First Revision No. 4-NFPA 12-2019 [Chapter 2]

Chapter 2 Referenced Publications

2.1 General.

The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications.

National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 4, *Standard for Integrated Fire Protection and Life Safety System Testing,* ~~2018~~ 2021 edition.

NFPA 70®, National Electrical Code®, ~~2017~~ 2020 edition.

NFPA 72®, National Fire Alarm and Signaling Code®, ~~2016~~ 2019 edition.

2.3 Other Publications.

2.3.1 ANSI Publications.

American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI Z535.2, *Standard for Environmental and Facility Safety Signs*, 2011, reaffirmed 2017 .

2.3.2 API Publications.

American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070.

API-ASME *Code for Unfired Pressure Vessels for Petroleum Liquids and Gases*, Pre–July 1, 1961.

2.3.3 ASME Publications.

American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

ASME B31.1, *Power Piping ~~Code~~* , ~~2016~~ 2018 .

2.3.4 ASTM Publications.

ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM A53/A53M, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*, ~~2012~~ 2018 .

ASTM A106/A106M, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*, ~~2015~~ 2018 .

ASTM A120, *Specification for Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless for Ordinary Uses*, 1984 (withdrawn 1987).

ASTM A182/A182M, *Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*, ~~2016~~ 2018 .

2.3.5 CGA Publications.

Compressed Gas Association, 14501 George Carter Way, Suite 103, Chantilly, VA 20151-2923.

CGA G-6.2, *Commodity Specification for Carbon Dioxide*, ~~2011~~ 2013 .

2.3.6 CSA Group Publications.

CSA Group, 178 Rexdale Blvd., Toronto, ON M9W 1R3, Canada.

CSA C22.1, *Canadian Electrical Code*, ~~2015~~ 2018 .

2.3.7 IEEE Publications.

IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997.

ANSI/IEEE C2, *National Electrical Safety Code*, 2017.

2.3.8 U.S. Government Publications.

U.S. Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*, U.S. Bureau of Mines Bulletin 503,1952.

Title 46, Code of Federal Regulations, Part 58.20.

Title 46, Code of Federal Regulations, Part 72.

Title 49, Code of Federal Regulations, Parts 171–190 (Department of Transportation).

Zabetakis, Michael G., *Flammability Characteristics of Combustible Gases and Vapors*, U.S. Bureau of Mines Bulletin 627, 1965.

2.3.9 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA 1, *Fire Code,* 2018 edition.

NFPA 122, *Standard for Fire Prevention and Control in Metal/Nonmetal Mining and Metal Mineral Processing Facilities,* 2015 edition.

NFPA 820, *Standard for Fire Protection in Wastewater Treatment and Collection Facilities,* 2016 edition.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 16:58:26 EDT 2019

Committee Statement

Committee Statement: Referenced updated editions.

Response Message: FR-4-NFPA 12-2019

Public Input No. 2-NFPA 12-2018 [Chapter 2]

First Revision No. 13-NFPA 12-2019 [Section No. 3.3.6]

3.3.6 Normally Occupied Enclosure or Space.

An enclosure or space where one or more persons are present under normal ~~circumstances~~ conditions .

Submitter Information Verification

Committee: GFE-AAA
Submittal Date: Tue Apr 30 18:46:40 EDT 2019

Committee Statement

Committee Statement: The definition is revised to match the one used in NFPA 2001.
Response Message: FR-13-NFPA 12-2019

First Revision No. 1-NFPA 12-2019 [Section No. 4.4.3.3.4]

4.4.3.3.4* Full Discharge Test.

4.4.3.3.4.1

A full discharge test shall be performed on ~~all systems~~ each installed system .

4.4.3.3.4.2

Where multiple hazards are protected from a common supply, a full discharge test shall be performed for each hazard.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 16:11:11 EDT 2019

Committee Statement

Committee Statement: This revision clarifies that the full discharge test must be performed for each installed system to eliminate confusion that identical systems do not require testing.

Response Message: FR-1-NFPA 12-2019

First Revision No. 2-NFPA 12-2019 [Section No. 4.5.5.2]

~~**4.5.5.2**~~

~~Supervision of automatic systems shall be provided, and the lockout required by 4.3.3.4 shall be supervised for both automatic and manual systems unless specifically waived by the authority having jurisdiction.~~

Submitter Information Verification

Committee: GFE-AAA
Submittal Date: Thu Apr 25 16:23:02 EDT 2019

Committee Statement

Committee Statement: The deleted sentence was redundant to 4.5.5.1.
Response Message: FR-2-NFPA 12-2019

First Revision No. 3-NFPA 12-2019 [Section No. 5.2.3]

5.2.3* Types of Fires.

Fires that can be extinguished by total flooding methods shall be divided into the following two categories:

(1) Surface fires involving flammable liquids, gases, and solids

(2) Deep-seated fires involving solids subject to smoldering

5.2.3.1* Surface Fires.

~~Carbon dioxide~~ For surface fires, carbon dioxide shall be quickly introduced into the enclosure in a quantity to overcome leakage and provide an extinguishing concentration for the ~~particular~~ specific materials involved ~~for surface fires that are subject to prompt extinguishment~~ .

5.2.3.2* Deep-Seated Fires.

For deep-seated fires, the ~~required extinguishing~~ design concentration shall be maintained for a period of time to allow the smoldering to be extinguished and the material to cool to a point at which re-ignition will not occur when the inert atmosphere is dissipated.

A.5.2.3.2

In any event, it is necessary to inspect the hazard immediately after a deep-seated fire to make certain that extinguishment is complete and to remove any material involved in the fire.

Where there is an explosive atmosphere of flammable vapors or combustible dust within an enclosure, discharge of liquid CO_2 could produce a static spark thereby causing an explosion. The danger of explosion can be mitigated by injecting CO_2 vapor into the hazard to build an inert atmosphere. The CO_2 vapor injection should be done gently to minimize turbulence that could raise and suspend combustible dust within the enclosure. An example of such a hazard is a coal storage silo. *(NOTE: Fire protection and inerting of coal silos is beyond the scope of this standard.)* See A.4.2.1 .

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 16:40:37 EDT 2019

Committee Statement

Committee Statement: Section 5.2.3.2 is revised to clarify that it is the design concentration that must be maintained, not the minimum extinguishing concentration.

The additional annex material gives advice on the application of CO2 to coal silos and similar applications, which are outside the scope of this document.

Response Message: FR-3-NFPA 12-2019

Public Input No. 1-NFPA 12-2018 [Global Input]

Public Input No. 11-NFPA 12-2018 [Section No. A.5.5.2]

First Revision No. 6-NFPA 12-2019 [Section No. 5.4.4.2]

5.4.4.2

If leakage is appreciable, consideration shall be given to an extended discharge system~~ as covered in~~ ~~5.5.3~~ . *(See ~~also~~ A.5.5.2 ~~5.2.1.3~~ .)*

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 17:54:38 EDT 2019

Committee Statement

Committee Statement: This revision eliminates confusion with regard to extended discharge requirements for leaky systems that are not "enclosed rotation electrical equipment". The reference to the annex is updated to a more appropriate section.

Response Message: FR-6-NFPA 12-2019

Public Input No. 10-NFPA 12-2018 [Section No. 5.4.4.2]

First Revision No. 7-NFPA 12-2019 [Section No. 5.5.3]

5.5.3* Enclosed Rotating Electrical Equipment.

For enclosed rotating electrical equipment, a minimum concentration of 30 percent shall be maintained for the deceleration period, but not less than 20 minutes.

A.5.5.3

Protection of stationary combustion engines and gas turbines is addressed in NFPA 37 .

For enclosed recirculating-type electrical equipment, the initial discharge quantity should not be less than 1 lb (0.45 kg) of gas for each 10 ft^3 (0.28 m^3) of enclosed volume up to 2000 ft^3 (56.6 m^3). For larger volumes, 1 lb (0.45 kg) of gas for each 12 ft^3 (0.34 m^3) or a minimum of 200 lb (90.8 kg) should be used. Table A.5.5.3(a) and Table A.5.5.3(b) can be used as a guide to estimate the quantity of gas needed for the extended discharge to maintain a minimum concentration of 30 percent for the deceleration time. The quantity is based on the internal volume of the machine and the deceleration time, assuming average leakage. For dampered, non-recirculating-type machines, add 35 percent to the indicated quantities in Table A.5.5.3(a) and Table A.5.5.3(b) for extended discharge protection.

Table A.5.5.3(a) Extended Discharge Protection for Enclosed Recirculating Rotating Electrical Equipment (Cubic Feet Protected for Deceleration Time)

	Time (minutes)							
lb CO_2	5	10	15	20	30	40	50	60
100	1,200	1,000	800	600	500	400	300	200
150	1,800	1,500	1,200	1,000	750	600	500	400
200	2,400	1,950	1,600	1,300	1,000	850	650	500
250	3,300	2,450	2,000	1,650	1,300	1,050	800	600
300	4,600	3,100	2,400	2,000	1,650	1,300	1,000	700
350	6,100	4,100	3,000	2,500	2,000	1,650	1,200	900
400	7,700	5,400	3,800	3,150	2,500	2,000	1,600	1,200
450	9,250	6,800	4,900	4,000	3,100	2,600	2,100	1,600
500	10,800	8,100	6,100	5,000	3,900	3,300	2,800	2,200
550	12,300	9,500	7,400	6,100	4,900	4,200	3,600	3,100
600	13,900	10,900	8,600	7,200	6,000	5,200	4,500	3,900
650	15,400	12,300	9,850	8,300	7,050	6,200	5,500	4,800
700	16,900	13,600	11,100	9,400	8,100	7,200	6,400	5,600
750	18,500	15,000	12,350	10,500	9,150	8,200	7,300	6,500
800	20,000	16,400	13,600	11,600	10,200	9,200	8,200	7,300
850	21,500	17,750	14,850	12,700	11,300	10,200	9,100	8,100
900	23,000	19,100	16,100	13,800	12,350	11,200	10,050	9,000
950	24,600	20,500	17,350	14,900	13,400	12,200	11,000	9,800
1,000	26,100	21,900	18,600	16,000	14,500	13,200	11,900	10,700
1,050	27,600	23,300	19,900	17,100	15,600	14,200	12,850	11,500
1,100	29,100	24,600	21,050	18,200	16,600	15,200	13,750	12,400
1,150	30,600	26,000	22,300	19,300	17,700	16,200	14,700	13,200
1,200	32,200	27,300	23,550	20,400	18,800	17,200	15,600	14,100
1,250	33,700	28,700	24,800	21,500	19,850	18,200	16,500	14,900
1,300	35,300	30,100	26,050	22,650	20,900	19,200	17,450	15,800
1,350	36,800	31,400	27,300	23,750	22,000	20,200	18,400	16,650
1,400	38,400	32,800	28,550	24,900	23,100	21,200	19,350	17,500
1,450	39,900	34,200	29,800	26,000	24,200	22,200	20,300	18,350
1,500	41,400	35,600	31,050	27,100	25,250	23,200	21,200	19,200

Table A.5.5.3(b) Extended Discharge for Enclosed Recirculating Rotating Electrical Equipment (Cubic Meters Protected for Deceleration Time) (SI Units)

	Time (minutes)							
kg CO_2	5	10	15	20	30	40	50	60
45.4	34.0	28.3	22.6	17.0	14.2	11.3	8.5	5.7
68.1	50.9	42.5	34.0	28.3	21.2	17.0	14.0	11.3
90.8	67.9	55.2	45.3	36.8	28.3	24.1	18.4	14.2
113.5	93.4	69.3	56.6	46.7	36.8	29.7	22.6	17.0
136.2	130.2	87.7	67.9	56.6	46.7	36.8	28.3	19.8
158.9	172.6	116.0	84.9	70.8	56.6	46.7	34.0	25.5
181.6	217.9	152.8	107.5	89.1	70.8	56.6	45.3	34.0
204.3	261.8	192.4	138.7	113.2	87.7	73.6	59.4	45.3
227.0	305.6	229.2	172.6	141.5	110.4	93.4	79.2	62.3
249.7	348.1	268.9	209.4	172.6	138.7	118.9	101.9	87.7
272.4	393.4	308.5	243.4	203.8	169.8	147.2	127.4	110.4
295.1	435.8	348.1	278.8	234.9	199.5	175.5	155.7	135.8
317.8	478.3	384.9	314.1	266.0	229.2	203.8	181.1	158.5
340.5	523.6	424.5	349.5	297.2	258.9	232.1	206.6	184.0
363.2	586.0	464.1	384.9	328.3	288.7	260.4	232.1	206.6
385.9	608.4	502.3	420.3	359.4	319.8	288.7	257.5	229.2
408.6	650.9	540.5	455.6	390.5	349.5	317.0	284.4	254.7

	Time (minutes)							
kg CO_2	5	10	15	20	30	40	50	60
431.3	696.2	580.2	491.0	421.7	379.2	345.3	311.3	277.3
454.0	738.6	619.8	526.4	452.8	410.4	373.6	336.8	302.8
476.7	781.1	659.4	563.2	483.9	441.5	401.9	363.7	325.5
499.4	823.5	696.2	595.7	515.1	469.8	430.2	389.1	350.9
522.1	866.0	735.8	631.1	546.2	500.9	458.5	416.0	373.6
544.8	911.3	772.6	666.5	577.3	532.0	486.8	441.5	399.0
567.5	953.7	812.2	701.8	609.4	561.8	515.1	467.0	421.7
590.2	999.0	851.8	737.2	641.0	591.5	543.4	493.8	447.1
612.9	1041.4	888.6	772.6	672.1	622.6	571.7	520.7	471.2
635.6	1086.7	928.2	808.0	704.7	653.7	600.0	547.6	495.3
658.3	1129.2	967.9	843.3	735.8	684.9	628.3	574.5	519.3
681.0	1171.6	1007.5	878.7	766.9	713.2	656.6	600.0	543.4

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri Apr 26 09:58:03 EDT 2019

Committee Statement

Committee Statement: This revision makes it clear that this section addresses electrical equipment and is not intended to address stationary combustion engines and gas turbines.

Response Message: FR-7-NFPA 12-2019

Public Input No. 8-NFPA 12-2018 [Section No. 5.5.3]

Public Input No. 9-NFPA 12-2018 [Section No. A.5.5.3]

First Revision No. 12-NFPA 12-2019 [Section No. A.4.4.3.3.4]

A.4.4.3.3.4

It is anticipated that full discharge tests will be waived by the authority having jurisdiction only under extremely unusual conditions. Factors such as extra cost and interruptions to production or business operations are not considered valid reasons for waiver of full discharge tests.

The full discharge test is intended to verify the full functionality of the system in accordance with 4.4.4. The test should verify the following:

(1) That all of the carbon dioxide cylinders open as intended. This can be verified by checking the liquid level gauge on a low-pressure supply or by weighing each cylinder of a high-pressure system. Measurements should be taken before and after discharge.

(2) That carbon dioxide flows through the pipe network and discharges from each nozzle as intended. This can be verified visually or by use of blow-off caps. Where piping is not normally under pressure, it is possibly not bubbletight. However, where a slow discharge is involved, or if under continual pressure, bubbletightness should be achieved.

(3) That the time delays, notification appliances, and system interlocks, such as damper closures and/or power shutdown, operate as intended.

(4) That the discharge performance meets or exceeds the minimum design criteria.

  (a) For total flooding systems, that a sufficient concentration of carbon dioxide is developed within the maximum time and is held for the intended duration. The carbon dioxide concentration can be verified by use of a gas analyzer or by another means acceptable to the authority having jurisdiction. The sample locations should be selected to show that the extinguishing concentration is achieved throughout the enclosure. The time to achieve the design concentration is measured from the time that the concentration measurement rises above zero to the time at which the benchmark concentration is indicated by the measuring device. If the response time of the instrument circuitry is known to cause a delay in the measurement of concentration, that delay can be considered in determining pass/fail criteria. Refer to 5.5.2.1 and 5.5.2.3 for the time requirements for total flooding systems.

  (b) For local application systems, that the duration of the liquid discharge meets the design requirements and that the discharge provides adequate coverage on or around the hazard. The discharge duration should be measured at the nozzles with a stopwatch. For local application systems, the watch should be started when all nozzles flow liquid and stopped when the discharge changes from liquid to gas at any nozzle. See 6.3.3 and A.6.3.3.2. Coverage on or around the hazard is visually observed. It is useful, but not required, to use video of the discharge to aid in determining if adequate CO_2 coverage is developed during the discharge test.

Prior to the test, personnel should be warned and removed from the area. The local fire department and any remote monitoring stations should also be notified that a test is being conducted. Following the test, the system should be recharged and reset. For more specific instructions, consult the system manufacturer's installation manual, which should outline the system acceptance test procedures.

Submitter Information Verification

Committee: GFE-AAA
Submittal Date: Fri Apr 26 13:06:59 EDT 2019

Committee Statement

Committee Statement: Paragraph (4) is revised to allow for differences in instrumentation.
Response Message: FR-12-NFPA 12-2019

Public Input No. 14-NFPA 12-2018 [Section No. 5.5.2.1]

First Revision No. 5-NFPA 12-2019 [Section No. A.4.6.1]

A.4.6.1

Not all of the carbon dioxide in the low-pressure container can be rapidly discharged. As the storage container empties, a quantity of cold carbon dioxide vapor remains in the container and pipe . The quantity of this residual vapor varies, depending on the physical configuration of the container and distribution network . ~~This residual vapor~~ In addition, liquid carbon dioxide can be temporarily trapped in the pipeline and might not be available for immediate discharge into other hazards served by the system. This residual carbon dioxide should be considered in determining the storage capacity.

Where the system provides an extended discharge, additional carbon dioxide could be required to maintain pressure in the supply over the discharge period.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 17:41:46 EDT 2019

Committee Statement

Committee Statement: This revision recognizes that distribution systems with large internal volumes could require additional carbon dioxide.

Additional guidance is provided for extended discharge systems to ensure that the calculated flow rates can be maintained for the design time.

Response Message: FR-5-NFPA 12-2019

Public Input No. 12-NFPA 12-2018 [Section No. 4.6.1 [Excluding any Sub-Sections]]

First Revision No. 8-NFPA 12-2019 [Section No. A.5.5.2]

A.5.5.2

The minimum design rates of application established are considered adequate for the usual surface or deep-seated fire. However, where the spread of fire can be faster than normal for the type of fire, or where high values or vital machinery or equipment are involved, rates higher than the minimums can, and in many cases should, be used. Where a hazard contains material that will produce both surface and deep-seated fires, the rate of application should be at least the minimum required for surface fires. Having selected a rate suitable to the hazard, the tables and information that follow should be used or such special engineering as is required should be carried out to obtain the proper combination of container releases, supply piping, and orifice sizes that will produce this desired rate.

The leakage rate from an enclosure in the absence of forced ventilation depends mainly on the difference in density between the atmosphere within the enclosure and the air surrounding the enclosure. The following equation can be used to calculate the rate of carbon dioxide loss, assuming that there is sufficient leakage in the upper part of the enclosure to allow free ingress of air:

~~$R = 60C\rho A\sqrt{\frac{2_g(\rho_1 - \rho_2)h}{\rho_1}}$~~

$$R = 60C\rho A\sqrt{\frac{2g(\rho_1 - \rho_2)h}{\rho_1}} \quad \textbf{[A.5.5.2]}$$

where:

R = rate of CO_2 [lb/min (kg/min)]

C = CO_2 concentration fraction

ρ = density of CO_2 vapor [lb/ft^3 (kg/m^3)]

A = area of opening [ft^2 (m^2) (flow coefficient included)]*

g = gravitational constant [32.2 ft/sec^2 (9.81 m/sec^2)]

$\rho 1$ = density of atmosphere [lb/ft^3 (kg/m^3)]

$\rho 2$ = density of surrounding air [lb/ft^3 (kg/m^3)]

h = static head between opening and top of enclosure [ft (m)]

*If there are openings in the walls only, the area of the wall openings can be divided by 2 for calculations because it is presumed that fresh air can enter through one-half of the openings and that protective gas will exit through the other half.

Figure E.1(b) can be used as a guide in estimating discharge rates for extended discharge systems. The curves were calculated using the preceding equation, assuming a temperature of 70°F (21°C) inside and outside the enclosure. In an actual system, the inside temperature will normally be reduced by the discharge, thus increasing the rate of loss. Because of the many variables involved, a test of the installed system could be needed to ensure proper performance.

Where leakage is appreciable, the design concentration should be obtained quickly and maintained for an extended period of time. Carbon dioxide provided for leakage compensation should be applied at a reduced rate. The extended rate of discharge should be sufficient to maintain the ~~minimum~~ design concentration.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri Apr 26 10:25:06 EDT 2019

Committee Statement

Committee Statement: Corrects equation A.5.5.2, which included the gravitational constant, g, as a subscript.

The last paragraph is revised to clarify that it is the design concentration that should be maintained, not the minimum extinguishing concentration.

Response Message: FR-8-NFPA 12-2019

Public Input No. 6-NFPA 12-2018 [Section No. A.5.5.2]

First Revision No. 9-NFPA 12-2019 [Section No. C.1]

C.1

Computing pipe sizes for carbon dioxide systems is complicated by the fact that the pressure drop is nonlinear with respect to the pipeline. Carbon dioxide leaves the storage vessel as a liquid at saturation pressure. As the pressure drops due to pipeline friction, the liquid boils and produces a mixture of liquid and vapor. Consequently, the volume of the flowing mixture increases and the velocity of flow must also increase. Thus, the pressure drop per unit length of pipe is greater near the end of the pipeline than it is at the beginning.

Pressure drop information for designing piping systems can best be obtained from curves of pressure versus equivalent length for various flow rates and pipe sizes. Such curves can be plotted using the theoretical equation given in 4.7.5.1. The *Y* and *Z* factors in the equation in that paragraph depend on storage pressure and line pressure. In the following equations, *Z* is a dimensionless ratio, and the *Y* factor has units of pressure times density and will therefore change the system of units. The *Y* and *Z* factors can be evaluated as follows:

$$Y = -\int_{P_1}^{P} \rho \, dP$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln \frac{\rho_1}{\rho} \qquad \textbf{[C.1a]}$$

where:

P = pressure at end of pipeline [psi (kPa)]

P_1 = storage pressure [psi (kPa)]

ρ = density at pressure P [lb/ft^3 (kg/m^3)]

ρ_1 = density at pressure P_1 [lb/ft^3 (kg/m^3)]

ln = natural logarithm

The storage pressure is an important factor in carbon dioxide flow. In low-pressure storage, the starting pressure in the storage vessel will recede to a lower level, depending on whether all or only part of the supply is discharged. Because of this, the average pressure during discharge will be about 285 psi (1965 kPa). The flow equation is based on absolute pressure; therefore, 300 psi (2068 kPa) is used for calculations involving low-pressure systems.

In high-pressure systems, the storage pressure depends on the ambient temperature. Normal ambient temperature is assumed to be 70°F (21°C). For this condition, the average pressure in the cylinder during discharge of the liquid portion will be about 750 psi (5171 kPa). This pressure has therefore been selected for calculations involving high-pressure systems.

Using the base pressures of 300 psi (2068 kPa) and 750 psi (5171 kPa), values have been determined for the *Y* and *Z* factors in the flow equation. These values are listed in Table C.1(a) and Table C.1(b).

Table C.1(a) Values of *Y* and *Z* for 300 psi Initial Storage Pressure

Pressure		*Y*									
(psi)	*Z*	0	1	2	3	4	5	6	7	8	9
300	0.000	0	0	0	0	0	0	0	0	0	0
290	0.135	596	540	483	426	367	308	248	187	126	63
280	0.264	1119	1070	1020	969	918	866	814	760	706	652
270	0.387	1580	1536	1492	1448	1402	1357	1310	1263	1216	1168
260	0.505	1989	1950	1911	1871	1831	1790	1749	1708	1666	1623
250	0.620	2352	2318	2283	2248	2212	2176	2139	2102	2065	2027
240	0.732	2677	2646	2615	2583	2552	2519	2487	2454	2420	2386
230	0.841	2968	2940	2912	2884	2855	2826	2797	2768	2738	2708
220	0.950	3228	3204	3179	3153	3128	3102	3075	3049	3022	2995
210	1.057	3462	3440	3418	3395	3372	3349	3325	3301	3277	3253
200	1.165	3673	3653	3632	3612	3591	3570	3549	3528	3506	3485
190	1.274	3861	3843	3825	3807	3788	3769	3750	3731	3712	3692
180	1.384	4030	4014	3998	3981	3965	3948	3931	3914	3896	3879
170	1.497	4181	4167	4152	4138	4123	4108	4093	4077	4062	4046
160	1.612	4316	4303	4291	4277	4264	4251	4237	4223	4210	4196
150	1.731	4436	4425	4413	4402	4390	4378	4366	4354	4341	4329

Table C.1(b) Values of *Y* and *Z* for 750 psi Initial Storage Pressure

Pressure		*Y*									
(psi)	*Z*	0	1	2	3	4	5	6	7	8	9
750	0.000	0	0	0	0	0	0	0	0	0	0
740	0.038	497	448	399	350	300	251	201	151	101	51
730	0.075	975	928	881	833	786	738	690	642	594	545
720	0.110	1436	1391	1345	1299	1254	1208	1161	1115	1068	1022
710	0.143	1882	1838	1794	1750	1706	1661	1616	1572	1527	1481
700	0.174	2314	2271	2229	2186	2143	2100	2057	2013	1970	1926
690	0.205	2733	2691	2650	2608	2567	2525	2483	2441	2399	2357
680	0.235	3139	3099	3059	3018	2978	2937	2897	2856	2815	2774
670	0.265	3533	3494	3455	3416	3377	3338	3298	3259	3219	3179
660	0.296	3916	3878	3840	3802	3764	3726	3688	3649	3611	3572
650	0.327	4286	4250	4213	4176	4139	4102	4065	4028	3991	3953

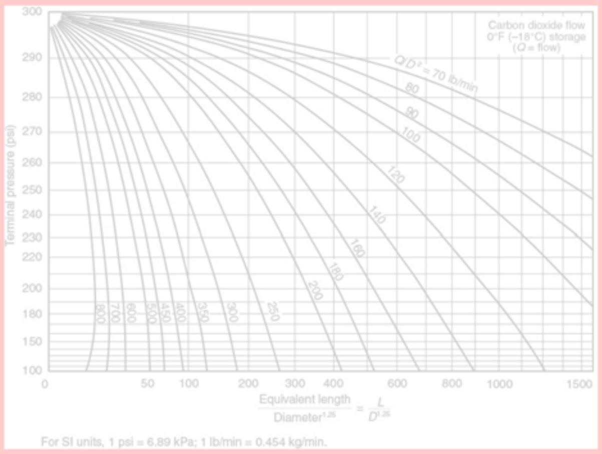
Pressure (psi)	*Z*	*Y*									
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
640	0.360	4645	4610	4575	4539	4503	4467	4431	4395	4359	4323
630	0.393	4993	4959	4924	4890	4855	4821	4786	4751	4716	4681
620	0.427	5329	5296	5263	5229	5196	5162	5129	5095	5061	5027
610	0.462	5653	5621	5589	5557	5525	5493	5460	5427	5395	5362
600	0.498	5967	5936	5905	5874	5843	5811	5780	5749	5717	5685
590	0.535	6268	6239	6209	6179	6149	6119	6089	6058	6028	5997
580	0.572	6560	6531	6502	6473	6444	6415	6386	6357	6328	6298
570	0.609	6840	6812	6785	6757	6729	6701	6673	6645	6616	6588
560	0.646	7110	7084	7057	7030	7003	6976	6949	6922	6895	6868
550	0.683	7371	7345	7320	7294	7268	7242	7216	7190	7163	7137
540	0.719	7622	7597	7572	7548	7523	7498	7472	7447	7422	7396
530	0.756	7864	7840	7816	7792	7768	7744	7720	7696	7671	7647
520	0.792	8098	8075	8052	8028	8005	7982	7958	7935	7911	7888
510	0.827	8323	8301	8278	8256	8234	8211	8189	8166	8143	8120
500	0.863	8540	8519	8497	8476	8454	8433	8411	8389	8367	8345
490	0.898	8750	8730	8709	8688	8667	8646	8625	8604	8583	8562
480	0.933	8953	8933	8913	8893	8873	8852	8832	8812	8791	8771
470	0.967	9149	9129	9110	9091	9071	9052	9032	9012	8993	8973
460	1.002	9338	9319	9301	9282	9263	9244	9225	9206	9187	9168
450	1.038	9520	9502	9484	9466	9448	9430	9412	9393	9375	9356
440	1.073	9697	9680	9662	9644	9627	9609	9592	9574	9556	9538
430	1.109	9866	9850	9833	9816	9799	9782	9765	9748	9731	9714
420	1.146	10030	10014	9998	9982	9966	9949	9933	9916	9900	9883
410	1.184	10188	10173	10157	10141	10126	10110	10094	10078	10062	10046
400	1.222	10340	10325	10310	10295	10280	10265	10250	10234	10219	10204
390	1.262	10486	10472	10458	10443	10429	10414	10399	10385	10370	10355
380	1.302	10627	10613	10599	10585	10571	10557	10543	10529	10515	10501
370	1.344	10762	10749	10735	10722	10708	10695	10681	10668	10654	10641
360	1.386	10891	10878	10866	10853	10840	10827	10814	10801	10788	10775
350	1.429	11015	11003	10991	10978	10966	10954	10941	10929	10916	10904
340	1.473	11134	11122	11110	11099	11087	11075	11063	11051	11039	11027
330	1.518	11247	11236	11225	11214	11202	11191	11180	11168	11157	11145
320	1.564	11356	11345	11334	11323	11313	11302	11291	11280	11269	11258
310	1.610	11459	11449	11439	11428	11418	11408	11398	11387	11377	11366
300	1.657	11558	11548	11539	11529	11519	11509	11499	11489	11479	11469

For practical application, it is desirable to plot curves for each pipe size that can be used. However, the flow equation can be rearranged as shown in the following equation:

$$\frac{L}{D^{1.25}} = \frac{3647Y}{\left(\frac{Q}{D^2}\right)^2} - 8.08Z \qquad \textbf{[C.1b]}$$

Thus, by plotting values of $L/D^{1.25}$ and Q/D^2, it is possible to use one family of curves for any pipe size. Figure C.1(a) gives flow information for 0°F (−18°C) storage temperature on this basis. Figure C.1(b) gives similar information for high-pressure storage at 70°F (21°C). For an inside pipe diameter of exactly 1 in., D^2 and $D^{1.25}$ reduce to unity and cancel out. For other pipe sizes, it is necessary to convert the flow rate and equivalent length by dividing or multiplying by these factors. Table C.1(c) gives values for *D*.

Figure C.1(a) Pressure Drop in Pipeline for 300 psi (2068 kPa) Storage Pressure.



For SI units, 1 psi = 6.89 kPa; 1 lb/min = 0.454 kg/min.

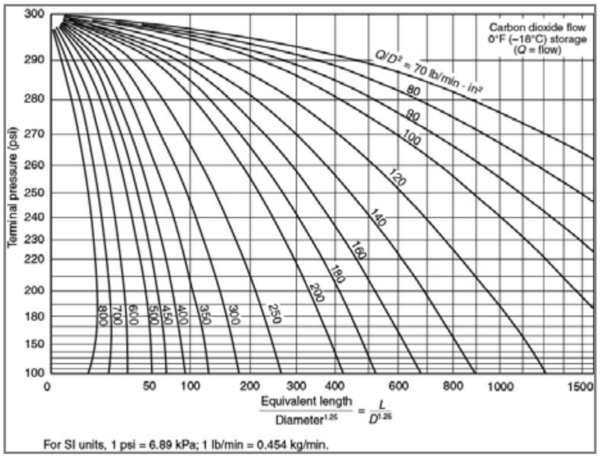
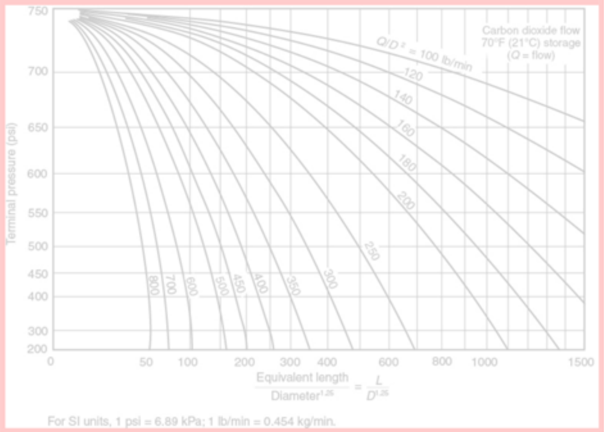


Figure C.1(b) Pressure Drop in Pipeline for 750 psi (5171 kPa) Storage Pressure.



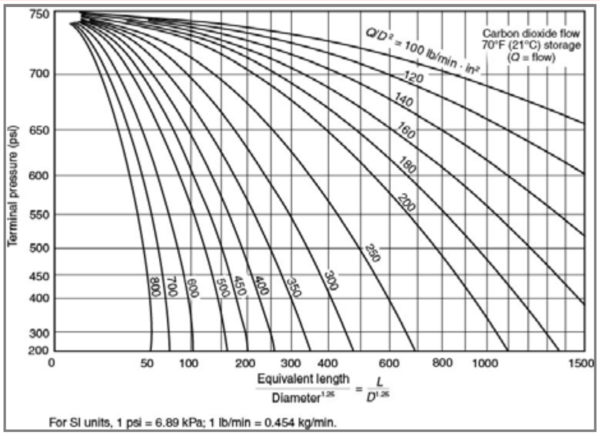


Table C.1(c) Values of $D^{1.25}$ and D^2 for Various Pipe Sizes

Pipe Size and Type	Inside Diameter (in.)	$D^{1.25}$	D^2
½ Std.	0.622	0.5521	0.3869
¾ Std.	0.824	0.785	0.679
1 Std.	1.049	1.0615	1.100
1 XH	0.957	0.9465	0.9158
1¼ Std.	1.380	1.496	1.904
1¼ XH	1.278	1.359	1.633
1½ Std.	1.610	1.813	2.592
1½ XH	1.500	1.660	2.250
2 Std.	2.067	2.475	4.272
2 XH	1.939	2.288	3.760
2½ Std.	2.469	3.09	6.096
2½ XH	2.323	2.865	5.396
3 Std.	3.068	4.06	9.413

Pipe Size and Type	Inside Diameter (in.)	$D^{1.25}$	D^2
3 XH	2.900	3.79	8.410
4 Std.	4.026	5.71	16.21
4 XH	3.826	5.34	14.64
5 Std.	5.047	7.54	25.47
5 XH	4.813	7.14	23.16
6 Std.	6.065	9.50	36.78
6 XH	5.761	8.92	33.19

These curves can be used for designing systems or for checking possible flow rates. For example, assume the problem is to determine the terminal pressure for a low-pressure system consisting of a single 2 in. Schedule 40 pipeline with an equivalent length of 500 ft and a flow rate of 1000 lb/min. The flow rate and the equivalent length must be converted to terms of Figure C.1(a) as follows:

$$\frac{Q}{D^2} = \frac{1000}{4.28} = 234 \text{ lb/min} \cdot \text{in.}^2$$

$$\frac{L}{D^{1.25}} = \frac{500}{2.48} = 201 \text{ ft/in.}^{1.25} \qquad \text{[C.1c]}$$

From Figure C.1(a), the terminal pressure is found to be about 228 psi at the point where the interpolated flow rate of 234 lb/min intersects the equivalent length scale at 201 ft.

If this line terminates in a single nozzle, the equivalent orifice area must be matched to the terminal pressure in order to control the flow rate at the desired level of 1000 lb/min. Referring to Table 4.7.5.2.1, it will be noted that the discharge rate will be 1410 lb/min·in.^{2} of equivalent orifice area when the orifice pressure is 230 psi. The required equivalent orifice area of the nozzle is thus equal to the total flow rate divided by the rate per square inch, as shown in the following equation:

$$\text{Equivalent orifice area} = \frac{1000 \text{ lb/min}}{1410 \text{ lb/min} \cdot \text{in.}^2} = 0.709 \text{ in.}^2 \qquad \text{[C.1d]}$$

From a practical viewpoint, the designer would select a standard nozzle having an equivalent area nearest to the computed area. If the orifice area happened to be a little larger, the actual flow rate would be slightly higher and the terminal pressure would be somewhat lower than the estimated 228 psi (1572 kPa).

If, in the previous example, instead of terminating with one large nozzle, the pipeline branched into two smaller pipelines, it would be necessary to determine the pressure at the end of each branch line. To illustrate this procedure, assume that the branch lines are equal and consist of 1½ in. Schedule 40 pipe with equivalent lengths of 200 ft (61 m) and that the flow in each branch line is to be 500 lb/min (227 kg/min). Converting to terms used in Figure C.1(a), the following equations result:

$$\frac{Q}{D^2} = \frac{500}{2.592} = 193 \text{ lb/min} \cdot \text{in.}^2$$

$$\frac{L}{D^{1.25}} = \frac{200}{1.813} = 110 \text{ ft/in.}^{1.25} \qquad \text{[C.1e]}$$

From Figure C.1(a), the starting pressure of 228 psi (1572 kPa) (terminal pressure of main line) intersects the flow rate line [193 lb/min (87.6 kg/min)] at an equivalent length of about 300 ft (91.4 m). In other words, if the branch line started at the storage vessel, the liquid carbon dioxide would have to flow through 300 ft (91.4 m) of pipeline before the pressure dropped to 228 psi (1572 kPa). This length thus becomes the starting point for the equivalent length of the branch line. The terminal pressure of the branch line is then found to be 165 psi (1138 kPa) at the point where the 193 lb/min (87.6 kg/min) flow rate line intersects the total equivalent length line of 410 ft (125 m), or 300 ft + 110 ft (91 m + 34 m). With this new terminal pressure [165 psi (1138 kPa)] and flow rate [500 lb/min (227 kg/min)], the required equivalent nozzle area at the end of each branch line will be approximately 0.567 in.^{2} (366 mm^2). This is about the same as the single large nozzle example, except that the discharge rate is cut in half due to the reduced pressure.

The design of the piping distribution system is based on the flow rate desired at each nozzle. This in turn determines the required flow rate in the branch lines and the main pipeline. From practical experience, it is possible to estimate the approximate pipe sizes required. The pressure at each nozzle can be determined from suitable flow curves. The nozzle orifice sizes are then selected on the basis of nozzle pressure from the data given in 4.7.5.2.

In high-pressure systems, the main header is supplied by a number of separate cylinders. The total flow is thus divided by the number of cylinders to obtain the flow rate from each cylinder. The flow capacity of the cylinder valve and the connector to the header vary with each manufacturer, depending on design and size. For any particular valve, dip tube, and connector assembly, the equivalent length can be determined in terms of feet of standard pipe size. With this information, the flow equation can be used to prepare a curve of flow rate versus pressure drop. This curve provides a convenient method of determining header pressure for a specific valve and connector combination.

Table C.1(d) and Table C.1(e) list the equivalent lengths of pipe fittings for determining the equivalent length of piping systems. Table C.1(d) is for threaded joints, and Table C.1(e) is for welded joints. Both tables were computed for Schedule 40 pipe sizes; however, for all practical purposes, the same figures can also be used for Schedule 80 pipe sizes. These tables should be used to determine the equivalent length of pipe for fittings unless manufacturer's test data indicate that other factors are appropriate. For mechanical grooved fittings listed for use in carbon dioxide systems, equivalent length data should be obtained from the manufacturer.

Table C.1(d) Equivalent Lengths in Feet of Threaded Pipe Fitting

Pipe Size (in.)	Elbow Std. 45 Degrees	Elbow Std. 90 Degrees	Elbow 90 Degrees Long Radius and Tee Thru Flow	Tee Side	Union Coupling or Gate Valve
⅜	0.6	1.3	0.8	2.7	0.3
½	0.8	1.7	1.0	3.4	0.4
¾	1.0	2.2	1.4	4.5	0.5
1	1.3	2.8	1.8	5.7	0.6
1¼	1.7	3.7	2.3	7.5	0.8

Pipe Size (in.)	Elbow Std. 45 Degrees	Elbow Std. 90 Degrees	Elbow 90 Degrees Long Radius and Tee Thru Flow	Tee Side	Union Coupling or Gate Valve
1½	2.0	4.3	2.7	8.7	0.9
2	2.6	5.5	3.5	11.2	1.2
2½	3.1	6.6	4.1	13.4	1.4
3	3.8	8.2	5.1	16.6	1.8
4	5.0	10.7	6.7	21.8	2.4
5	6.3	13.4	8.4	27.4	3.0
6	7.6	16.2	10.1	32.8	3.5

For SI units, 1 ft = 0.3048 m.

Table C.1(e) Equivalent Lengths in Feet of Welded Pipe Fitting

Pipe Size (in.)	Elbow Std. 45 Degrees	Elbow Std. 90 Degrees	Elbow 90 Degrees Long Radius and Tee Thru Flow	Tee Side	Gate Valve
⅜	0.2	0.7	0.5	1.6	0.3
½	0.3	0.8	0.7	2.1	0.4
¾	0.4	1.1	0.9	2.8	0.5
1	0.5	1.4	1.1	3.5	0.6
1¼	0.7	1.8	1.5	4.6	0.8
1½	0.8	2.1	1.7	5.4	0.9
2	1.0	2.8	2.2	6.9	1.2
2½	1.2	3.3	2.7	8.2	1.4
3	1.8	4.1	3.3	10.2	1.8
4	2.0	5.4	4.4	13.4	2.4
5	2.5	6.7	5.5	16.8	3.0
6	3.0	8.1	6.6	20.2	3.5

For SI units, 1 ft = 0.3048 m.

For nominal changes in elevation of piping, the change in head pressure is negligible. However, if there is a substantial change in elevation, this factor should be taken into account. The head pressure correction per foot of elevation depends on the average line pressure where the elevation takes place because the density changes with pressure. Correction factors are given in Table C.1(f) and Table C.1(g) for low-pressure and high-pressure systems, respectively. The correction is subtracted from the terminal pressure when the flow is upward and is added to the terminal pressure when the flow is downward.

Table C.1(f) Elevation Correction Factors for Low-Pressure System

Average Line Pressure		Elevation Correction	
psi	kPa	psi/ft	kPa/m
300	2068	0.443	10.00
280	1930	0.343	7.76
260	1792	0.265	5.99
240	1655	0.207	4.68
220	1517	0.167	3.78
200	1379	0.134	3.03
180	1241	0.107	2.42
160	1103	0.085	1.92
140	965	0.067	1.52

Table C.1(g) Elevation Correction Factors for High-Pressure System

Average Line Pressure		Elevation Correction	
psi	kPa	psi/ft	kPa/m
750	5171	0.352	7.96
700	4826	0.300	6.79
650	4482	0.255	5.77
600	4137	0.215	4.86
550	3792	0.177	4.00
500	3447	0.150	3.39
450	3103	0.125	2.83
400	2758	0.105	2.38
350	2413	0.085	1.92
300	2068	0.070	1.58

Supplemental Information

File Name	Description Approved
12_FR9_C.1.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA
Submittal Date: Fri Apr 26 11:49:03 EDT 2019

Committee Statement

Committee Statement: This revision corrects the units for Q/D^2 in Figures C.1(a) and C.1(b), which should be lb/min-in^2.

Additional guidance is provided for calculating systems that use fittings not addressed by the existing tables.

Response Message: FR-9-NFPA 12-2019

Public Input No. 15-NFPA 12-2018 [Section No. C.1]

First Revision No. 10-NFPA 12-2019 [New Section after G.1]

G.2

Additional information on the physical properties of carbon dioxide can be found in the SFPE *Handbook of Fire Protection Engineering* .

Submitter Information Verification

Committee: GFE-AAA
Submittal Date: Fri Apr 26 12:16:10 EDT 2019

Committee Statement

Committee Statement: The information provided in the SFPE Handbook can be useful for users of the standard.
Response Message: FR-10-NFPA 12-2019

Public Input No. 5-NFPA 12-2018 [New Section after G.1]

First Revision No. 11-NFPA 12-2019 [Section No. G.1]

G.1

Carbon dioxide is present in the atmosphere at an average concentration of about ~~0.03 percent~~ 0.04 percent by volume. It is also a normal end product of human and animal metabolism. Carbon dioxide influences certain vital functions in a number of important ways, including control of respiration, dilation and constriction of the vascular system — particularly the cerebrum — and the pH of body fluids. The concentration of carbon dioxide in the air governs the rate at which carbon dioxide is released from the lungs and thus affects the concentration of carbon dioxide in the blood and tissues. An increasing concentration of carbon dioxide in air can, therefore, become dangerous due to a reduction in the rate of release of carbon dioxide from the lungs and decreased oxygen intake. [Further details of carbon dioxide exposure can be obtained from DHHS (NIOSH) Publication No. 76-194.] Personnel safety considerations are covered in Section 4.3.

Table G.1 provides information on acute health effects of high concentrations of carbon dioxide.

Table G.1 Acute Health Effects of High Concentrations of Carbon Dioxide (with Increasing Exposure Levels of Carbon Dioxide)

Concentration of Carbon Dioxide in Air (%)	Time	Effects
2	Several hours	Headache, dyspnea upon mild exertion
3	1 hour	Dilation of cerebral blood vessels, increased pulmonary ventilation, and increased oxygen delivery to the tissues
4–5	Within a few minutes	Mild headache, sweating, and dyspnea at rest
6	1–2 minutes	Hearing and visible disturbances
	<16 minutes	Headache and dyspnea
	Several hours	Tremors
7–10	Few minutes	Unconsciousness or near unconsciousness
	1.5 minutes–1 hour	Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing
10–15	1+ minute	Dizziness, drowsiness, severe muscle twitching, and unconsciousness
17–30	<1 minute	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, and death

Source: EPA 430-R-00-002, February 2000.

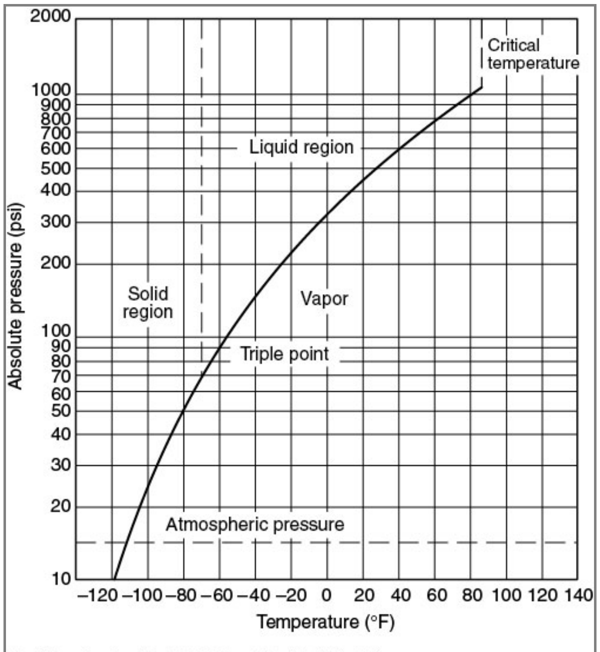
Carbon dioxide is a standard commercial product with many uses. It is perhaps most familiar as the gas that gives the “fizz” in soda pop and other carbonated beverages. In industrial applications, it is used for its chemical properties, its mechanical properties as a pressurizing agent, or its refrigerating properties as dry ice.

For fire-extinguishing applications, carbon dioxide has a number of desirable properties. It is noncorrosive, nondamaging, and leaves no residue to clean up after the fire. It provides its own pressure for discharge through pipes and nozzles. Because it is a gas, it will penetrate and spread to all parts of a hazard. It will not conduct electricity and can therefore be used on live electrical hazards. It can effectively be used on practically all combustible materials except for a few active metals and metal hydrides and materials, such as cellulose nitrate, that contain available oxygen.

Under normal conditions, carbon dioxide is an odorless, colorless gas with a density about 50 percent greater than the density of air. Many people insist they can detect an odor of carbon dioxide, but this could be due to impurities or chemical effects in the nostrils. Carbon dioxide is easily liquefied by compression and cooling. By further cooling and expansion, it can be converted to the solid state.

The relationship between the temperature and the pressure of liquid carbon dioxide is shown on the curve given in Figure G.1. As the temperature of the liquid increases, the pressure also increases. As the pressure increases, the density of the vapor over the liquid increases. On the other hand, the liquid expands as the temperature goes up and its density decreases. At 87.8°F (31°C), the liquid and the vapor have the same density, and of course the liquid phase disappears. This is called the critical temperature for carbon dioxide. Below the critical temperature [87.8°F (31°C)], carbon dioxide in a closed container is part liquid and part gas. Above the critical temperature, it is entirely gas.

Figure G.1 Variation of Pressure of Carbon Dioxide with Change in Temperature (constant volume).



For SI units, 1 psi = 6.89 kPa; °C = 5⁄9 (°F – 32).

An unusual property of carbon dioxide is the fact that it cannot exist as a liquid at pressures below 60.4 psi [75 psi absolute (517 kPa)]. This is the triple point pressure where carbon dioxide could be present as a solid, a liquid, or a vapor. Below this pressure, it must be either a solid or a gas, depending on the temperature.

If the pressure in a storage container is reduced by bleeding off vapor, some of the liquid will vaporize and the remaining liquid will become colder. At 60.4 psi [75 psi absolute (517 kPa)], the remaining liquid will be converted to dry ice at a temperature of −69.9°F (−57°C). Further reduction in the pressure to atmospheric will lower the temperature of the dry ice to the normal −109.3°F (−79°C).

The same process takes place when liquid carbon dioxide is discharged to the atmosphere. A large portion of the liquid flashes to vapor with a considerable increase in volume. The rest is converted to finely divided particles of dry ice at −109.3°F (−79°C). It is this dry ice or snow that gives the discharge its typical white cloudy appearance. The low temperature also causes the condensation of water from the entrained air so that ordinary water fog tends to persist for a while after the dry ice has sublimed.

Carbon dioxide is a colorless, odorless, electrically nonconductive inert gas that is a suitable medium for extinguishing fires. Liquid carbon dioxide forms solid dry ice (“snow”) when released directly into the atmosphere. Carbon dioxide gas is 1.5 times heavier than air. Carbon dioxide extinguishes fire by reducing the concentrations of oxygen, the vapor phase of the fuel, or both in the air to the point where combustion stops. *(See Section 4.3.)*

Carbon dioxide fire-extinguishing systems are useful within the limits of this standard in extinguishing fires involving specific hazards or equipment in the following occupancies:

(1) Where an inert electrically nonconductive medium is essential or desirable

(2) Where cleanup of other media presents a problem

(3) Where such systems are more economical to install than systems using other media

Some of the types of hazards and equipment that carbon dioxide systems can satisfactorily protect include the following:

(1) Flammable liquid materials *(See 4.5.4.9.)*

(2) Electrical hazards such as transformers, switches, circuit breakers, rotating equipment, and electronic equipment

(3) Engines utilizing gasoline and other flammable liquid fuels

(4) Ordinary combustibles such as paper, wood, and textiles

(5) Hazardous solids

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri Apr 26 12:18:43 EDT 2019

Committee Statement

Committee Statement: The percentage of carbon dioxide in the atmosphere is updated.

Response Message: FR-11-NFPA 12-2019