44.01	44.01
Vapor pressure[1)] at 2 °F (–16.7 °C)	302 psi	2082 kPa
Specific gravity of the gas at 70 °F (21.1 °C) and 1 atm	1.522	1.522
Solid to gas expansion ratio (specific volume of the gas) at 70 °F (21.1 °C) and 1 atm	8.741 ft^3/lb	0.5457 m^3/kg
Density of the gas at 70 °F (21.1 °C) and 1 atm	0.1144 lb/ft^3	1.833 kg/m^3
Density of the liquid saturated at 2 °F (–16.7 °C)	63.3 lb/ft^3 (8.46 lb/gal)	1014 kg/m^3
Density of solid (dry ice) at 1 atm and –109.3 °F (–78.5 °C)	97.6 lb/ft^3	1563 kg/m^3
Sublimation temperature at 1 atm	–109.3 °F	–78.5 °C
Critical temperature	87.9 °F	31.1 °C
Critical pressure	1070.6 psia	7381.8 kPa, abs
Critical density	29.2 lb/ft^3	468 kg/m^3
Triple point	–69.9 °F at 75.1 psia	–56.6 °C at 518 kPa, abs
Latent heat of vaporization at 2 °F (–16.7 °C)	119.0 Btu/lb	276.8 kJ/kg
Latent heat of fusion at 1 atm and –69.9 °F (–56.6 °C)	85.6 Btu/lb	199 kJ/kg
Latent heat of sublimation at 1 atm and –109.3 °F (–78.5 °C)	245.5 Btu/lb	571.0 kJ/kg
Specific heat of the gas at 77 °F (25.0 °C) and 1 atm		
C_p	0.203 Btu/(lb)(°F)	0.850 kJ/(kg)(°C)
C_v	0.157 Btu/(lb)(°F)	0.657 kJ/(kg)(°C)
Ratio of specific heats (C_p/C_v) at 59 °F (15.0 °C)	1.304	1.304
Solubility in water, vol/vol at 68 °F (20.0 °C)	0.90	0.90
Viscosity of saturated liquid at 2 °F (–16.7 °C)	0.287 lb/(ft)(hr)	0.000119 Pa • s
1) All psi values are referenced to 14.696 psia (101.325 kPa, abs).		

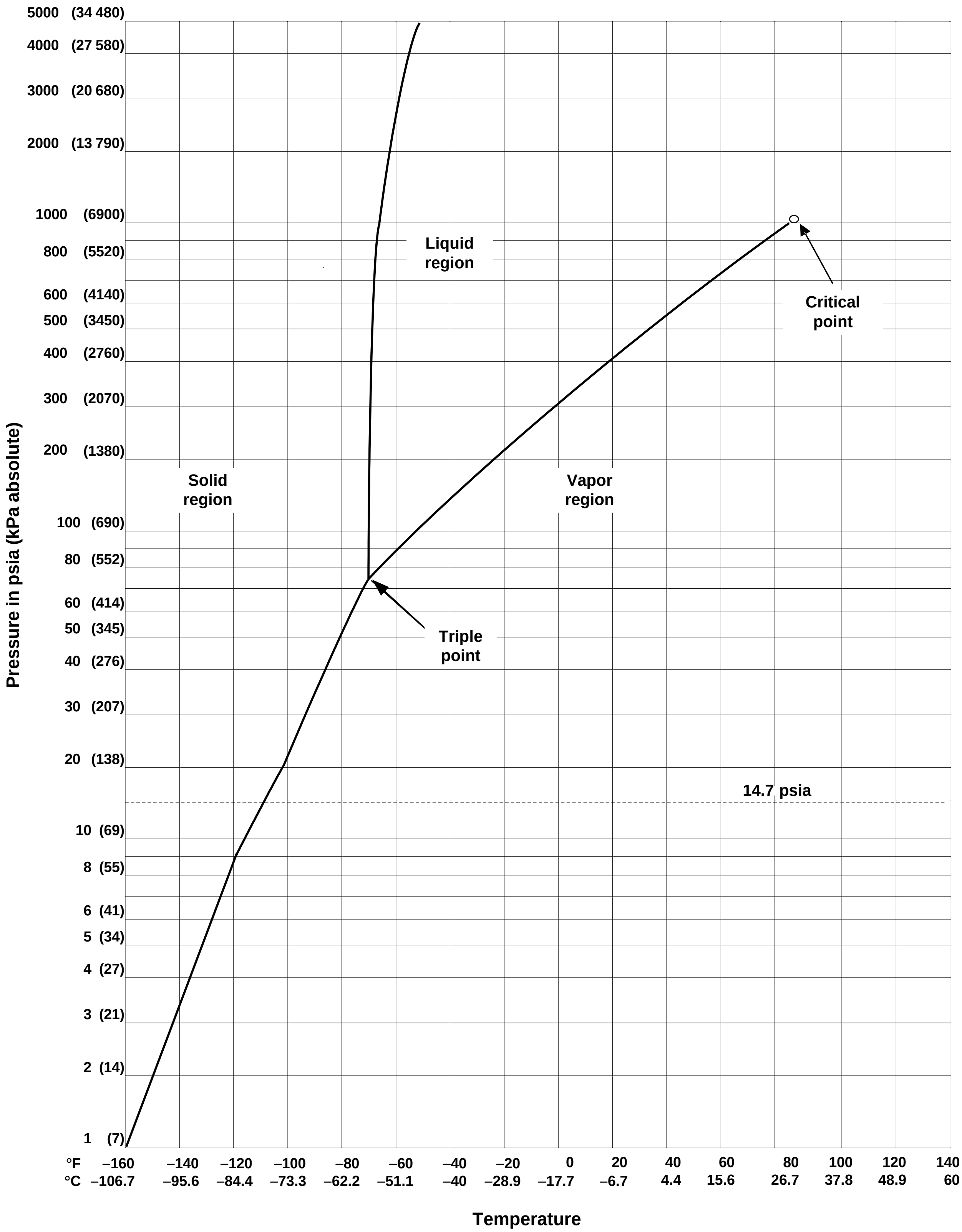


Figure 1—Carbon dioxide phase diagram

Table 2—Solubility of carbon dioxide in water (volume carbon dioxide/volume water) [4]

Water pressure psi (kPa)	Water temperature °F (°C)												
	32 (0)	36 (2.2)	40 (4.4)	44 (6.7)	48 (8.9)	55 (12.8)	60 (15.6)	65 (18.3)	70 (21.1)	75 (23.9)	80 (26.7)	85 (29.4)	90 (32.2)
15 (103)	3.46	3.19	2.93	2.70	2.50	2.20	2.02	1.86	1.71	1.58	1.48	1.35	1.27
20 (138)	4.04	3.73	3.42	3.15	2.92	2.57	2.36	2.17	2.00	1.84	1.69	1.58	1.48
25 (172)	4.58	4.27	3.92	3.61	3.35	2.95	2.69	2.48	2.29	2.10	1.93	1.80	1.70
30 (207)	5.21	4.81	4.41	4.06	3.77	3.31	3.03	2.80	2.58	2.37	2.18	2.03	1.91
35 (241)	5.80	5.35	4.91	4.52	4.19	3.69	3.37	3.11	2.86	2.63	2.42	2.26	2.13
40 (276)	6.37	5.89	5.39	4.97	4.61	4.05	3.71	3.42	3.15	2.89	2.67	2.49	2.34
45 (310)	6.95	6.43	5.88	5.43	5.03	4.43	4.06	3.74	3.44	3.16	2.91	2.72	2.56
50 (345)	7.53	6.95	6.36	5.89	5.45	4.80	4.40	4.05	3.73	3.42	3.16	2.94	2.77
55 (379)	8.11	7.48	6.86	6.34	5.87	5.17	4.74	4.37	4.02	3.69	3.40	3.17	2.99
60 (414)	8.71	8.02	7.35	6.79	6.29	5.53	5.08	4.68	4.31	3.95	3.64	3.39	3.20
70 (483)	9.86	9.09	8.33	7.70	7.13	6.27	5.76	5.30	4.89	4.49	4.14	3.86	3.63
80 (552)	11.02	10.17	9.31	8.61	7.98	7.00	6.43	5.92	5.46	5.02	4.62	4.31	4.06
90 (621)	12.18	11.25	10.30	9.52	8.82	7.74	7.11	6.54	6.04	5.55	5.12	4.77	4.49
100 (690)	13.34	12.33	11.29	10.43	9.66	8.40	7.79	7.18	6.62	6.08	5.60	5.22	4.91

NOTE—This table shows the equivalent volume of carbon dioxide measured at 32 °F (0 °C) and 0 psi (0 kPa) that dissolves in one volume of water at the pressure and temperature indicated.

Table 3—Thermodynamic properties of saturated carbon dioxide solid, liquid, and vapor phases (U.S. customary units)

Phase	Temp °F	Pressure psia	Pressure psi	Density lb/ft³ solid or liquid	Specific volume ft³/lb vapor	Enthalpy [1)] Btu/lb solid or liquid	Enthalpy [1)] Btu/lb vapor	Entropy [1)] Btu/(lb)(°R) solid or liquid	Entropy [1)] Btu/(lb)(°R) vapor
Solid and Vapor	–150	1.793	26.26 [2)]	99.7	41.81	53.55	305.50	0.3394	1.1530
	–140	3.171	23.46 [2)]	99.2	24.41	56.36	306.90	0.3483	1.1318
	–130	5.405	18.92 [2)]	98.8	14.69	59.22	308.30	0.3571	1.1126
	–120	8.923	11.75 [2)]	98.3	9.131	62.15	309.62	0.3658	1.0945
	–110	14.34	7.725 [2)]	97.5	5.829	65.16	310.81	0.3743	1.0770
	–109.3	14.70	0.000	97.5	5.683	65.38	310.90	0.3748	1.0758
	–105	17.94	3.244	97.2	4.708	66.69	311.45	0.3786	1.0687
	–100	22.28	7.584	96.9	3.814	68.24	312.01	0.3829	1.0606
	–95	27.67	12.97	96.6	3.103	69.80	312.50	0.3872	1.0527
	–90	34.14	19.44	96.2	2.531	71.41	312.89	0.3915	1.0449
	–85	41.63	26.93	95.7	2.074	73.01	313.11	0.3959	1.0372
	–80	50.58	35.88	95.3	1.714	74.63	313.22	0.4002	1.0292
	–75	61.72	47.02	94.9	1.418	76.28	313.29	0.4045	1.0215
	–70	74.76	60.06	94.4	1.182	77.96	313.42	0.4089	1.0151
	–69.9	75.13	60.43	94.4	1.157	78.01	313.42	0.4112	1.0150
Triple point									
Liquid and Vapor	–69.9	75.13	60.43	73.53	1.157	163.6	313.42	0.6308	1.0150
	–68	78.48	63.78	73.30	1.117	164.4	313.49	0.6318	1.0128
	–66	82.34	67.64	73.05	1.060	165.3	313.58	0.6340	1.0107
	–64	86.35	71.65	72.79	1.011	166.1	313.67	0.6362	1.0088
	–62	90.50	75.80	72.54	0.9659	167.0	313.76	0.6384	1.0070
	–60	94.76	80.06	72.28	0.9254	167.9	313.85	0.6406	1.0053
	–58	99.15	84.45	72.01	0.8876	168.8	313.94	0.6427	1.0038
	–56	103.7	89.00	71.76	0.8501	169.6	314.03	0.6448	1.0024
	–54	108.4	93.70	71.49	0.8145	170.5	314.12	0.6469	1.0010
	–52	113.2	98.50	71.23	0.7809	171.4	314.23	0.6490	0.9996
	–50	118.2	103.50	70.97	0.7489	172.3	314.33	0.6511	0.9982
	–48	123.4	108.70	70.71	0.7184	173.2	314.44	0.6533	0.9967
	–46	128.8	114.10	70.44	0.6896	174.1	314.57	0.6555	0.9952
	–44	134.3	119.60	70.16	0.6622	175.0	314.68	0.6577	0.9938
	–42	140.0	125.30	69.88	0.6361	175.9	314.78	0.6599	0.9924
	–40	145.9	131.20	69.60	0.6113	176.8	314.89	0.6621	0.9910
	–38	152.0	137.30	69.33	0.5876	177.7	314.98	0.6642	0.9897
	–36	158.1	143.40	69.04	0.5648	178.7	315.09	0.6663	0.9883
	–34	164.6	149.90	68.76	0.5432	179.6	315.20	0.6684	0.9869
	–32	171.2	156.50	68.48	0.5227	180.5	315.31	0.6704	0.9855
	–30	178.0	163.30	68.20	0.5031	181.4	315.40	0.6725	0.9842
	–28	184.9	170.20	67.92	0.4844	182.3	315.49	0.6746	0.9829
	–26	192.1	177.40	67.64	0.4665	183.2	315.58	0.6767	0.9817
	–24	199.6	184.90	67.35	0.4492	184.3	315.67	0.6788	0.9805
	–22	207.2	192.50	67.06	0.4325	185.2	315.74	0.6810	0.9793
	–20	215.0	200.30	66.77	0.4166	186.1	315.81	0.6831	0.9781
	–18	223.1	208.40	66.47	0.4014	187.0	315.86	0.6852	0.9769
	–16	231.3	216.60	66.17	0.3868	188.1	315.92	0.6873	0.9756
	–14	239.8	225.10	65.87	0.3731	189.0	315.95	0.6894	0.9743
	–12	248.7	234.00	65.56	0.3599	189.9	315.99	0.6916	0.9730
	–10	257.6	242.90	65.25	0.3473	191.0	316.01	0.6937	0.9717
	–8	266.9	252.20	64.93	0.3351	191.9	316.01	0.6958	0.9704
	–6	276 3	261.6	64.62	0.3233	193.0	316.01	0.6979	0.9691
	–4	285.8	271.1	64.29	0.3119	193.9	315.99	0.7000	0.9678
	–2	295.7	281.0	63.96	0.3010	194.9	315.95	0.7022	0.9666

Temp °F		Pressure		Density	Specific volume	Enthalpy [1]		Entropy [1]	
		psia	psi	lb/ft³	ft³/lb	Btu/lb		Btu/(lb)(°R)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Liquid and Vapor	+ 0	305.8	291.1	63.63	0.2906	195.8	315.92	0.7043	0.9654
	2	316.3	301.6	63.30	0.2805	196.9	315.88	0.7064	0.9642
	4	327.0	312.3	62.97	0.2707	198.0	315.83	0.7085	0.9629
	6	337.9	323.2	62.64	0.2613	198.9	315.76	0.7106	0.9616
	8	349.0	334.3	62.30	0.2523	200.0	315.68	0.7127	0.9603
	10	360.5	345.8	61.99	0.2436	200.9	315.59	0.7148	0.9589
	12	372.2	357.5	61.69	0.2353	202.0	315.50	0.7169	0.9575
	14	384.3	369.6	61.32	0.2273	203.0	315.40	0.7190	0.9561
	16	396.5	381.8	61.02	0.2196	204.1	315.27	0.7211	0.9547
	18	409.0	394.3	60.67	0.2122	205.2	315.13	0.7232	0.9533
	20	421.9	407.2	60.32	0.2050	206.3	314.96	0.7253	0.9520
	22	435.1	420.4	59.91	0.1980	207.4	314.80	0.7275	0.9507
	24	448.7	434.0	59.57	0.1911	208.4	314.62	0.7297	0.9493
	26	462.5	447.8	59.17	0.1845	209.5	314.42	0.7319	0.9479
	28	476.6	461.9	58.78	0.1783	210.6	314.19	0.7341	0.9465
	30	490.8	476.1	58.40	0.1722	211.7	313.90	0.7363	0.9450
	32	505.5	490.8	58.02	0.1663	212.8	313.58	0.7385	0.9434
	34	520.5	505.8	57.59	0.1602	214.0	313.20	0.7407	0.9417
	36	536.0	521.3	57.12	0.1542	215.1	312.77	0.7429	0.9399
	38	551.7	537.0	56.70	0.1482	216.4	312.28	0.7452	0.9380
	40	567.7	553.0	56.29	0.1425	217.4	311.76	0.7475	0.9360
	42	584.0	569.3	55.89	0.1372	218.7	311.20	0.7598	0.9340
	44	600.8	586.1	55.44	0.1321	220.0	310.63	0.7521	0.9321
	46	617.8	603.1	54.95	0.1273	221.2	310.05	0.7544	0.9302
	48	635.2	620.5	54.43	0.1226	222 5	309.47	0.7568	0.9283
	50	652.9	638.2	53.91	0.1181	223.7	308.90	0.7593	0.9264
	52	671.2	656.5	53.45	0.1138	225.0	308.32	0.7618	0.9246
	54	689.7	675.0	52.95	0.1095	226.4	307.75	0.7643	0.9227
	56	708.6	693.9	52.37	0.1054	227.7	307.13	0.7668	0.9207
	58	727.9	713.2	51.81	0.1014	229.1	306.49	0.7694	0.9187
	60	747.6	732.9	51.17	0.09752	230.6	305.78	0.7720	0.9166
	62	767.7	753.0	50.47	0.09372	232.0	305.03	0.7746	0.9145
	64	788.3	773.6	49.78	0.08999	233.5	304.22	0.7773	0.9123
	66	809.3	794.6	49.08	0.08631	235.1	303.35	0.7801	0.9100
	68	830.8	816.1	48.39	0.08261	236.7	302.45	0.7830	0.9077
	70	852.7	838.0	47.62	0.07894	238 3	301.52	0.7861	0.9053
	72	875.0	860.3	46.80	0.07535	240.3	300.51	0.7894	0.9030
	74	897.8	883.1	45.90	0.07173	242.1	299.39	0.7930	0.9006
	76	921.1	906.4	44.94	0.06811	244.3	298.10	0.7970	0.8982
	78	945.1	930.4	43.90	0.06411	246.4	296.57	0.8013	0.8957
	80	969.5	954.8	42.67	0.06013	248.9	294.75	0.8060	0.8924
	82	994.5	979.8	41.23	0.05603	251.5	292.46	0.8112	0.8881
	84	1020	1005	39.59	0.05171	254.7	289.67	0.8170	0.8821
	86	1046	1031	37.03	0.04711	259.0	285.64	0.8249	0.8737
	87.9	1071	1056	29.21	0.03423	272.7	272.70	0.8483	0.8483

[1] Based on 0 for the perfect crystal at absolute zero temperature, –459.67 °F (–273.15 °C).

[2] Inches of mercury below atmospheric pressure.

Table 4—Thermodynamic properties of saturated carbon dioxide solid, liquid, and vapor phases (SI units)

	Temp °C	Pressure		Density	Specific volume	Enthalpy [1]		Entropy	
		kPa, abs	kPa	kg/m³	m³/kg x 10⁻³	kJ/kg		kJ/(kg)(K)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Solid and Vapor	–102	11.36	–89.97	1597	2837	123.5	710.1	1.415	4.841
	–100	13.97	–87.36	1595	2327	125.8	711.3	1.428	4.809
	–98	17.15	–84.18	1593	1916	128.2	712.4	1.442	4.777
	–96	20.95	–80.38	1591	1583	130.5	713.6	1.455	4.746
	–94	25.49	–75.84	1588	1314	132.9	714.8	1.469	4.716
	–92	30.89	–70.44	1585	1095	135.3	715.9	1.482	4.687
	–90	37.27	–64.06	1582	917.3	137.7	717.1	1.495	4.658
	–88	44.76	–56.57	1579	771.9	140.2	718.2	1.508	4.630
	–86	53.53	–47.80	1576	651.3	142.6	719.3	1.521	4.603
	–84	63.77	–37.56	1573	550.7	145.1	720.4	1.534	4.376
	–82	75.72	–25.61	1569	467.1	147.6	721.4	1.548	4.550
	–80	89.62	–11.71	1565	397.7	150.1	722.4	1.561	4.523
	–78.5	101.3	0.0	1562	354.7	152.1	723.1	1.569	4.504
	–78	105.7	4.4	1561	339.8	152.7	723.4	1.574	4.498
	–76	124.2	22.9	1558	291.1	155.3	724.4	1.586	4.473
	–74	145.6	44.3	1554	249.9	157.9	725.4	1.599	4.449
	–72	170.0	68.7	1549	215.1	160.5	726.3	1.612	4.425
	–70	198.1	96.8	1545	185.7	163.1	727.1	1.625	4.402
	–68	230.2	128.9	1541	160.8	165.8	727.7	1.638	4.378
	–66	267.0	165.7	1536	139.5	168.4	728.1	1.651	4.353
	–64	308.9	207.6	1532	121.1	171.1	728.4	1.664	4.328
	–62	356.7	255.4	1527	105.1	173.9	728.6	1.677	4.304
	–60	409.8	308.5	1522	91.23	176.7	728.7	1.690	4.281
	–58	467.1	365.8	1517	81.00	179.5	728.8	1.703	4.262
	–56.6	518.0	416.7	1513	72.22	181.4	729.0	1.722	4.250
Triple point									
Liquid and Vapor	–56.6	518.0	416.7	1178	72.22	380.5	729.0	2.641	4.250
	–56	531.7	430.4	1176	71.10	381.5	729.1	2.643	4.244
	–54	578.9	477.6	1168	64.72	385.2	729.5	2.659	4.229
	–52	629.5	528.2	1161	59.78	388.9	729.8	2.675	4.215
	–50	683.6	582.3	1154	55.41	392.5	730.2	2.691	4.203
	–48	741.0	639.7	1146	51.36	396.2	730.6	2.707	4.192
	–46	801.9	700.6	1139	47.63	399.9	731.1	2.723	4.181
	–44	866.3	865.0	1131	44.20	403.7	731.5	2.739	4.170
	–42	934.3	833.0	1123	41.05	407.5	732.0	2.756	4.160
	–40	1006	904.7	1115	38.16	411.3	732.4	2.772	4.149
	–38	1082	981	1107	35.52	415.1	732.9	2.788	4.139
	–36	1162	1061	1099	33.11	419.0	733.3	2.803	4.129
	–34	1246	1145	1091	30.90	422.9	733.7	2.819	4.119
	–32	1335	1234	1083	28.87	426.8	734.1	2.835	4.109
	–30	1429	1328	1074	27.00	430.8	734.4	2.851	4.100
	–28	1527	1426	1066	25.27	434.8	734.7	2.867	4.091
	–26	1630	1529	1057	23.66	438.8	734.9	2.883	4.081
	–24	1739	1638	1048	22.16	442.8	735.0	2.899	4.072
	–22	1852	1751	1039	20.76	446.9	735.0	2.915	4.062
	–20	1971	1870	1030	19.45	451.0	735.0	2.931	4.053
	–18	2095	1994	1021	18.24	455.1	734.9	2.947	4.044
	–16	2226	2125	1011	17.13	459.3	734.7	2.963	4.034
	–14	2362	2261	1002	16.09	463.6	734.4	2.979	4.024
	–12	2503	2402	991.9	15.11	467.8	734.1	2.994	4.014
	–10	2649	2548	982.0	14.19	472.2	733.6	3.010	4.004

Temp °C		Pressure		Density	Specific volume	Enthalpy [1)]		Entropy	
		kPa, abs	kPa	kg/m³	m³/kg x 10⁻³	kJ/kg		kJ/(kg)(K)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Liquid and Vapor	–8	2804	2703	971.8	13.34	476.6	733.0	3.027	3.993
	–6	2964	2863	961.5	12.54	481.1	732.2	3.043	3.983
	–4	3131	3030	951.5	11.79	485.6	731.4	3.059	3.973
	–2	3305	3204	940.7	11.07	490.3	730.5	3.076	3.962
	0.0	3485	3384	929.4	10.38	495.0	729.4	3.092	3.950
	2.0	3673	3572	917.4	9.703	499.8	727.7	3.109	3.937
	4.0	3869	3768	905.0	9.046	504.7	725.4	3.126	3.923
	6.0	4071	3970	892.1	8.435	509.8	723.1	3.143	3.908
	8.0	4282	4181	878.0	7.878	515.0	720.8	3.161	3.894
	10.0	4501	4400	863.6	7.375	520.4	718.5	3.179	3.879
	12.0	4730	4629	848.2	6.900	525.9	716.1	3.198	3.864
	14.0	4966	4865	831.9	6.446	531.6	713.5	3.217	3.849
	16.0	5210	5109	814.3	6.006	537.6	710.5	3.236	3.833
	18.0	5464	5363	795.5	5.577	543.8	707.2	3.256	3.817
	20.0	5727	5626	775.2	5.157	550.4	703.5	3.278	3.800
	22.0	6001	5900	753.6	4.745	557.8	699.4	3.303	3.783
	24.0	6285	6184	728.9	4.337	566.0	694.6	3.331	3.765
	26.0	6581	6480	696.4	3.914	575.4	688.2	3.364	3.745
	28.0	6890	6789	655.7	3.460	586.3	679.1	3.403	3.710
	30.0	7211	7110	593.1	2.910	602.5	664.4	3.454	3.658
	31.1	7382	7281	467.9	2.137	634.3	634.3	3.552	3.552

1) Based on 0 for the perfect crystal at zero Kelvin (–273.15 °C).

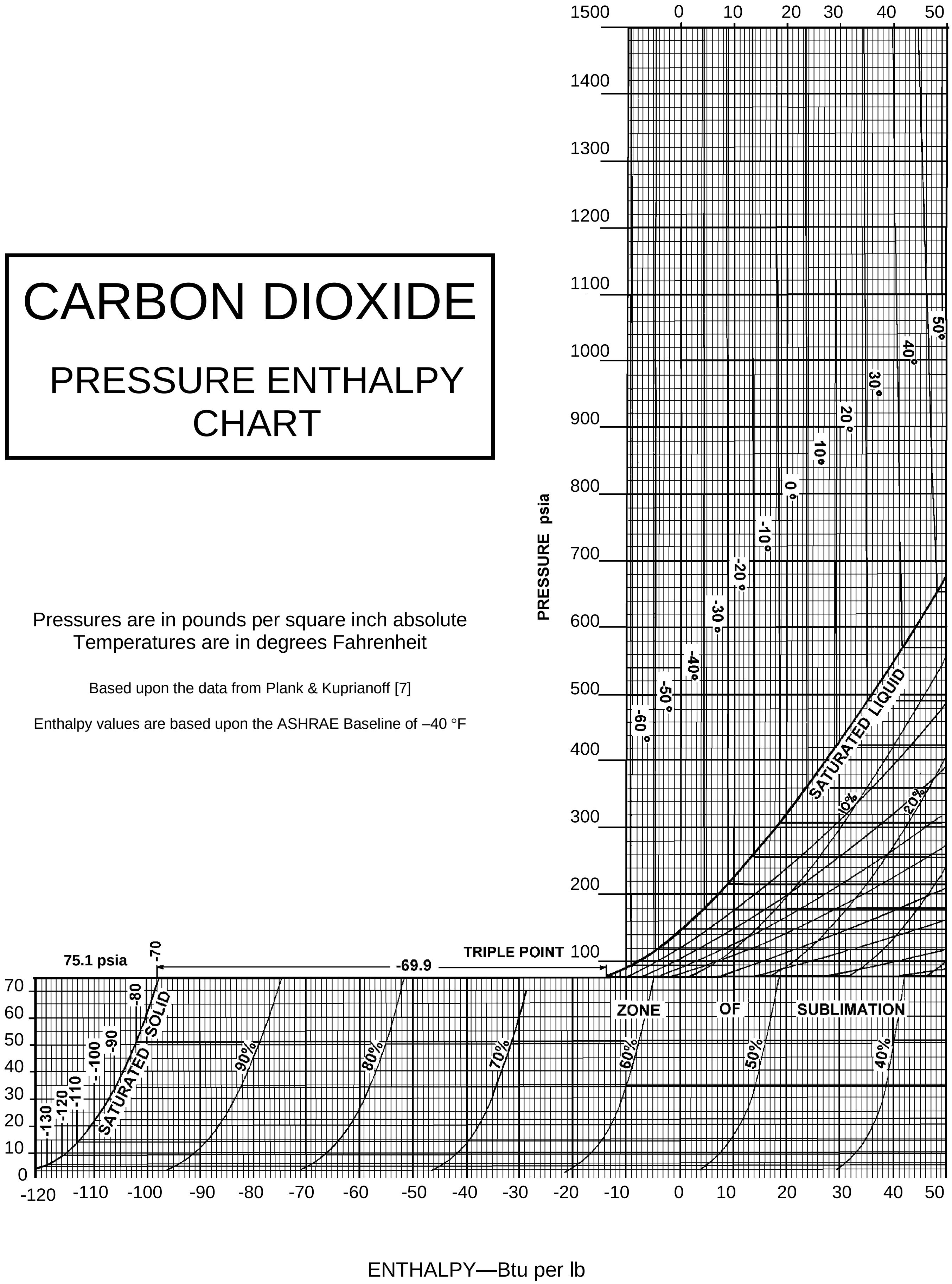


Figure 2a—Pressure enthalpy chart (Part 1)

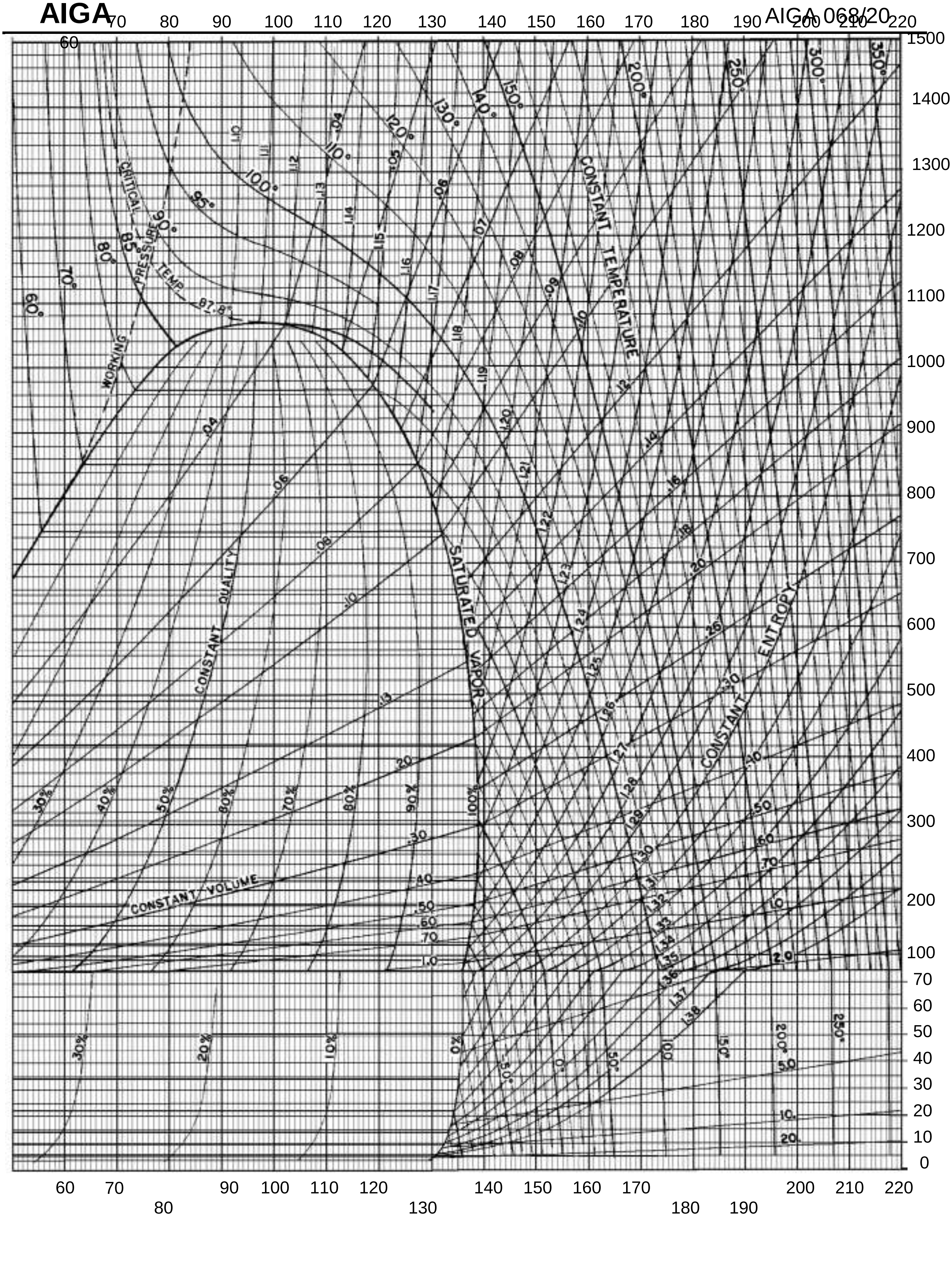


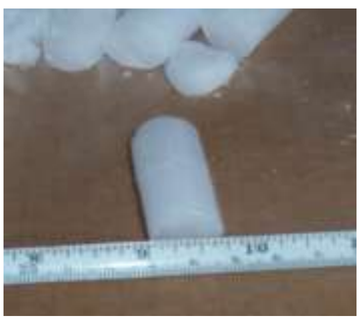
Figure 2a—Pressure enthalpy chart (Part 1)

Extruded dry ice (1/4 in [0.635 cm])

Extruded dry ice pellets (1/2 in [1.27 cm])

Extruded dry ice pellets (5/8 in [1.588cm])

Cryo/high density/blasting ice (0.14 in [0.289 cm])



Extruded dry ice pellets (3/4 in [1.905 cm])

Whole block dry ice

Slab dry ice

Airline size dry ice

Figure 3—Typical block or formed product offerings

5 Hazards

5.1 General

Personnel handling carbon dioxide shall be thoroughly familiar with its associated hazards. There are several conditions in which extreme danger to personnel and equipment can exist. The following describes these conditions and offers procedures and guidelines to prevent dangerous conditions from developing.

5.2 Personal protective equipment

Contact between exposed skin and cold piping or carbon dioxide vapor can cause frost burns. Dry ice particles formed by depressurizing liquid carbon dioxide are extremely cold and can cause severe damage to unprotected eyes or skin. Appropriate gloves and eye protection shall be worn when handling equipment containing carbon dioxide.

Additional personal protective equipment (PPE) that may be required includes but is not limited to hearing protection, supplied air breathing apparatus, and safety shoes.

5.3 Dry ice blocking

Liquid carbon dioxide in a hose or pipe flows like water. However, when the pressure is reduced below 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.

The pressure behind or within a plug can increase as the dry ice sublimes 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 or the sudden whip of the hose or pipe as the plug ejects or both.

5.3.1 Liquid line depressurization

Any residual liquid carbon dioxide in the hose or pipe shall be purged from the hose or pipe with vapor prior to reducing the pressure below 75.1 psia (518 kPa, abs) to prevent dry ice blockage. This is typically done by supplying 200 psi (1380 kPa) or greater vapor to one end of the hose or piping system to maintain the pressure above the triple point while removing the liquid from the other end. This can be accomplished by using a crossover line connecting a vapor source to the liquid line. For further information, see CGA G-6.4, *Safe Transfer of Liquefied Carbon Dioxide in Insulated Cargo Tanks, Tank Cars, and Portable Containers* [8].

5.3.2 Liquid line pressurization to prevent dry ice blockage when liquid is introduced

Liquid piping shall be pressurized with carbon dioxide vapor to greater than 75.1 psia (518 kPa, abs) prior to introducing liquid carbon dioxide to prevent dry ice blocking. This is typically done by supplying 200 psi (1380 kPa) or greater vapor to the hose or piping system prior to introducing the liquid. This also prevents the introduction of liquid carbon dioxide colder than the system design temperature.

Bending hoses that contain residual dry ice can result in the fracturing of the inner liner, which can lead to catastrophic failure.

5.3.3 Low temperature effects on materials

Depressurization of a liquid carbon dioxide system can result in low temperature liquid carbon dioxide and/or the formation of dry ice placing the container, piping, and hoses in an upset condition colder than the system design temperatures. For further information, see CGA G-6.7, *Safe Handling of Liquid Carbon Dioxide Containers That Have Lost Pressure* [9].

Many materials safe to use at normal liquid carbon dioxide temperatures become brittle and can fail if stressed while subjected to dry ice temperatures (–109.3 °F [–78.5 °C]). Materials used in the construction of carbon dioxide transfer systems including hoses shall be compatible with carbon dioxide and the temperature and pressure conditions encountered.

Piping systems subject to operating temperatures below ambient will contract. Allowances shall be made in piping and support systems to compensate for these changes in dimensions. Commonly used copper tubing will shrink approximately 1 in per 100 ft for every 100 °F (2.5 cm per 30.5 m for every 55.6 °C) reduction in temperature.

For further information on piping systems, see G-6.1, *Standard for Insulated Liquid Carbon Dioxide Systems at Consumer Sites* [10].

5.4 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 vapor space in the valve or pipe, the pressure rises approximately 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 pressure relief devices (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*) [11].

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.

5.5 Trapped solid (dry ice and water ice) in discharge and blowdown piping

The design of piping and/or mufflers for the discharge of liquid carbon dioxide to atmosphere shall be configured to prevent blockage with dry ice, water ice, or a combination of both. Piping downstream of the blowdown valve shall be minimized to prevent formation of dry ice blockage, internal water condensation, and be designed to prevent movement. Dry ice formed by depressurized liquid can accumulate inside the piping and baffles of a muffler or discharge device such that the flow can be obstructed. This solid blockage can lead to the unintended pressurization of piping or components to greater than the design pressures and colder than the design temperatures. The use of discharge mufflers on liquid carbon dioxide discharge piping is discouraged to prevent blockages and users shall carefully consider the potential for plugging with dry ice and/or water ice. Any mufflers or discharge device for carbon dioxide liquid shall be protected by appropriate pressure relieving devices as required.

5.6 Personnel overexposure

When carbon dioxide is used in an enclosed area, ventilate the area to maintain a safe working environment for personnel. Carbon dioxide in the gaseous state is colorless and odorless and not easily detectable. Since gaseous carbon dioxide is 1.5 times denser than air, it will be found in greater concentrations at lower elevations. Therefore, ventilation systems should be designed to exhaust from the lowest level and allow make-up air to enter at a higher point in the enclosed area. Do not depend on measuring the oxygen content of the air because carbon dioxide can be dangerous even with adequate oxygen for life support. For additional information, see CGA G-6.5 [11]. Areas with conflicting ventilation requirements (i.e., heavier and lighter than air components) shall have engineered ventilation systems and are otherwise not subject to these criteria.

A carbon dioxide detector with an appropriate alarm system should be installed to detect dangerous concentrations of carbon dioxide. Carbon dioxide leak detection systems should be equipped with audible and/or visual warning devices located in the area leading to the location of the leak detector to warn personnel of a hazardous condition before entering this location. Carbon dioxide can cause asphyxiation because vapors accumulate in low elevations, such as basements, and in nonventilated rooms not necessarily limited to the location of the container. Slow leaks of small percentages of the system capacity can cause hazardous gas concentrations. For additional information, see CGA SB-29, *Prevention of Injury and Loss from Carbon Dioxide Delivery to Small Customer Sites* [12].

Enclosed, improperly ventilated areas can include but are not limited to basements and outside locations such as one with four solid walls and no ceilings. See Figures 4, 5, 6, and 7.

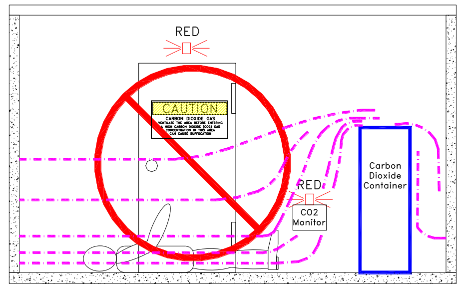


Figure 4—Example of an unsafe, enclosed space

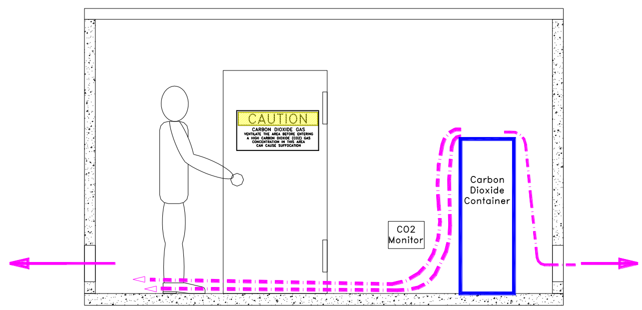


Figure 5—Example of a naturally ventilated and monitored enclosed space

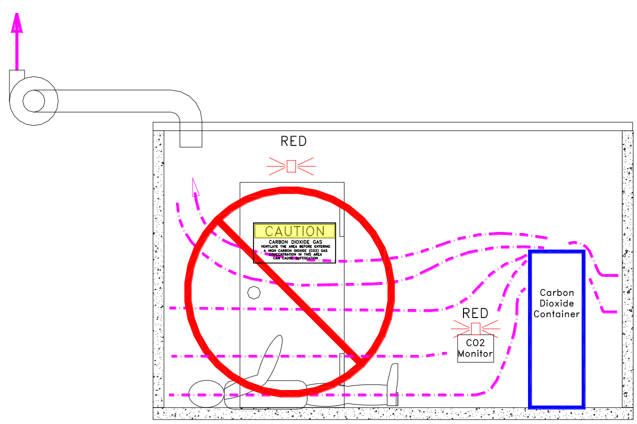


Figure 6—Example of a properly monitored but improperly ventilated enclosed space

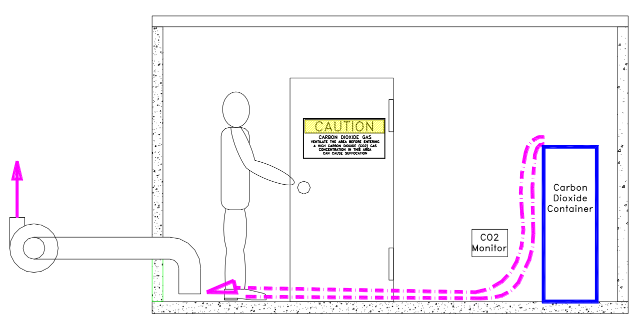


Figure 7—Example of a properly ventilated and monitored enclosed space

Carbon dioxide systems may be enclosed in fenced outdoor enclosures. Any enclosed space shall have a minimum of 25% open area at ground level on a minimum of two sides as indicated in Figure 8. Some enclosures may use concrete block or other solid materials that shall provide the same 25% open area at ground level to prevent the dense carbon dioxide vapors from accumulating in unsafe concentrations. See Figure 9. For additional information, see CGA P-41, *Locating Bulk Liquid Storage Systems in Courts* [13].

Carbon dioxide storage containers installed outdoors should be above grade and in an unenclosed free airflow area. See Figures 8 and 9. An unenclosed area shall have:

- At least 25% of the perimeter area shall be open to atmosphere;
- Openings spaced to create cross ventilation and located as low as possible to ensure that carbon dioxide will not pool and cause exposure to occupants; and
- Openings in direct conveyance with ground level, whenever possible;

Any installation that does not meet these criteria should be considered an enclosed installation.

NOTE—Small enclosures not large enough for human access or occupancy are not subject to these criteria.

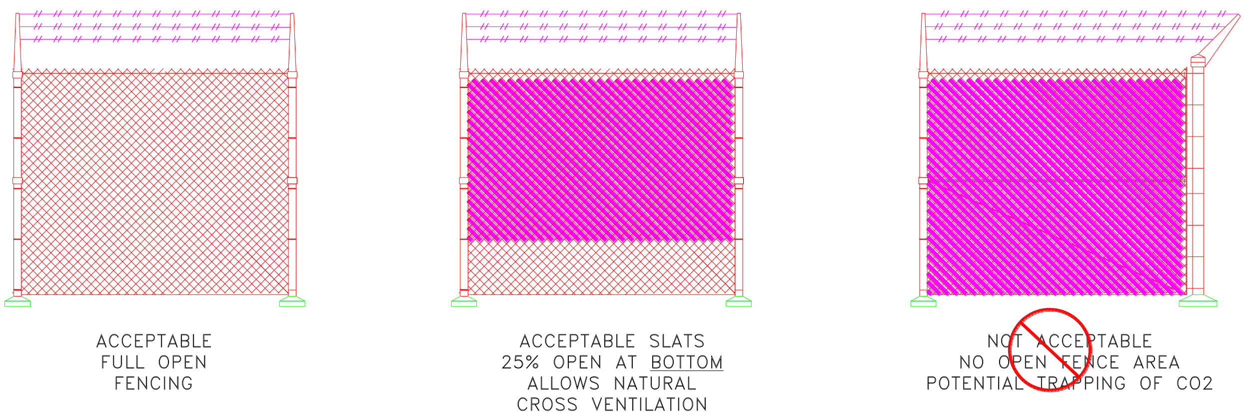


Figure 8—Fenced outdoor enclosures for carbon dioxide installations

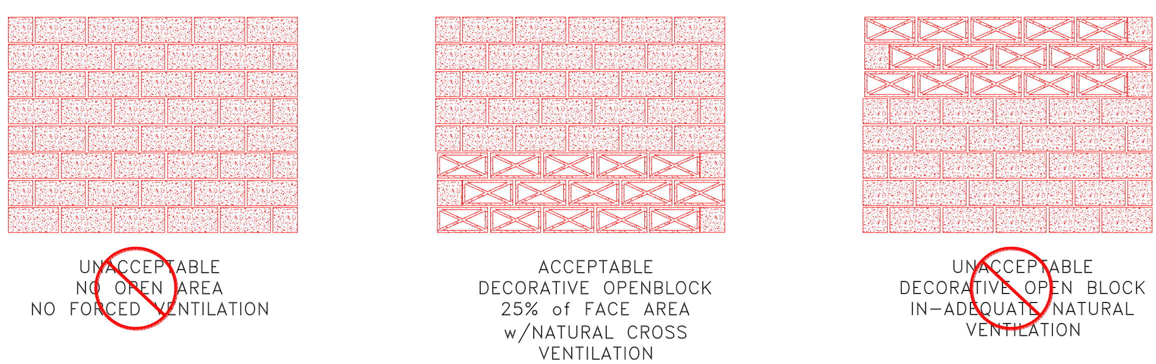


Figure 9—Outdoor walls or courtyards for carbon dioxide installations

5.7 Carbon dioxide leak detection system

Indoor areas, rooms, or enclosed outdoor locations where carbon dioxide systems are filled and/or used shall be provided with a leak detection and alarm system. This system shall be capable of detecting and notifying the building occupants of a gas release of carbon dioxide at, or in excess of, the Time-Weighted Average–Permissible Exposure Limit (TWA–PEL) published by the Occupational Safety and Health Administration (OSHA) [14].

More conservative set points are permitted to be used. For more information, see the gas supplier's safety data sheet (SDS) [15].

The carbon dioxide leak detection system when activated shall sound an audible alarm within the room or area in which the system is installed. Gas detection systems shall be installed and maintained in accordance with the manufacturer's instructions.

5.8 Overfilling containers and cylinders

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 5 and Figure 10 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. Although storage containers are generally equipped with refrigeration systems to maintain the liquid temperature near 0 °F (–17.8 °C), power failures can occur. Small and portable containers are not equipped with refrigeration. All storage containers can potentially become liquid full.

To prevent undue stresses to the container and nuisance cycling of the PRD with consequent product loss, liquid carbon dioxide storage containers should not be filled to a level that allows them to become liquid full before reaching the PRD setting, which is generally 350 psi (2410 kPa).

Typical symptoms of overfilling containers include the refrigeration unit operating but not decreasing pressure, erratic level gauge operation, and excessive frost on vapor lines. Contact the supplier or a qualified carbon dioxide technician to resolve these problems.

The safe filling level depends on the temperature of the liquid being transferred into the container. The colder the liquid, the more vapor space is required for liquid expansion. Figure 10 shows safe filling levels for a range of liquid temperatures. Filling above the safe filling level leads to an overfilled condition. Please note that Figure 10 only applies to filling of insulated containers with PRDs set at 350 psi (2410 kPa) or less. Those quantities would be a significant overfill of uninsulated high pressure cylinders and also would exceed the maximum filling density allowed for DOT-4L/TC-4LM insulated cylinders with PRDs set greater than 350 psi (2410 kPa). DOT tables for filling density go as high as a maximum 625 psi (4310 kPa) PRD setting with an 86% maximum filling density (see 49 CFR 173.304a(e)(2) [3]. For TC, the table in CSA B340, *Selection and Use of Cylinders, Spheres, Tubes, and Other Containers for the Transportation of Dangerous Goods, Class 2,* goes up to a 4300 kPa pressure control valve setting at 86% maximum filling density [16].

5.9 Static electricity

The manufacture of solid dry ice produces static electricity charges (greater than 100 000 volts). This can lead to a discharge of the static electricity to any grounded object or person.

Use of carbon dioxide snow or solid dry ice in combustible environments should be carefully evaluated. Liquid carbon dioxide should not be used for inerting combustible atmospheres because of the extremely high static charges produced during the formation of dry ice. Gaseous carbon dioxide can be used for inerting combustible atmospheres without the risk of generating static charges. See CGA SB-33, *Static Electricity Hazards of Liquid or Solid Carbon Dioxide* for additional information [17].

Table 5—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	–28.9	92.6
210	1450	–18	–27.8	93.1
220	1520	–15	–26.1	93.5
230	1590	–13	–25.0	94.1
240	1650	–11	–23.9	94.6
250	1720	–8	–22.2	95.1
260	1790	–6	–21.1	95.6
270	1860	–4	–20.0	96.1
280	1930	–2	–18.9	96.6
290	2000	0	–17.8	97.1
300	2070	2	–16.7	97.6
310	2140	4	–15.6	98.1
320	2210	5	–15.0	98.6
330	2280	7	–13.9	99.0
340	2340	9	–12.8	99.5
350	2410	11	–11.7	100.0

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

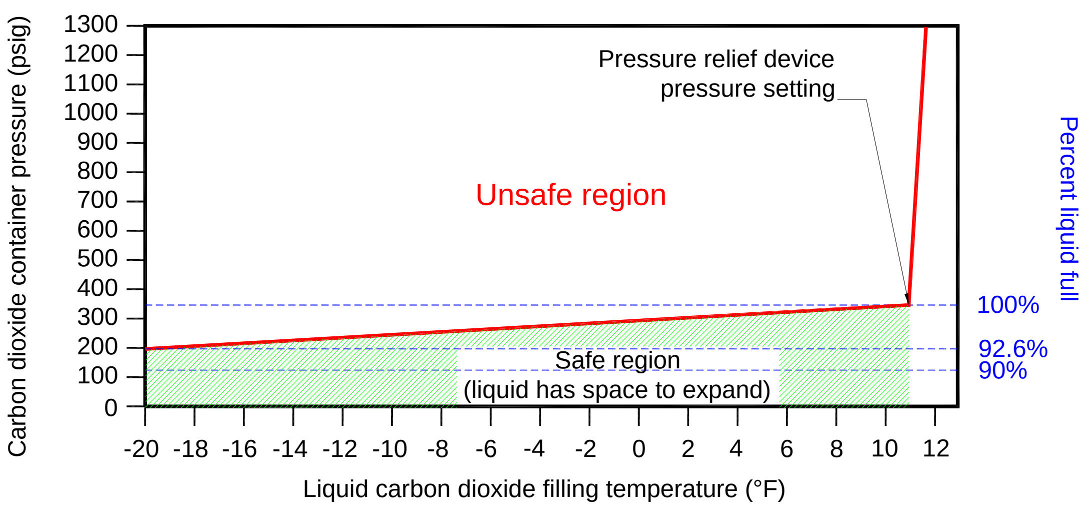


Figure 10—Safe filling volumes for 350 psi carbon dioxide containers

6 Physiological effects of carbon dioxide

6.1 General

The physiological effects of carbon dioxide are unique because it is a product of normal metabolism, a requirement of the body's normal internal chemical environment, and an active messenger substance in the linking of respiration, circulation, and vascular response to the demands of metabolism both at rest and in exercise.

The respiratory control system maintains carbon dioxide pressure at a relatively high level of approximately 50 mm Hg pressure in the arterial blood and tissue fluids. This maintains the acidity of the tissue and cellular fluids at the proper level for essential metabolic reactions and membrane functions. Changes in the normal carbon dioxide tissue pressure can be damaging. If tissue pressure becomes excessively low, which can occur from hyperventilation, failure of critical neuromuscular function or loss of consciousness can occur.

Inhaled carbon dioxide produces the same physiological effects as metabolically produced carbon dioxide. As the carbon dioxide tissue pressure rises from inhaling carbon dioxide, the body responds by using respiratory and adaptive processes to adjust to the change. These adaptive processes are limited and cannot cope with severe exposures, which cause pH change to the body fluids. Toxic effects of carbon dioxide, namely severe and disruptive acidosis, occur when high concentrations of carbon dioxide are inhaled.

The blood and cellular fluids are actually solutions of sodium bicarbonate containing numerous other substances. Severe exposure to carbon dioxide forms carbonic acid in the blood for which the sodium bicarbonate is not very effective as a buffer. The decrease in pH has a rapid toxic effect because the neural control systems are excessively driven. It is important to note that these effects are independent of the amount of oxygen in the atmosphere being breathed.

The effects produced by low and moderate concentrations of carbon dioxide are physiological and reversible, but the effects of high concentrations are toxic and damaging [18].

The response to carbon dioxide inhalation depends on the degree and duration of exposure, and it varies greatly even in healthy individuals. The medical term for the physiological effects of excess carbon dioxide in the blood is hypercapnia. Carbon dioxide can be toxic even when normal oxygen levels are present. Low concentrations of inspired carbon dioxide can be tolerated for a considerable period of time without noticeable effect, or may merely cause an unnatural feeling of shortness of breath. Sustained exposure to 5% carbon dioxide produces stressful rapid breathing. When the level of inspired carbon dioxide exceeds 7%, the rapid breathing becomes labored (dyspnea) and restlessness, faintness, severe headache, and dulling of consciousness occur. At 15%, unconsciousness accompanied by rigidity and tremors occurs in less than 1 minute, and in the 20% to 30% range it produces unconsciousness and convulsions in less than 30 seconds. The reason these effects occur quickly is that carbon dioxide diffuses in the tissue fluids at a rate approximately 20 times more rapidly than oxygen. High concentrations of carbon dioxide can asphyxiate quickly without warning and with no possibility of self-rescue regardless of the oxygen concentration.

6.2 Physical effects of overexposure to carbon dioxide

Skin, mouth, or eye contact with solid carbon dioxide that has a temperature of –109.3 °F (–78.5 °C) can cause severe frostbite, skin lesions, corneal burn, or more serious injury from deep-freezing of the tissues. Liquid discharging from a container produces high velocity carbon dioxide snow particles that are abrasive in addition to being cold and will cause similar injuries.

6.3 Regulatory standards

Carbon dioxide is present in the atmosphere at approximately 350 ppm (0.035%) by volume. The OSHA standard found in Title 29 of the U.S. *Code of Federal Regulations* (29 CFR) 1910.1000, specifies that employee exposure to carbon dioxide in any 8-hour shift of a 40-hour workweek shall not exceed the 8-hour TWA–PEL of 5000 ppm (0.5%) (9000 mg/m^3) [14]. For additional information, see the gas suppliers safety data sheet (SDS) [15]. In Canada, similar limits are mandated by provincial legislation.

6.4 Safety precautions

Appropriate warning signs shall be placed at the entrance to areas where high concentrations of carbon dioxide gas can accumulate. A typical warning is shown in Figure 11.

Carbon dioxide monitoring shall be performed prior to entering a confined space or low area in which carbon dioxide vapor could have accumulated. The carbon dioxide shall be removed by ventilation to a concentration below 3% or a supplied-air respirator shall be donned before entering the confined space or low area, see 29 CFR 1910.146 [14]. For more information see 5.6.

WARNING: *Cartridge-style respirators shall not be substituted for supplied-air respirators.*

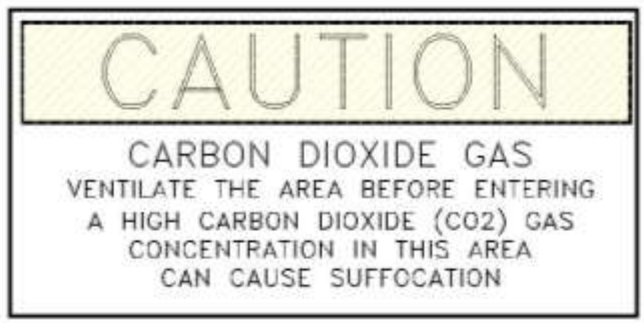


Figure 11—Typical caution sign

6.5 Rescue and first aid

Do not attempt to remove anyone exposed to high concentrations of carbon dioxide without using proper rescue equipment or the potential rescuer could also become a casualty. Rescuers account for over 60% of confined space fatalities. If the exposed person is unconscious, obtain assistance and use established emergency procedures.

If a person has inhaled large amounts of carbon dioxide and is exhibiting adverse effects, move the exposed individual to fresh air at once. If breathing has stopped, perform artificial respiration. Only qualified personnel may give oxygen to the victim. Keep the affected person warm and at rest. Get medical attention as soon as possible. Fresh air and assisted breathing are appropriate for all cases of overexposure to gaseous carbon dioxide. With prompt response to a carbon dioxide emergency, recovery is usually complete and uneventful.

NOTE—Supplied-air respirators should only be used by authorized personnel with appropriate training and qualification for use of the respirator.

If dry ice or compressed carbon dioxide gas comes in contact with the skin or mouth, stop the exposure immediately. If frostbite has occurred, obtain medical attention. Do not rub the area. Immerse in warm water, 100 °F to 105 °F (37.8 °C to 40.6 °C).

7 Transportation, storage, and handling of carbon dioxide

7.1 General

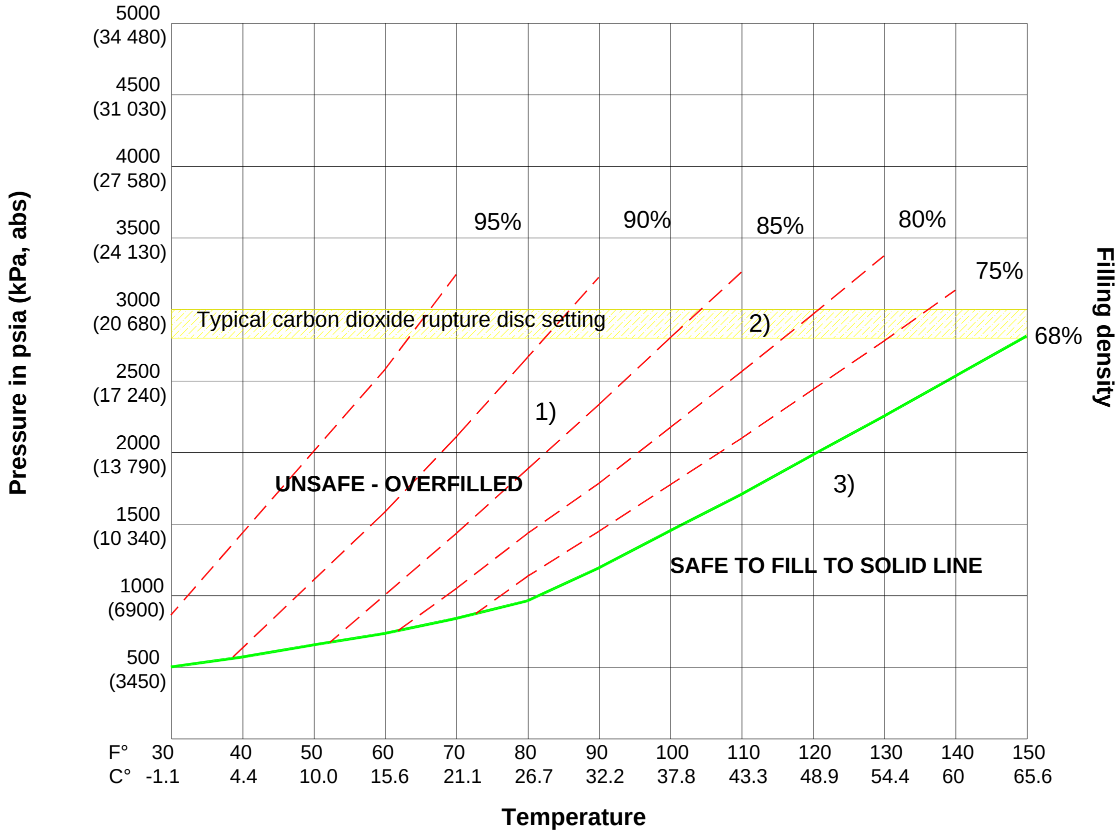
Cylinders and containers used for the transportation of carbon dioxide are either insulated or uninsulated. Insulated liquid containers commonly have a working pressure between 200 psi and 500 psi (1380 kPa and 3450 kPa). They may be refrigerated to compensate for heat gained by the contents during transport. These containers include insulated liquid cylinders, tank cars, portable tanks, and cargo tanks.

Uninsulated cylinders have a design pressure that will safely contain carbon dioxide at normal ambient temperatures. The pressure in these cylinders varies with ambient temperature, see Figure 12.

The product shipping names and product identification numbers for the three forms of carbon dioxide shipped are as follows:

- carbon dioxide, UN 1013;
- carbon dioxide, refrigerated liquid, UN 2187; and
- carbon dioxide, solid or dry ice, UN 1845.

The DOT and TC hazard classification for carbon dioxide and carbon dioxide refrigerated liquid is 2.2 (nonflammable gas). Under DOT, carbon dioxide solid is Class 9 (miscellaneous hazardous materials) when transported by air or water and unclassified when transported by rail or highway. In Canada, it is Class 9 (miscellaneous dangerous goods) regardless of mode of transportation.



NOTE—This chart is based upon a DOT-3AL 1800 cylinder filled to its correct maximum liquid carbon dioxide capacity of 68% of the total volume (water weight capacity). An overfilled cylinder experiences enormous internal pressures from expansion of the liquid carbon dioxide as it warms to higher temperatures after filling.

1) Dashed lines indicate temperature-pressure relationship when a 68% maximum allowable fill density cylinder is overfilled.

2) A correctly installed carbon dioxide cylinder rupture disk functions at 2800 psi to 3000 psi (19 310 kPa to 20 680 kPa) depending on design.

3) DOT-3AL 1800 maximum permitted filling capacity is 68%.

Figure 12—Example of pressure in a DOT-3AL 1800 carbon dioxide cylinder filled to indicated densities at selected temperature

CGA's recommended hazard ratings for carbon dioxide gas, liquid, and solid are shown in Table 6 in accordance with the National Fire Protection Association (NFPA) rating system as referenced in CGA P-19, *CGA Recommended Hazard Ratings for Compressed Gases* [19, 20].

For an example of an NFPA hazard label for liquid carbon dioxide, see Figure 13.

Table 6—NFPA hazard label designations for carbon dioxide

Gas	
Health	3
Flammability	0
Instability	0
Special	SA [1)]
Liquid	
Health	3
Flammability	0
Instability	0
Special	SA [1)]
Solid	
Health	3
Flammability	0
Instability	0
Special	SA [1)]

NOTE—CGA's recommended rating of carbon dioxide using NFPA's rating system.

[1)] CGA recommends SA to designate a simple asphyxiant. The SA symbol shall be used for refrigerated liquid, liquefied compressed gas, and nonliquified compressed carbon dioxide systems and where large quantities of dry ice are used in confined areas.

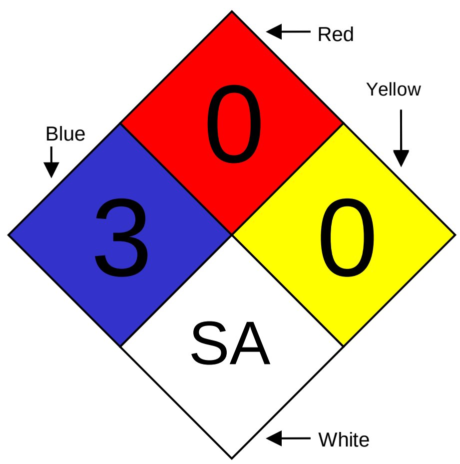


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Figure 13—NFPA hazard label for liquid carbon dioxide

7.2 Regulations applying to containers and cylinders

In the United States, the transportation of carbon dioxide in interstate commerce by rail, highway, air, and water is governed by federal authority under regulations by DOT [3]. In Canada, TC regulates all modes of transport through the *Transportation of Dangerous Goods (TDG) Regulations* [21]. The Canadian regulations adopt the following standards:

- For rail transport—Transport Canada, TP 14877 *Containers for Transport of Dangerous Goods by Rail* [22];
- For cylinder shipments—CSA B339, *Cylinders, spheres, and tubes for the transportation of dangerous goods*, or CSA B340 [23, 16]; and
- For bulk shipments by road—CSA B620, *Highway tanks and TC portable tanks for the transportation of dangerous goods*, or CSA B622, *Selection and use of highway tanks, TC portable tanks, and ton containers for the transportation of dangerous goods, Class 2* [24, 25].

The specifications of these regulatory authorities require, among other things, that the materials used for carbon dioxide containers and cylinders meet certain chemical and physical requirements, pass specified hydrostatic pressure tests, and be protected by adequate PRDs.

7.3 Uninsulated carbon dioxide cylinders

7.3.1 General

In the United States, uninsulated carbon dioxide steel cylinders shall comply with DOT specifications 3, 3A-1800, 3AX-1800, 3AA-1800, 3AAX-1800, 3E1800, 3T1800, 3HT2000, or 39. Aluminum uninsulated carbon dioxide cylinders shall comply with DOT-3AL1800.

In Canada, uninsulated carbon dioxide steel cylinders shall comply with TC specifications TC-3AM138, CTC-3A1800, TC-3AXM138, CTC-3AX1800, TC-3AAM138, CTC-3AA1800, TC-3AAXM138, CTC-3AAX1800, TC-3EM124, CTC-3E1800, ICC-3, TC-3TM138, TC-39M, CTC-39, TC-3HTM138, CTC-3HT2000, or TC-3ASM138. Aluminum uninsulated carbon dioxide cylinders shall comply with specifications TC-3ALM124 or CTC-3AL1800. Since 1993, Canadian uninsulated carbon dioxide cylinders have been made to metric units as indicated by the letter M in the specification with the service pressure expressed in bar. One bar equals 100 kPa, or approximately 14.5 psi.

Uninsulated carbon dioxide cylinders are currently fabricated from steel or aluminum with a minimum rated service pressure of 1800 psi (124 bar). DOT and TC are the recognized regulatory agencies in the United States and Canada that regulate the manufacture of uninsulated carbon dioxide cylinders [3, 21]. Typical dimensions and capacities of the most commonly used uninsulated carbon dioxide cylinders are listed in Table 7.

7.3.2 Connections

Uninsulated carbon dioxide cylinder valve connection standards are provided in CGA V-1, *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections* and are recognized as U.S. and Canadian standards [26]. Uninsulated carbon dioxide cylinders use a CGA 320 outlet connection. Small medical uninsulated carbon dioxide cylinders equipped with a yoke-type valve use a CGA 940 outlet connection.

7.3.3 Pressure relief devices

Uninsulated carbon dioxide cylinders, with certain exceptions, shall be equipped with PRDs designed to release excessive pressure that can occur from overfilling, exposure to fire, or high temperatures. The minimum permissible service pressure rating for uninsulated carbon dioxide cylinders is 1800 psi (12 410 kPa). They shall have a rupture disk designed to rupture at no greater than the minimum required test pressure of the cylinder (e.g., 5/3 of the service pressure for DOT uninsulated carbon dioxide cylinders). Details of PRD requirements are in CGA S-1.1, *Pressure Relief Device Standards–Part 1–Cylinders for Compressed Gases* [27].

Table 7—Typical dimensions and capacities of uninsulated carbon dioxide cylinders

Nominal carbon dioxide capacity lb	Internal volume in^3	Water weight capacity lb	Overall length in	Outside diameter in
0.22 (3.5 oz)	9	0.32	5.3	2.0
0.45 (7 oz)	18	0.65	9.4	2.0
0.66 (10.5 oz)	27	0.97	13.0	2.0
0.75 (12 oz)	31	1.1	9.4	2.5
1.0	41	1.5	7.8	3.2
1.25	51	1.6	9.4	3.2
1.5	61	2.2	11.1	3.2
1.75	71	2.6	12.5	3.2
2	84	3.0	9.3	4.4
5	205	7.4	14.8	5.3
10	408	14.7	16.8	6.9
15	612	22.1	23.4	6.9
20	816	29.4	23.6	8.0
35	1429	51.5	38.6	8.0
50	2040	73.5	46.6	8.6
50	2370	85.2	51	8.5
50 or 60	2675	96.0	51	9.0
75	3055	110.3	56	9.3
100	4080	147.3	58	10.6

7.3.4 Filling limits

Uninsulated carbon dioxide cylinders shall be filled by weight. Care shall be exercised to avoid overfilling, which can contribute to catastrophic failure. DOT and CSA B340 limits the weight of carbon dioxide that may be charged into an uninsulated carbon dioxide cylinder [3, 16]. Care shall be exercised to avoid overfilling, which can contribute to catastrophic failure. If an uninsulated carbon dioxide cylinder is filled over its maximum permitted filling density, a rise in temperature could cause the cylinder to become liquid full. The pressure in an uninsulated carbon dioxide cylinder filled with carbon dioxide to various percentages of its water capacity is given in Figure 12. For detailed information on filling uninsulated carbon dioxide cylinders, see CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures* [28].

7.3.5 Retesting

Uninsulated carbon dioxide cylinders, except specifications 3HT, 3E, and 39, are required by DOT and TC regulations to be requalified for continued service every 5 years by an authorized retester. Specification 3HT cylinders shall be retested every 3 years. Specification 3E cylinders do not require retesting because they are smaller than 2 in (5 cm) in diameter and 24 in (61 cm) in length. Specification 39 cylinders may not be refilled.

This requalification includes a thorough external and internal visual inspection as well as an internal hydrostatic pressure test, see CGA C-1, *Methods for Pressure Testing Compressed Gas Cylinders*; CGA C-6, *Standard for Visual Inspection of Steel Compressed Gas Cylinders*; CGA C-6.1, *Standard for Visual Inspection of High Pressure Aluminum Alloy Compressed Gas Cylinders*; and CGA C-8, *Standard for Requalification of DOT-3HT, CTC-3HT, and TC-3HTM Seamless Steel Cylinders* [29, 30, 31, 32]. For DOT uninsulated carbon dioxide cylinders and older Canadian (CTC, BTC, or CRC) cylinders, the hydrostatic test shall be performed at 5/3 of the stamped service pressure. For metric TC uninsulated carbon dioxide cylinders, the hydrostatic test shall be performed at 1.5 times the marked service pressure. The internal visual inspection shall be carefully performed to detect harmful corrosion because wet carbon dioxide can rapidly corrode a steel cylinder.

Uninsulated carbon dioxide cylinders that have evidence of physical damage (dents, pitting, cracks, arc burns, fire/heat damage, damaged threads, bulges, or any other signs of physical damage) or fail the hydrostatic test shall be removed from service.

Each requalified cylinder shall be plainly and permanently stamped with the month and year of the test with the retester's identification number (RIN) between the month and year of the retest date. In the United States, the cylinder owner shall keep a record of the inspection and retest data on all uninsulated carbon dioxide cylinders until the next requalification. In Canada, the cylinder owner shall keep a copy of the requalification report for 10 years.

Note: Users in countries in Asia should also check for any local regulatory requirement for the testing periodicity and procedure to be followed and ensure compliance.

7.3.6 Marking and labeling

The following marks are required by DOT and TC to be plainly stamped on the shoulder, top head, or neck of all uninsulated carbon dioxide cylinders:

- DOT or TC specification number followed by the service pressure, for example, DOT-3A1800 or TC-3AM138;
- Serial number and identifying symbol of the cylinder manufacturer. The symbol shall be registered with DOT or TC, or both; and
- Independent inspector's (third party) official mark and the manufacturing test date. The word SPUN and/or PLUG shall be added when an end closure is made by the spinning process or affected by plugging (see 49 CFR, Part 178, Subpart C, *Specifications for cylinders,* or CSA B339) [3, 23].

The required markings on cylinders shall not be changed except as prescribed in DOT or TC regulations. The serial number and identifying symbol of the maker shall never be obliterated or changed and shall be kept in a legible condition.

In addition to the required marking listed previously, uninsulated carbon dioxide cylinders shall be labeled with the following:

- Product shipping name—Carbon Dioxide;
- Product identification number—UN 1013. These markings shall be by means of stenciling, printing, or labeling; shall not be readily removable; and shall be in accordance with 49 CFR or *TDG Regulations* [8, 21];
- A 100-mm (3.9-in) green diamond-shaped nonflammable gas label with a cylinder symbol in the upper corner and the hazard class number, 2, in the bottom corner shall be used on every uninsulated carbon dioxide cylinder. In the United States, the use of NONFLAMMABLE GAS on the label is optional. The use of words NONFLAMMABLE GAS in the green diamond is acceptable for U.S. shipments into Canada, however those words may not be included for transport or shipment of product within Canada [3, 21];
- Alternately, DOT regulations (see 49 CFR 172.400a) allow the use of 30 mm (1.25-in) square-on-point labels as long as the cylinder(s) are not overpacked and are durably and legibly marked in accordance with CGA C-7, *Guide to Classification and Labeling of Compressed Gases*, Appendix A [3, 33]; and
- In Canada, the general requirement is for each side of a label to be at least 100 mm in length with a line running 5 mm inside the edge. However, if that size label, together with the shipping name, technical name, and UN number, cannot be displayed because of the irregular shape or size of the small means of containment, each side of the label may be reduced in length by the same amount to the point where the label, together with the shipping name, technical name, and UN number, will fit that small means of containment, but shall not be reduced to less than 30 mm. See subsection 4.10(4) of the *TDG Regulations* [21].

For additional details on U.S. and Canadian marking and labeling, see CGA G-6.3 and CGA C-7 [28, 33].

Uninsulated carbon dioxide cylinders equipped with a dip or siphon tube, allowing withdrawal of liquid when the cylinder is upright, shall be clearly identified on the exterior of the cylinder by the words siphon, dip tube, or other descriptive phrase. This does not apply to fire extinguishing cylinders. A gas pressure regulator shall never be attached to an uninsulated carbon dioxide cylinder with a siphon tube.

Note: Users in countries in Asia should also check for any local regulatory requirement for labeling and marking on the cylinders to be followed and ensure compliance.

7.3.7 Storage precautions

Uninsulated carbon dioxide cylinders shall be stored in an assigned location, see CGA P-1, *Standard for Safe Handling of Compressed Gases in Containers* [34]. It is important to remember that liquid carbon dioxide in uninsulated cylinders is stored at approximately 850 psi (5860 kPa) at room temperature, and cylinder failure can result in a violent release of energy. Carbon dioxide vapor is approximately 1.5 times heavier than air. Gas escaping from an uninsulated carbon dioxide cylinder will tend to collect in low areas or confined spaces and can cause asphyxiation.

Uninsulated carbon dioxide cylinders are designed for a normal operating temperature not to exceed 125 °F (51.7 °C) because of the excessive pressure that will occur. Uninsulated carbon dioxide cylinders should not be stored in direct sunlight, near furnaces, radiators, or any other source of heat. Uninsulated carbon dioxide steel cylinders subjected to fire or high heat shall either be condemned or returned to the cylinder manufacturer for examination to determine their suitability for continued service. Temperatures in excess of 350 °F (177 °C) will irreversibly change the properties of aluminum. Aluminum uninsulated carbon dioxide cylinders that have been subjected to heat or fire shall be condemned, see CGA G-6.3 [28].

Uninsulated carbon dioxide cylinders shall not be dropped or otherwise subjected to abnormal mechanical shock that could damage the cylinder, valve, or PRD. Uninsulated carbon dioxide cylinders should not be stored near elevators or gangways or in locations where heavy moving objects could strike or fall on them. Uninsulated carbon dioxide cylinders shall be prevented from falling over through the use of chains or restraints. Uninsulated carbon dioxide cylinder filling operations may utilize cylinder nesting as an acceptable means of securing.

Uninsulated carbon dioxide cylinders should be stored in a dry, well-ventilated location above ground level. External corrosion can cause uninsulated carbon dioxide cylinder failure, and cylinders should not be stored in plating rooms or other locations that can have a corrosive atmosphere.

7.3.8 Handling precautions

Personnel shall be trained in the proper handling and use of uninsulated carbon dioxide cylinders. They shall also be made aware of the hazards involved when approved procedures are bypassed, altered, or ignored. For additional information, see CGA G-6.3, CGA P-1, CGA P-65, and CGA C-7 [28, 34, 35, 33].

The internal pressure of uninsulated carbon dioxide cylinders varies with ambient temperature. For example, under equilibrium conditions at –40 °F (–40 °C) the pressure would be approximately 131 psi (900 kPa); and at 85 °F (29.4 °C) the pressure would be 1018 psi (7020 kPa). Extreme care should be exercised when connecting, disconnecting, filling, discharging, and maintaining uninsulated carbon dioxide cylinders.

The piping system to the use point shall be designed to safely accommodate the pressures encountered. Piping or tubing shall be adequately braced and protected from mechanical damage. Examples of acceptable piping specifications are provided in CGA G-6.1 [10].

Adequate PRDs shall be provided where liquid carbon dioxide can become trapped, see 5.4.

CAUTION: *Ordinary cast iron pipe and malleable iron pipe shall not be used because they can fracture upon impact, especially under cold conditions.*

Gas pressure-reducing regulators shall be specifically designed for carbon dioxide service. Neoprene, nylon, ethylene-propylene diene monomer (EPDM), and polytetrafluoroethylene (PTFE) are commonly used in both carbon dioxide regulators and cylinder valves. Avoid using materials that absorb carbon dioxide and swell or deform such as certain formulations of Buna-N and natural rubber. High consumption rates may require a regulator preheater.

The valves on empty uninsulated carbon dioxide cylinders should be tightly closed to prevent air or moisture from entering while they are being returned for refilling.

7.4 Insulated carbon dioxide cylinders

7.4.1 General

Insulated liquid carbon dioxide cylinders used for transport of liquid carbon dioxide shall comply with DOT 4L and TC 4LM specifications.

7.4.2 Connections

Insulated carbon dioxide cylinder valve connection standards have been adopted by CGA and recognized as U.S. and Canadian standards. Connections for insulated carbon dioxide cylinders are defined in CGA V-1 [26].

7.4.3 Pressure relief devices

Insulated carbon dioxide cylinders shall be equipped with PRDs designed to release excessive pressure that can occur from normal pressure rise due to heat leak, overfilling, and exposure to fire or high temperatures. An insulated carbon dioxide cylinder filled with liquid carbon dioxide and offered for transportation shall be equipped with one or more PRDs sized and specified by type, location, and quantity in accordance with CGA S-1.2, *Pressure Relief Device Standards–Part 2–Portable Containers for Compressed Gas* [36]. PRDs shall be tested in accordance with CGA S-1.2 [36].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.4.4 Filling limits

Insulated carbon dioxide cylinders manufactured to DOT 4L and TC 4LM specifications shall be filled by weight. Insulated carbon dioxide cylinders should not be filled to a level that allows them to reach a liquid full condition before reaching the PRD setting. For detailed information on filling insulated carbon dioxide cylinders, see CGA G-6.4 [8].

7.4.5 Retesting/inspection

7.4.5.1 Retesting

Insulated carbon dioxide cylinders designed to DOT and TC specifications are not required to be periodically retested according to 49 CFR, Part 180.209 and *TDG Regulations* [3, 21].].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.4.5.2 Inspection

Significant physical damage (e.g., pitting, dents, cracks, fire or heat damage) can cause the insulated carbon dioxide cylinder to lose vacuum. Vacuum loss will cause the insulated carbon dioxide cylinder pressure to rise up to the pressure relief setting and create a significant release of carbon dioxide vapor through the PRD. Insulated carbon dioxide cylinders with damage shall be inspected and determination made if the insulated carbon dioxide cylinder can be repaired or if it should be condemned. Inspections and repairs shall be made by qualified personnel.

7.4.6 Marking and labeling

DOT and TC require insulated carbon dioxide cylinders manufactured to DOT 4L and TC 4LM specifications to have the following markings plainly and permanently stamped on the shoulder, top head, or permanently attached plate:

- DOT and/or TC specification number followed by the service pressure;
- Serial number and the insulated carbon dioxide cylinder manufacturer's name or the identifying symbol; and

- Independent inspector's (third party) official mark (TC) and the manufacturing test date.

The required markings on insulated carbon dioxide cylinders shall not be changed except as prescribed in DOT or TC regulations. The serial number and the cylinder manufacturers name or identifying symbol of the manufacturer shall never be obliterated or changed and shall be kept in legible condition.

Insulated carbon dioxide cylinders should also be marked with a 360 degree label showing the product shipping name - carbon dioxide. See Appendix F in CGA C-7 for detailed labeling instructions [33].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.4.7 Storage precautions

Insulated carbon dioxide cylinders shall be stored in an assigned location. These cylinders are designed to vent carbon dioxide gas to limit the pressure as the contents warm. Therefore, the location shall be well ventilated, out of traffic patterns, and above ground away from cellars or low areas where the heavy carbon dioxide gas (1.5 times heavier than air) can collect. Storage shall be away from excessive heat sources.

7.4.8 Handling precautions

7.4.8.1 General handling of insulated carbon dioxide cylinders

Insulated carbon dioxide cylinders are very heavy and shall be moved only on a four-wheel cart designed for that purpose. Rolling of insulated carbon dioxide cylinders is extremely hazardous. A falling insulated carbon dioxide cylinder can cause severe injuries from its weight alone.

Never lift an insulated carbon dioxide cylinder by the handling ring because the ring is not designed for that purpose and can be damaged. If an insulated carbon dioxide cylinder must be moved with a hoist, forklift, etc., attach the hooks to the lifting lugs provided for that purpose using an appropriate spreader bar.

7.4.8.2 Specific handling of vacuum-insulated carbon dioxide cylinders

Vacuum-insulated carbon dioxide cylinders have an inner container suspension system designed to minimize heat input. These cylinders depend upon the vacuum in the insulation space to provide the required degree of insulation. Loss of this vacuum will cause excessive amounts of gaseous carbon dioxide to be vented through the PRDs. In such cases, these cylinders should be immediately moved outdoors and the cylinder supplier should be notified. These cylinders should never be subjected to shocks, falls, or impact and shall always be kept upright, see Figure 14.

Should the vacuum-insulated carbon dioxide cylinder fall, the inner container could fail. Releasing full pressure to the vacuum space can cause a catastrophic failure of the outer shell.

Figure 14—Vacuum-insulated carbon dioxide cylinder

7.4.9 Operating precautions

Many vacuum-insulated carbon dioxide cylinders have a vaporizer in the annular space to provide gaseous carbon dioxide at near ambient temperatures. Should the use rate become excessive, the outer shell of the insulated carbon dioxide cylinder will frost heavily and the withdrawn carbon dioxide can become extremely cold. Never apply heat to the outside of the vacuum-insulated carbon dioxide cylinder to correct this condition; instead, reduce the use rate or manifold additional cylinders.

An insulated carbon dioxide cylinder is equipped with a filling/liquid-use valve, gas-use valve, pressure-building valve, vent valve, pressure gauge, liquid-level gauge, and various regulators and PRDs. The gas- and liquid-use valves, pressure-building valve, liquid-level gauge, and pressure gauge are the only devices intended for customer use.

7.5 Small stationary insulated carbon dioxide container

Containers shall be designed, constructed, and tested in accordance with the requirements of the ASME *Boiler and Pressure Vessel Code* (ASME Code), Section VIII, Division 1, or any other local/international codes accepted by the Authorities in the specific country in Asia, current at the time the vessel is constructed, see Figure 15 [1]. For a typical piping schematic for a small stationary insulated carbon dioxide container, see Figure 16.

Containers shall be designed and constructed to minimize the risk of overfilling.

Containers shall never be allowed to become completely liquid full.

For more information on mini-bulk containers, see CGA G-6.5 [11].

Figure 15—Small stationary insulated carbon dioxide container (mini-bulk)

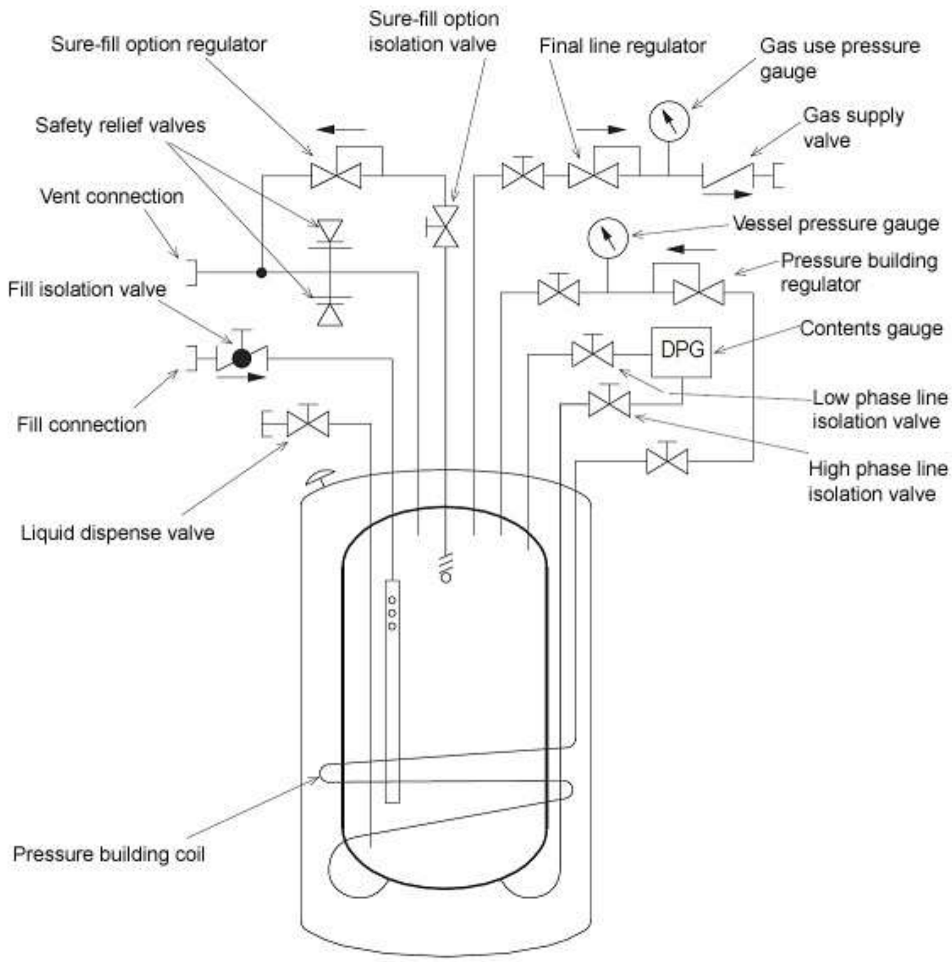


Figure 16—Typical piping schematic for small stationary insulated carbon dioxide container

7.6 Tank cars

7.6.1 General

DOT regulations governing the shipment of liquid carbon dioxide are found in 49 CFR 173.314 and 173.31 [3]. TC regulations are found in TP14877 [22]. Both authorize shipments in DOT or TC specification 105A500W, 105S500W, and 105J500W tank cars, see Figure 17 [3, 22].

Figure 17—Liquid carbon dioxide tank car

7.6.2 Pressure relief devices

The PRDs for DOT 105A500 and DOT/TC 105A500W tank cars consist of a primary PRD set to open at 375 psi (2590 kPa) or lower, a rupture disk designed to burst at a pressure less than the tank test pressure (500 psi [3450 kPa]), and two pressure regulating devices set to open at 350 psi (2410 kPa). These devices shall be approved by the Association of American Railroad's Committee on Tank Cars, see 49 CFR 173.314(b)(4) and 173.314(c) [3]. Personnel such as railroad employees should be made aware that one or both of the pressure regulating devices routinely open during transportation. The carbon dioxide escaping during such a valve opening can create a sound that an untrained person might believe to be a hazardous leak. This is normal operation and such railroad tank cars can be safely moved. Railroad tank cars in liquid carbon dioxide service should display a stencil that reads REGULATING VALVES VENTING NORMAL.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.6.3 Filling limits

U.S. and Canadian regulations require that railroad tank cars be filled so the liquid portion of the gas at 0 °F (–17.8 °C) does not completely fill the tank, see 49 CFR 173.314, Note 5 and TP14877 [3, 22]. A relationship of volume to temperature in containers is shown in Table 5 and Figure 10.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.6.4 Retesting and requalification

Tank cars in liquid carbon dioxide service shall be requalified at least once every 10 years, see 49 CFR 180.509(c) and TP14877 [3, 22]. PRDs shall be requalified every 5 years, see 49 CFR 180.509(c)(3)(ii) and 180.509(h) [3]. The dates of requalification of the tank and PRDs shall be stenciled on the tank car.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.7 Portable tanks

7.7.1 General

DOT authorizes the shipment of liquefied carbon dioxide in portable tanks complying with DOT specification 51 as well as certain other portable tanks as outlined in 49 CFR 173.32(b), for further details, refer to 49 CFR 173.315 [3]. In Canada, TC 51 portable tanks may be used in accordance with CSA B622 or TP14877 [25, 22].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.7.2 Pressure relief devices

Each portable tank shall be provided with one or more PRDs of the pilot-operated or spring-loaded type. A portable tank may also be provided with a pressure-controlling device that regulates the internal pressure by venting when the pressure reaches a preset point below the start-to-discharge pressure of the PRD see 49 CFR 173.315(i)(9) and (11) [3]. Details of PRD requirements are contained in CGA S-1.2 [36].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.7.3 Filling limits

DOT regulations prohibit filling portable tanks in excess of 95% of their volumetric capacity, which is typically determined during the filling operation by using fixed-length internal dip tubes or by weighing [3]. Depending upon the temperature of the carbon dioxide being loaded, it may be necessary to fill to a lower percentage level to prevent them from becoming liquid full before reaching the start-to-discharge pressure of the PRD, see 49 CFR 173.315 [3]. A relationship of volume to temperature in containers is shown in Table 5 and Figure 10**.**

7.7.4 Retesting

Portable tanks in carbon dioxide service shall be subjected to a hydrostatic pressure test at least once every 5 years. The retest pressure shall be a minimum of 1.5 times the design pressure. For a specification DOT/TC-51 portable tank, the minimum design pressure is 200 psi (1380 kPa). A portable tank that has been out of service for a period of 1 year or more shall be retested before being returned to service, see 49 CFR 180.605(b) or CSA B620 [3, 24]. The date of the most recent retest shall be marked on the portable tank on or near the metal certification plate, see 49 CFR 180.605(k) or CSA B620 [3, 24].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.7.5 Refrigeration system

Refrigeration systems are uncommon on portable containers. If needed, the system should be similar to those used on a stationary container, see 7.9.5.

7.8 Cargo tanks

7.8.1 General

DOT authorizes the shipment of liquid carbon dioxide in cargo tanks complying with specifications MC-330 and TC/MC-331 [3]. In Canada, TC authorizes the shipment of liquid carbon dioxide in TC 331 or TC 338 highway tanks as outlined in CSA B622 [25]. See Figures 18 and 19.

Figure 18—Liquid carbon dioxide cargo tank

Figure 19—Liquid carbon dioxide cargo tank (straight truck)

7.8.2 Pressure relief devices

Each cargo tank shall be provided with one or more PRDs of the spring-loaded type and may be equipped with a rupture disk-type device rated between 1.5 and 2 times the design pressure. A cargo tank may also be provided with a pressure-controlling device, which regulates the internal pressure by venting when the pressure reaches a preset point below the start-to-discharge pressure of the PRD, see 49 CFR 173.315(i)(9) and (10) and CSA B620 [3, 24]. Details of PRD requirements are contained in CGA S-1.2 [36].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.8.3 Filling limits

DOT regulations prohibit filling cargo tanks in excess of 95% of their volumetric capacity, which is typically determined during the filling operation by using fixed-length internal dip tubes or by weighing. Depending upon the temperature of the carbon dioxide being loaded, it may be necessary to fill to a lower percentage level to prevent cargo tanks from becoming liquid full before reaching the start-to-discharge pressure of the PRD, see 49 CFR 173.315 and CSA B620 [3, 24]. A relationship of volume to temperature in containers is shown in Table 5 and Figure 10.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.8.4 Retesting

Cargo tanks in carbon dioxide service shall be subjected to an internal inspection and a hydrostatic or pneumatic pressure test by a Registered Inspector at least once every 5 years. External visual inspection is required annually. The retest pressure for a specification MC-330 and TC/MC-331 cargo tank shall be a minimum of 1.5 times the design pressure. A written report of the retest should be retained in the vehicle file for at least 5 years. The month and year of the last test shall be durably and legibly marked on the cargo tank jacket in letters at least 1.25 in (32 mm) high near the metal certification plate, see 49 CFR 180.407 and CSA B620 [3, 24].

MC-330 and TC/MC-331 cargo tanks in carbon dioxide service shall also be subjected to an annual leakage test. The month and year of the test shall be durably and legibly marked on the cargo tank jacket in letters at least 1.25 in (32 mm) high near the metal certification plate, see 49 CFR 180.407(h) and CSA B620 [3, 24].

A cargo tank that has been out of service for a period of 1 year or more shall be retested before being returned to service, see 49 CFR 180.407(b)(3) and CSA B620 [3, 24].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.9 Bulk liquid carbon dioxide storage containers

7.9.1 General

Containers shall be designed, constructed, and tested in accordance with the requirements of the ASME Code, Section VIII, Division 1, or any other national/international codes accepted by the Authorities in the specific countries in Asia current at the time the vessel is constructed, see Figure 20 [1].

Containers shall be designed and constructed to minimize the risk of overfilling and shall never be allowed to become completely liquid full, see Table 5.

Containers shall be adequately insulated and may be equipped with refrigerating and vaporizing systems to maintain the pressure within the design pressure and temperature limitations. See Figure 21 for a typical horizontal piping schematic and Figure 22 for a typical vertical piping schematic for carbon dioxide storage systems.

Carbon dioxide storage quantities greater than 10 000 lb (4536 kg) are covered in 40 CFR, Part 370, and by Title III of the *Superfund Amendments and Reauthorization Act* (SARA), Section 312, Tier II Hazardous Chemical Inventory Report requirements [37, 38]. It is the responsibility of the user to file the appropriate government reports by March 1 of each calendar year. Tier II reports are typically sent to the appropriate State Emergency Response Commission (SERC), the appropriate Local Emergency Planning Committee (LEPC), and the local fire department.

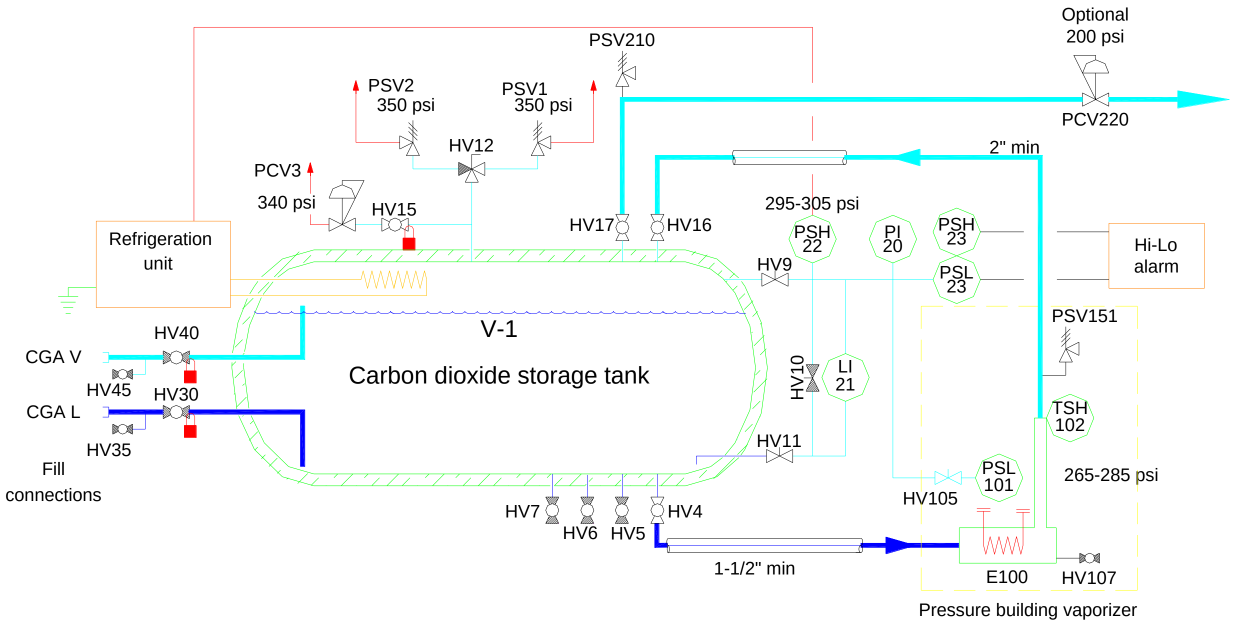
Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

Figure 20—Bulk liquid carbon dioxide container

7.9.2 Connections

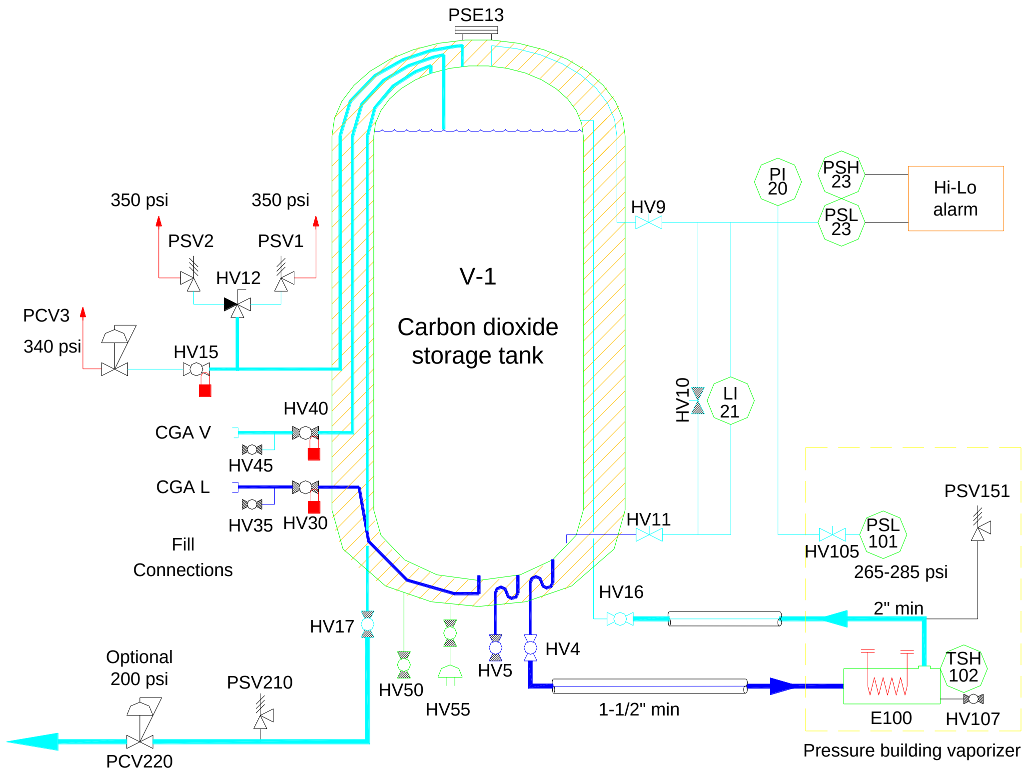
Bulk liquid carbon dioxide container connection standards in various sizes have been adopted by CGA and recognized as U.S. and Canadian standards. Connections for insulated carbon dioxide containers are defined in CGA V-6, *Standard Bulk Refrigerated Liquid Transfer Connections* [39].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.



CGA L	Liquid fill connection	HV40	Vapor balance fill valve
CGA V	Vapor balance fill connection	HV45	Vapor balance fill blow-down valve
E100	Pressure build (PB) vaporizer	HV105	PB vaporizer sensor valve
HV4	PB vaporizer liquid valve	HV107	PB vaporizer blow-down valve
HV5	Liquid process valve	LI21	Liquid level indicator
HV6	Liquid process valve	PCV3	Secondary pressure relief device
HV7	Liquid process valve	PCV220	Back pressure control valve
HV9	Level gauge low pressure valve	PI20	Pressure indicator
HV10	Level gauge equalization valve	PSH22	Refrigeration on/off pressure switch
HV11	Level gauge high pressure valve	PSH23, PSL23	Hi/low alarm pressure switch
HV12	Safety relief diverter valve	PSL101	PB vaporizer on/off pressure switch
HV15	Back pressure control device valve	PSV1, PSV2	Primary pressure relief device
HV16	PB vaporizer vapor valve	PSV151	PB vaporizer pressure relief device
HV17	Vapor process valve	PSV210	Process pressure relief valve
HV30	Liquid fill valve	TSH102	PB vaporizer overheat temperature switch
HV35	Liquid fill blow-down valve	V1	Bulk liquid carbon dioxide storage container
NOTE—Not all of the above components are present on every container.			

Figure 21—Typical piping schematic for horizontal polyurethane insulated carbon dioxide storage system



NOTE—Schematic representation only; exit points through outer jackets may vary by tank design and manufacturer.

CGA L	Liquid fill connection	HV50	Evacuation valve
CGA V	Vapor balance fill connection	HV55	Vacuum thermocouple valve
E100	Pressure build (PB) vaporizer	HV105	PB vaporizer sensor valve
HV4	PB vaporizer liquid valve	HV107	PB vaporizer blow-down valve
HV5	Liquid process valve	LI21	Liquid level indicator
HV9	Level gauge low pressure valve	PCV3	Secondary pressure relief device
HV10	Level gauge equalization valve	PCV220	Back pressure control valve
HV11	Level gauge high pressure valve	PI20	Pressure indicator
HV12	Safety relief diverter valve	PSE13	Relief device – outer vessel lift plate
HV15	Back pressure control device valve	PSH23, PSL23	Hi/low alarm pressure switch
HV16	PB vaporizer vapor valve	PSL101	PB vaporizer on/off pressure switch
HV17	Vapor process valve	PSV1, PSV2	Primary pressure relief device
HV30	Liquid fill valve	PSV151	PB vaporizer pressure relief device
HV35	Liquid fill blow-down valve	PSV210	Process pressure relief valve
HV40	Vapor balance fill valve	TSH102	PB vaporizer overheat temperature switch
HV45	Vapor balance fill blow-down valve	V1	Bulk liquid carbon dioxide storage container
NOTE—Not all of the listed components are present on every container.			

Figure 22—Typical piping schematic for vertical vacuum-insulated carbon dioxide storage system

7.9.3 Pressure relief devices

Containers used for liquid carbon dioxide service, regardless of size, shall be equipped with properly sized PRDs compatible with carbon dioxide. While the sizing of the PRD assumes vapor flow, it is recommended that all PRD materials, including seals and soft goods, be suitable for exposure to liquid carbon dioxide. ASME PRDs shall be pop action valves; modulating ASME PRD valves shall not be used.

See the ASME Code and CGA S-1.3, *Pressure Relief Device Standards–Part 3–Stationary Storage Containers for Compressed Gases*, for the more detailed requirements on the topics covered in this section [1, 40]. The information in this section is for normal situations, if the ASME Code or CGA S-1.3 allows alternatives; they can be applied based on the results of an engineered analysis [1, 40].

CGA S-1.3 requires primary and secondary systems for handling operational emergencies and exposure to fire [40]. Both the primary and secondary systems shall be active at the same time. Traditionally for carbon dioxide containers, the primary system has been either a single ASME PRD or an assembly of diverter valve and dual ASME PRDs. The secondary system has traditionally been a non-ASME pressure control valve (also called a back pressure regulator or bleeder valve) set 20 psi (138 kPa) below the primary PRD set pressure, which vents to atmosphere.

The primary system is designed to meet the requirements of the ASME Code [1]. The secondary system is not required to meet the ASME Code, but it is a requirement of CGA S-1.3 [1, 40]. The secondary system is purposely set at a lower pressure than the primary system to handle operational upsets such as a malfunction of a refrigeration unit without opening the primary system. When the secondary system opens, the noise and vapor from its exhaust can also serve as an added alarm that the storage unit is in need of service. If non-ASME PRDs are used as part of the secondary system, their capacity cannot be included in meeting the ASME Code requirements [1].

The primary PRD shall have access to the top of the container vapor space. The secondary PRD shall have access to the vapor space at a point as high as practical. Their inlet piping should not pass through the liquid phase of the container. This prevents the formation of water ice in the PRD. The PRDs shall discharge into a well-ventilated area to prevent asphyxiation. Carbon dioxide is 1.5 times heavier than air and accumulates in low or poorly ventilated areas. The PRD and its discharge piping shall be designed and installed so it cannot accumulate moisture or foreign material that would restrict its proper operation. The outlet(s) of the PRD devices shall be arranged to prevent impingement of escaping gas or liquid on the container, jacket, control devices, structural parts or personnel. PRD discharge piping shall be configured to prevent the loosening of the PRD upon activation.

A rupture disk-type PRD is not recommended but may be used. Failure of a rupture disk completely depressurizes the container, causing the formation of dry ice at –109.3 °F (–78.5 °C). A return to service requires the removal of the dry ice or repressurization of the container using an approved procedure, see CGA G-6.7 [9].The type of outer jacket on the insulation system can have a significant effect on the size of the PRDs. The outer jacket of a vacuum-insulated container can lessen the effect of fire exposure and make an operational emergency the governing case for PRD sizing. The outer jacket of a foam-insulated container can make the fire exposure condition the governing case, instead of the operational emergency. All conditions should be examined.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.9.3.1 Primary pressure relief device system

While a single spring operated PRD can be used, it is recommended that either dual PRDs with a properly sized and configured three-way selector valve or a single pilot operated PRD with an external field test connection be used. Using one of the two recommended configurations allows for periodic maintenance and valve testing as required in CGA S-1.3 without depressurizing the container and removing it from service [40]. The PRD shall be clearly marked to show the pressure at which it is set to operate and its flow capacity. It shall have a means of sealing the set point adjustment. It shall be located and arranged as much as practical to prevent tampering and damage. The primary system PRD(s) shall be ASME certified.

The ASME Code requires the PRD to be sized to handle operational emergencies and exposure to fire or other source of external heat [1]. The first step in sizing the PRD is to develop a list of the potential operational emergencies as well as the possibility they will occur simultaneously. Operational emergencies are generally caused by equipment that fails to shut off or turn on at its proper set point. The following conditions shall be included in the review [40, 41, 42, 43]:

- pumps and vaporizers that fail to shut off;
- inoperative refrigeration systems;

- valves from other systems that fail to close or open; and
- overfilling at refill time, etc.

The factors to include in the analysis of exposure to fire or other sources of external heat include the type of insulation, the potential for exposure to fire, etc. [40, 42, 43]. The likelihood and severity of a container's exposure to fire can have a large effect on the size of the PRD(s). When installation factors reduce the likelihood and severity of fire to which a container can be exposed, CGA S-1.3 allows two different PRD capacity factors (1.0 and 0.3) to be used [40]. Per the ASME Code, it is the user's responsibility to ensure that properly sized PRDs are installed before tank operation [1].

The PRD(s) shall be sized so the pressure in the container does not exceed 110% of the MAWP for operation emergencies and 121% of the container MAWP for fire conditions [40]. The sizing of the PRD shall include the effect of the pressure drop in the piping, fittings, diverter valves, etc., between the container and the PRD. The ASME Code recommends a maximum pressure drop of 3% of the PRD set pressure in the inlet piping to the PRD; however the 3% can be exceeded based on the results of an engineered analysis [1, 40]. The engineered analysis shall consider the effects of the pressure drop on the PRD capacity and operational aspects such as valve chatter [42, 43]. Consult the ASME Code, Appendix M for the recommended practices on inlet and discharge piping for PRDs [1].

The length of PRD discharge piping shall be kept to a minimum. Any backpressure developed in the discharge piping shall not reduce the capacity of the PRD below the required level. Consult with the manufacturer of the PRD for the acceptable backpressure limits. The design of discharge piping shall prevent accumulation of water, ice, and debris that can obstruct proper operation.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.9.3.2 Secondary pressure relief device system

CGA S-1.3 requires a secondary PRD system, but allows three options for that system [40].

Option one is a pressure control valve set no higher than 97% of the set point of the primary PRD. The flow for this pressure control valve shall be sized to handle operational emergencies, except fire exposure. This valve shall have a minimum flow of 5000 scfh (142 m^3/hr) at a flow rating pressure no greater than the lowest set point of the primary relief system. This pressure control valve is not required to be ASME certified.

Option two is an additional active ASME certified PRD(s) sized to handle operational emergencies, except fire exposure.

Option three is a carbon dioxide container with a capacity of 1000 lb or less (mini-bulk) may be equipped with safety relief devices as follows:

- A primary pressure relief valve with a set pressure equal to the MAWP of the container that meets the minimum flow capacity requirements for operational emergencies (including fire) specified in CGA S-1.3 [40];
- A secondary pressure relief valve with a set pressure no higher than 150% of the MAWP of the container that also meets the minimum flow capacity requirements for operational emergencies (including fire) specified in CGA S-1.3 [40]; and
- Pressure control valve or bleeder valve set below MAWP is not required in this configuration.

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

7.9.4 Additional installation considerations

Most carbon dioxide containers are designed for locations that are suitably isolated from possible engulfment in a fire and for other locations, relief valve sizing shall be reassessed [40].

For indoor and courtyard installations, the following are required:

- All PRDs shall be piped externally to a safe location; and
- Container fill connections as well as level and pressure gauges shall be piped to an outdoor location readily accessible to the person responsible for filling the container with carbon dioxide in compliance with 49 CFR 177.834 (3) [3]. For more information on courtyards, see CGA P-41 [13].

Monitoring carbon dioxide concentrations is recommended for all indoor installations.

For additional installation considerations, see NFPA 55, *Compressed Gases and Cryogenic Fluids Code* [44].

7.9.5 Refrigeration system

A mechanical refrigeration system may be used on a liquid carbon dioxide storage container to maintain the desired operating pressure during periods of low usage or increased heat input.

The refrigeration unit removes heat from the contents by condensing carbon dioxide vapor, which results in a corresponding decline in pressure. The refrigeration evaporator coil is installed in the vapor space of the container. The refrigeration system automatically operates to maintain a preset maximum pressure, typically 290 psi to 310 psi (2000 kPa to 2140 kPa). Failure of the refrigeration system can lead to a gradual loss of carbon dioxide vapor through the pressure relief system.

The refrigeration system is designed and sized based on the normal heat entry into the container as well as any extra heat load due to the process being used. Examples of other heat loads are a circulating loop or a cylinder filling pump returning liquid to the container.

7.9.6 Pressure-building vaporizer system

A pressure-building vaporizing system may be required to maintain the desired operating pressure during periods of vapor usage or high liquid withdrawal. See Figure 23. A cooling effect takes place as product is withdrawn from the container resulting in a decrease of pressure and temperature.

The pressure-building vaporizer system is designed to prevent the pressure in the container from dropping below a preset value. A small portion of the liquid is vaporized and returned to the vapor space of the container.

The vaporizer should be sized for the expected vapor withdrawal rate. Typical electrically operated vaporizers range in capacities from 9 kW to 56 kW. Larger capacities are available using steam or hot water as the heat source. Electrically operated vaporizers shall be equipped with over-temperature shutdown device(s) to prevent damage if the vaporizer operates while it is empty of liquid or there is a control failure.

The vaporizer system operates at preset pressures, typically 245 psi to 255 psi (1690 kPa to 1760 kPa), to maintain a preset minimum pressure.

***CAUTION**: Failure of the vaporizer system can cause the container temperature to drop below the minimum design metal temperature. Continued product withdrawal after such a failure can cause the contents of the container to convert to dry ice. For further information, see CGA G-6.7* [9].

7.9.7 Direct-to-process vaporizer system

Direct-to-process vaporizers (sometimes referred to as in-line vaporizers) are designed to vaporize liquid carbon dioxide flowing directly from the container to the user application point. These vaporizers are typically used where a large volume of carbon dioxide vapor is required, see Figures 24 and 25.

Frequently used heat sources include steam, hot water, and electrically heated aluminum castings.

Direct-to-process vaporizers should include a low temperature shutoff system to prevent the flow of liquid carbon dioxide to the process in case there is a malfunction of the vaporizer.

A pressure-building vaporizer may be required in addition to the direct-to-process vaporizer when a large volume of liquid is being withdrawn from the container, see Figure 23.

Figure 23—Pressure-build vaporizer

Figure 24—Direct-to-process electric vaporizer

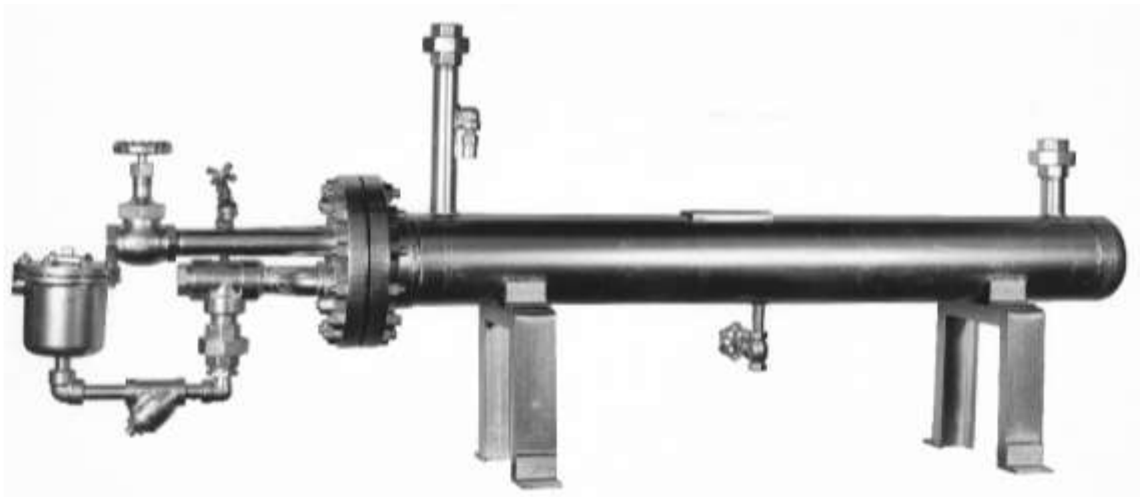


Figure 25—Direct-to-process steam vaporizer

7.10 Solid carbon dioxide (dry ice)

7.10.1 General

Dry ice should be handled in a well-ventilated area and, if possible, stored in a cool area to minimize heat transfer and sublimation.

Dry ice should not be stored in closed rooms because one pound of dry ice will sublime to form 8.7 ft^3 (246 L) of carbon dioxide vapor, see Table 1.

See CGA G-6.9 for more information [6].

7.10.2 Storage boxes

Storage boxes for dry ice are well insulated on the bottom and sides with either an open or closed top. If the top can be tightly closed, the box shall be designed to prevent pressure buildup due to sublimation. Open-top boxes are usually covered with an insulating blanket fitted tightly enough at the edges to eliminate the intrusion of air while still allowing the escape of carbon dioxide vapor. Proper storage and shielding from moisture in the air minimizes the accumulation of frost. Dry ice blocks may be stored with paper or plastic spacers to prevent the blocks from sticking together.

7.10.3 Personal protective equipment

Workers who routinely work with or cut dry ice should be equipped with the following PPE:

- protective gloves;
- safety glasses with side-shield protection;
- safety footwear;
- long-sleeved shirt; and
- long pants with cuffless bottoms (pant legs shall be worn outside of the boots).

7.10.4 Handling and use precautions

Personnel should be trained in the proper handling and use of dry ice. Refer to CGA P-61, *Ergonomic Guidelines for the Industrial and Medical Gas Industry*, for further information on handling dry ice [45]. They should also be made aware of the hazards involved when approved procedures are bypassed, altered, or ignored. For additional information, see CGA P-1 and CGA P-65 [34, 35].

The following are guidelines for using dry ice:

- Never handle dry ice with bare hands. Always use protective gloves;
- Handle dry ice carefully. Severe foot injury can occur if block product or a container is dropped without the use of safety footwear;
- Use tongs to handle blocks;
- Proper lifting techniques should be used to prevent back injuries;
- Dry ice should be in the form and size in which it is intended to be used;
- Avoid transporting dry ice in the cab of a truck or the passenger compartment of a car. If this is not possible, small quantities of dry ice should be in an insulated container (i.e., cooler) and adequate outside ventilation shall be maintained. Travel with open windows to ensure constant and adequate ventilation to prevent excessive exposure of carbon dioxide vapors to the occupants. Dry ice in a closed passenger vehicle can result in the accumulation of dangerous concentrations of carbon dioxide vapor; therefore, dry ice should not be left in a closed, parked passenger vehicle. Dry ice can be safely transported in closed cargo areas in trucks without special ventilation provided that passengers are restricted to the truck cabs. Special requirements are applicable when dry ice is transported by water or air (see 49 CFR 173.217 and *TDG Regulations* [3, 21]);
- Dry ice should not be used for direct cooling of beverages;
- If dry ice is ingested, it can cause severe internal burns;
- Never store dry ice in sealed (air-tight) containers, as it can result in a rupture or explosion of the container; and
- Be aware that subliming dry ice can attract insects.

7.10.5 Disposal of unused dry ice

Unused dry ice shall be disposed of properly. Improper disposal can pose several safety and environmental hazards such as:

- potential injuries due to misuse, especially by children;
- detrimental to the environment or wildlife;
- forced cleanup by untrained individuals;
- damage to property from the extreme cold temperature; and
- slippery surfaces resulting from the cold temperature.

The preferred method for disposal is to allow the dry ice to sublime or evaporate to the atmosphere in a well-ventilated area where no buildup of carbon dioxide vapor can occur. Such areas should be secured to ensure controlled access by trained and authorized personnel only and not in areas accessible to the general public.

Do not dispose of dry ice:

- in sewers, sinks, or toilets;
- in bodies of water;
- in garbage receptacles;
- on ground that is located above underground utilities; or
- in unprotected boxes.

7.11 Transfer hoses

Hoses used in the transfer of bulk liquid and gaseous carbon dioxide between containers, cargo tanks, and tank cars are designed specifically for the transfer of liquid carbon dioxide. These hoses shall meet or exceed the requirements of CGA G-6.6, *Standard for Carbon Dioxide Bulk Transfer Hoses* [46]. See Figures 26 and 27. Hoses of this type are to be inspected and requalified for continued service once every 6 months with a recommended maximum service life of 4 years in accordance with CGA P-7, *Standard for Requalification of Cargo Tank Hose Used in the Transfer of Carbon Dioxide Refrigerated Liquid* [47]. Hoses used in the transfer of carbon dioxide should be restrained at the ends to prevent whipping in the event of a hose connection failure.

Hoses used in the transfer of liquid carbon dioxide between cargo tanks and small stationary insulated carbon dioxide containers (mini-bulk) are typically nonmetallic hoses designed to meet or exceed the requirements of CGA G-6.5 [11].

Hoses used in the transfer of liquid carbon dioxide into DOT-4L and TC-4LM specification liquid cylinders shall be designed with a MAWP of at least 1.25 times the MAWP of the liquid cylinder being filled and a minimum design temperature of –65 °F (–53.9 °C). The hose material shall be compatible with the transfer of liquid carbon dioxide. See Figure 26.

Hoses used in the transfer of carbon dioxide into uninsulated cylinders are recommended to be in accordance with CGA E-9, *Standard for ETFE-Lined and PTFE-Lined Flexible Hoses for Compressed Gas Service* [48].

Note: Where available in Asia, check and ensure compliance with the applicable local country regulatory requirements also.

Figure 26—Insulated carbon dioxde cylinder fill hose

Figure 27—Bulk liquid transfer hose

8 Carbon dioxide applications

The following are examples of carbon dioxide applications:

- expendable refrigerants:
    - chilling
    - cryogenic grinding
    - dry ice blast cleaning
    - environmental testing
    - food freezing
    - plastic blow mold chilling
    - rubber deflashing
    - shrink fitting
    - transportation of chilled and frozen products;
- closed loop refrigerants:
    - automotive air conditioning systems
    - cascade refrigeration systems
    - supermarket display cases
    - water chillers (drinking fountains);
- carbonation:
    - beer and wine
    - beverage dispensing
    - soft drinks;
- chemical reactant:

    - foundry cores
    - manufacturing of carbonates
    - methanol
    - urea;
- pressurizing/solvent medium:
    - aerosol propellant
    - blowing agents
    - enhanced oil recovery;
- pH control:
    - potable water treatment
    - swimming pool and caustic waste neutralization;
- fire suppression;
- controlled atmospheres:
    - inerting and blanketing
    - greenhouse atmospheric enrichment
    - shielding gas
    - welding; and
- other:
    - dry cleaning;
    - grain fumigation
    - medical respiratory therapy mixtures
    - special effects
    - supercritical extraction.

9 References

Unless otherwise specified, the latest edition shall apply.

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