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

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Title: Improved clarity of the terms “fire” and “extinguishment”, highlighting electrostatic explosion hazard when fighting smoldering fires with CO2.

Concern:
There is a problem with CO_2 batteries. When liquid CO_2 is released, static discharges are generated. It's a known source of ignition, e.g. in NFPA 77.
This is not problem for fighting a fire with flames. But a smoldering fire will likely have filled the headspace with flammable gases. If ignited due to CO_2 injection, a confined explosion will result. NFPA 12 does not mention this hazard clearly. On the contrary, section 5.2.3 states that CO_2 can be used for "deep-seated fires". This is a problem.
I wrote an article on an explosion caused by this phenomenon:
Hedlund FH (2018) Carbon dioxide not suitable for extinguishment of smouldering silo fires: static electricity may cause silo explosion. Biomass and Bioenergy. 108:113-119. https://doi.org/10.1016/j.biombioe.2017.11.009

Quoting from this article:
NFPA 12 [21] on carbon dioxide extinguishing systems provides ambiguous advice on the electrostatic hazard. Annex A states that the discharge of liquid carbon dioxide is known to produce electrostatic
charges that, under certain conditions, could create a spark and duly refers to NFPA 77.
The standard also specifies, that “carbon dioxide fire extinguishing systems protecting areas where explosive atmospheres could exist shall utilize metal nozzles, and the entire system shall be
grounded” [[21], Sec. 4.2.1].
The first issue of concern is if the reader realizes that an ignitable (and explosive) atmosphere can exist not only when flammable liquids give off vapours but also when pyrolysis gases have accumulated.
The second issue of concern is if effective grounding is sufficient to prevent hazardous electrostatic discharges – the Bitburg accident would appear to contraindicate this.
The third and perhaps most important issue of concern is the standard's ill-conceived advice on the application of CO2 to “deep-seated fires involving solids subject to smoldering” [[21], Sec 5.2.3].

This is precisely the situation where pyrolysis gases may have accumulated in the headspace to an extent where they are in the ignitable range – but the reader may not have realized this, and the standard does not identify the potential presence of flammable pyrolysis gases.

The nub of the issue may well be lack of clarity in the meaning of the terms “fire” and “extinguishment”, which are not defined in the standard's terminology section.
The application of CO2 is excellent for extinguishing a fire with flames, but unsuitable for quenching a deep-seated smouldering fire without flame.

I'm not a US citizen and have no means to enter a lengthy comments procedure for a US standard. Unfortunately, I cannot pursue this issue further with NFPA.

Frank Huess Hedlund
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Statement of Problem and Substantiation for Public Input

Currently, the standard gives ill-conceived advice on the application of CO2 to “deep-seated fires involving solids subject to smoldering”, not alerting readers to explosion hazard

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Submittal Date:	Mon Jun 04 04:25:09 EDT 2018
Committee:	GFE-AAA

Committee Statement

Resolution:	FR-3-NFPA 12-2019
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.

Public Input No. 2-NFPA 12-2018 [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 edition.

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

NFPA 72®, National Fire Alarm and Signaling Code®, 2016 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~~ 201 **8** .

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~~ 201 **8** .

ASTM A106/A106M, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*, ~~2015~~ 201 **8** .

ASTM A120, *Specification for Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless for Ordinary Uses*, ~~1984 (withdrawn 1987)~~ **Superseded by ASTM A53/A53M** .

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~~ 201 **8** .

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~~ 201 **3** .

2.3.6 CSA Group Publications.

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

CSA C22.1, *Canadian Electrical Code*, ~~2015~~ 201 **8** .

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.

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).

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

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.

Statement of Problem and Substantiation for Public Input

Referenced updated editions.

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Committee: GFE-AAA

Committee Statement

Resolution: FR-4-NFPA 12-2019
Statement: Referenced updated editions.

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

The amount of the main supply of carbon dioxide in the system shall be at least sufficient for the largest single hazard protected or group of hazards that are to be protected simultaneously. The supply pipe from the tank to the hazard can contain a significant amount of CO2 at the completion of a discharge and shall be considered in sizing the supply.

Statement of Problem and Substantiation for Public Input

The supply pipe between the low pressure CO2 tank and the hazard can contain a large volume of CO2, especially for large hazards with 4 in pipe some distance away. It is our understanding that the flow calculations only figure the mass of CO2 that leaves the nozzles and enters the hazard during discharge. When the valve at the tank closes, the CO2 in the supply pipe is left abandoned in the pipe, not reliable for extinguishing and no longer available for another discharge from the tank. When sizing systems, this volume should be included as consumed CO2.

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Committee:	GFE-AAA

Committee Statement

Resolution: FR-5-NFPA 12-2019

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.

Public Input No. 10-NFPA 12-2018 [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 A. 5.5. 2 or 5.5. 3. *(See also 5.2.1.3.)*

Systems other than those covered in 5.5.3 (enclosed rotating electrical equipement) may require extended discharge systems. Annex A.5.5.2 paragraphs 2 and forward talks in depth about determining extended discharge requirements for leaky hazards. To send a user to 5.5.3 may send the wrong message to use the tables in A.5.5.3 when they should actually be considering A.5.5.2 information.

Statement of Problem and Substantiation for Public Input

There is confusion with regard to extended discharge requirements for leaky systems that are not "enclosed rotation electrical equipment". This change would provide clearer direction in this aspect of system designs, for ga turbine enclosures for instance.

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 8-NFPA 12-2018 [Section No. 5.5.3]	Same issue
Public Input No. 9-NFPA 12-2018 [Section No. A.5.5.3]	Same issue
Public Input No. 6-NFPA 12-2018 [Section No. A.5.5.2]	Different correction in a related section of the standard.

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Committee: GFE-AAA

Committee Statement

Resolution: FR-6-NFPA 12-2019

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.

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

5.5.2.1 *

For surface fires, the design concentration shall be achieved within 1 minute from start of discharge.

Response time of the instrument shall be considered in determining pass/fail criteria for concentration testing.

(Response time of the available sensors can consume significant portion of the discharge time requirement. They simply do not respond fast enough to accurately determine concentration with 1 minute. State of the art infrared detectors can take as long as 20 seconds to read 63% of full signal, and 50 seconds to read full signal from the time they are exposed to a full concentration calibrated CO2 gas sample. The older Tripoint thermal conductivity based instruments claimed a T95 of 60 seconds, so they could take 60 seconds to read 95% of the full concentration value, even longer to read the actual value.

These instrument dynamics can cause a technician to interpret a discharge test as a fail because the instrument doesn't reach the design concentration with 60 seconds on the instrument used to measure on the test. These values are independent of any additional time delays due to long lengths of tubing or delays in the discharge flow, they are just inherent in the detectors. In practical terms, the concentration inside a hazard is gradually increasing during the discharge, so the driving gain in the system is even worse than in the calibration setup.

Some guidance should be provided to accomodate the delays inherent in the instruments. The requirement is to achieve the design concentration within the hazard within 1 minute. If the available instrument takes 50 seconds to read full signal, a large portion of that additional time should be added to the pass/fail requirement for the test to fairly assess the actual concentration inside the enclosure.)

Additional Proposed Changes

File Name	Description	Approved
CO2_Analyzer_Response_Time_Characterization.pdf	Typical CO2 analyzer response time graph during a bench test.	

Statement of Problem and Substantiation for Public Input

The response time performance of CO2 concentration analyzers is not clearly considered in the standard requirement for application rate for short duration discharges. Without additional guidance, technicians can improperly assess test results resulting in system rework and delays. Describe typical performance of the devices and give guidance on how to use them to appropriately assess the concentration inside the hazard. Attached graph is provided for background for the technical committee, not to be considered to be included in the standard.

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Committee:	GFE-AAA

Committee Statement

Resolution: FR-12-NFPA 12-2019

Statement: Paragraph (4) is revised to allow for differences in instrumentation.

Public Input No. 8-NFPA 12-2018 [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. Enclosed rotating electrical equipment includes electrical machinery like electric motors and generators. Please clarifiy what this section pertains to. This section and the supporting annex A.5.5.3 are routinely mis-applied to gas turbine engines by manufacturers and integrators. Gas turbine engines are not electrical equipment in these terms Their hold time requirements should be considered under the provisions of NFPA 37. Ref 10/22/2015 NFPA Technical Question Response [ref:_00D5077Vx._50050hY3tt:ref].

Statement of Problem and Substantiation for Public Input

Clarify the definition of "enclosed rotating electrical equipment" and the applicability of this section to completely mechanical equipment like gas turbine engines.

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 9-NFPA 12-2018 [Section No. A.5.5.3]	
Public Input No. 10-NFPA 12-2018 [Section No. 5.4.4.2]	

Submitter Information Verification

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Committee:	GFE-AAA

Committee Statement

Resolution: FR-7-NFPA 12-2019

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

Public Input No. 11-NFPA 12-2018 [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:

$$R = 60C\rho A\sqrt{\frac{2_g\left(\rho_1 - \rho_2\right)h}{\rho_1}} \qquad \text{[A.5.5.2]}$$

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 concentration. Please clarify if the hold concentration is intended to be the Design Concentration or the Minimum Extinguishing Concentration. In our experience it is commonly interpreted as the MEC by manfacturers, integrators and underwriters (ref Retrotec enclosure integrity test software, FM Global Data Sheet 7-79 2.4.3.5.1 for two instances). The standard is not clear in this respect. The 30% requirement for enclosed rotating electrical equipment may contribute to the confusion.

Statement of Problem and Substantiation for Public Input

Clarify the hold concentration for extended discharge systems that aren't covered by the enclosed rotating electrical equipment section. (5.5.3).

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 6-NFPA 12-2018 [Section No. A.5.5.2]	Correction in the same section but unrelated issue.

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Committee:	GFE-AAA

Committee Statement

Resolution: FR-3-NFPA 12-2019

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.

Public Input No. 6-NFPA 12-2018 [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:

$$R = 60C\rho A\sqrt{\frac{2_g\left(\rho_1 - \rho_2\right)h}{\rho_1}} \qquad \text{[A.5.5.2]}$$

The gravitational constant "g" in this equation shows as a subscript, it should be a full size variable. It's a minor point but it is confusing the first time you use this equation.

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)]

ρ_1 = density of atmosphere [lb/ft^3 (kg/m^3)]

ρ_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 concentration.

Statement of Problem and Substantiation for Public Input

Corrects equation A.5.5.2, makes it easier to understand and use.

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 10-NFPA 12-2018 [Section No. 5.4.4.2]	
Public Input No. 11-NFPA 12-2018 [Section No. A.5.5.2]	

Submitter Information Verification

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Submittal Date: Thu Dec 27 10:40:30 EST 2018
Committee: GFE-AAA

Committee Statement

Resolution: FR-8-NFPA 12-2019

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.

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

A.5.5.3

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.

Please clarify what type of equipment this applies to. This section is routinely mis-applied to fully mechanical equipment like gas turbine engines.

Ref NFPA Technical Question Response 10/2/2015 [ref:_00D5077Vx._50050hY3tt:ref]:

The term "enclosed rotating electrical equipment," as used in 5.5.3 of NFPA 12 (2015), refers to both generators and electric motors. The windings can produce a deep-seated fire, which will require a significant amount of carbon dioxide to cool and extinguish. In addition, electricity that is generated during the wind-down could provide a constant source of ignition/re-ignition to the fire.

Barry Chase

Fire Protection Engineer

NFPA

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

	Time (minutes)							
kg CO_2	5	10	15	20	30	40	50	60
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
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

Statement of Problem and Substantiation for Public Input

Clarify the definition of "enclosed rotating electrical equipment" and the applicability (or non-applicability) of this section to completely mechanical equipment like gas turbine engines.

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 8-NFPA 12-2018 [Section No. 5.5.3]	Same issue in the body of the standard.
Public Input No. 10-NFPA 12-2018 [Section No. 5.4.4.2]	

Submitter Information Verification

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Committee:	GFE-AAA

Committee Statement

Resolution: FR-7-NFPA 12-2019

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

Public Input No. 13-NFPA 12-2018 [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)]

$\rho 1$ = 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. The mixing of absolute and gauge pressures in the standard are confusing. Recommend using psig/psia specific designators to clarify throughout.

Also, for extended discharge systems we have seen tank pressures much lower than the 285 psig (300 psia) stated. For an 8 ton tank on a 30 minute extended discharge we have seen pressure decay to under 250 psig, averaging under 270 psig. This is a significant impact on the flow rate on those nozzles, around 16% reduced flow according to T4.7.5.2.1. Recommend adding notes to caution the user to include some additional margin in the system sizing for extended discharge durations over 20 minutes.

Bleeding vapor off the vapor space of a low pressure tank has a particularly large impact on tank pressure over a long duration. Pneumatic sirens are typically plumbed off the vapor space and can have a detrimental effect on driving pressure and resulting flow. The system designer should consider this issue in the course of design. A simplified equation in the annex would be helpful to assist a designer in determining how much additional flow they should add to the discharge to compensate for reduced pressure due to vapor loss.

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

(psi)

					Y						
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

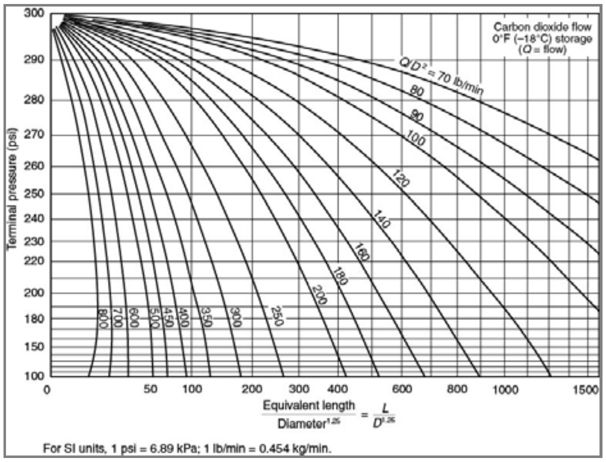
(psi)											
	Y										
Z	0	1	2	3	4	5	6	7	8	9	
750	0.000	0	0	0	0	0	0	0	0	0	0
740	0.038	497	448	399	350	300	251	201	151	101	51
730	0.075	975	928	881	833	786	738	690	642	594	545
720	0.110	1436	1391	1345	1299	1254	1208	1161	1115	1068	1022
710	0.143	1882	1838	1794	1750	1706	1661	1616	1572	1527	1481
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
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:

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

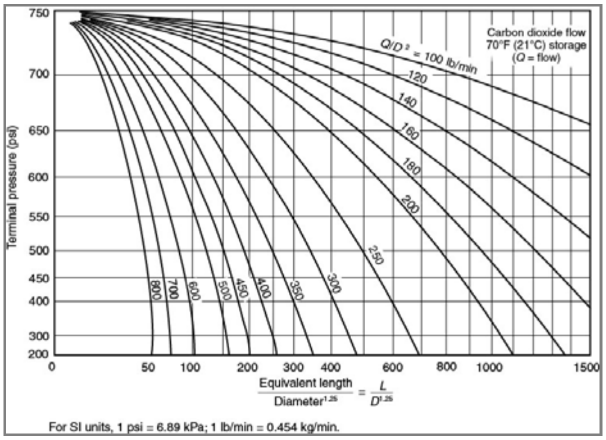
Thus, by plotting values of $L/D^{1.25}$ and Q/D^2, it is possible to use one family of curves for any pipe size. Figure C.1(a) gives flow information for 0°F (−18°C) storage temperature on this basis. Figure C.1(b) gives similar information for high-pressure storage at 70°F (21°C). For an inside pipe 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.



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

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
1/2 Std.	0.622	0.5521	0.3869
3/4 Std.	0.824	0.785	0.679
1 Std.	1.049	1.0615	1.100
1 XH	0.957	0.9465	0.9158
1 1/4 Std.	1.380	1.496	1.904
1 1/4 XH	1.278	1.359	1.633
1 1/2 Std.	1.610	1.813	2.592
1 1/2 XH	1.500	1.660	2.250
2 Std.	2.067	2.475	4.272
2 XH	1.939	2.288	3.760
2 1/2 Std.	2.469	3.09	6.096
2 1/2 XH	2.323	2.865	5.396
3 Std.	3.068	4.06	9.413
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:

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

$$\frac{L}{D^{1.25}} = \frac{500}{2.48} = 201 \text{ ft/in.}^{1.25}$$

[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:

$$\text{Equivalent orifice area} = \frac{1000 \text{ lb/min}}{1410 \text{ lb/min}\cdot\text{in.}^2} = 0.709 \text{ in.}^2$$

[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:

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

$$\frac{L}{D^{1.25}} = \frac{200}{1.813} = 110 \text{ ft/in.}^{1.25}$$

[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.

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
3/8	0.6	1.3	0.8	2.7	0.3
1/2	0.8	1.7	1.0	3.4	0.4
3/4	1.0	2.2	1.4	4.5	0.5
1	1.3	2.8	1.8	5.7	0.6
1 1/4	1.7	3.7	2.3	7.5	0.8
1 1/2	2.0	4.3	2.7	8.7	0.9
2	2.6	5.5	3.5	11.2	1.2
2 1/2	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	Elbow Std. 45 Degrees	Elbow Std. 90 Degrees	Elbow	Tee	Gate Valve

(in.)			90 Degrees Long Radius and Tee Thru Flow	Side	
3/8	0.2	0.7	0.5	1.6	0.3
1/2	0.3	0.8	0.7	2.1	0.4
3/4	0.4	1.1	0.9	2.8	0.5
1	0.5	1.4	1.1	3.5	0.6
1 1/4	0.7	1.8	1.5	4.6	0.8
1 1/2	0.8	2.1	1.7	5.4	0.9
2	1.0	2.8	2.2	6.9	1.2
2 1/2	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

Statement of Problem and Substantiation for Public Input

Long extended discharge systems require additional margin in the design to compensate for tank pressures that are lower than assumed by the standard. Pneumatic sirens venting vapor off the tank have a particularly large effect. The result is extended discharge amounts below what is designed. Revise to call this to the attention of system designers to compensate where necessary.

Related Public Inputs for This Document

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

Submitter Information Verification

Submitter Full Name: Matthew Taylor
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Submittal Date: Thu Dec 27 11:58:53 EST 2018
Committee: GFE-AAA

Committee Statement

Resolution: Regarding usage of gauge and absolute pressure in the standard, the NFPA Manual of Style does not use "psig" and "psia." The committee has formed a task group to study the usage of gauge and absolute pressures throughout the standard and to recommend clarifying language at Second Draft. Regarding the sizing of the supply for extended discharge systems, see the committee's action on A.4.6.1 (FR-5). Regarding compensation for pneumatic sirens, no simplified equation can be provided. Consult equipment manufacturers with regard to additional CO2 demand and usage.

Public Input No. 15-NFPA 12-2018 [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)]

$\rho 1$ = 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 (psi)		*Y*									
-	*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 (psi)		*Y*									
-	*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

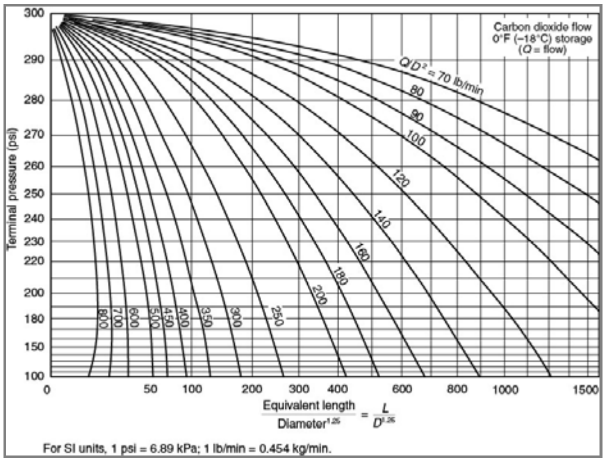
	Y										
Z	0	1	2	3	4	5	6	7	8	9	
710	0.143	1882	1838	1794	1750	1706	1661	1616	1572	1527	1481
700	0.174	2314	2271	2229	2186	2143	2100	2057	2013	1970	1926
690	0.205	2733	2691	2650	2608	2567	2525	2483	2441	2399	2357
680	0.235	3139	3099	3059	3018	2978	2937	2897	2856	2815	2774
670	0.265	3533	3494	3455	3416	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
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.

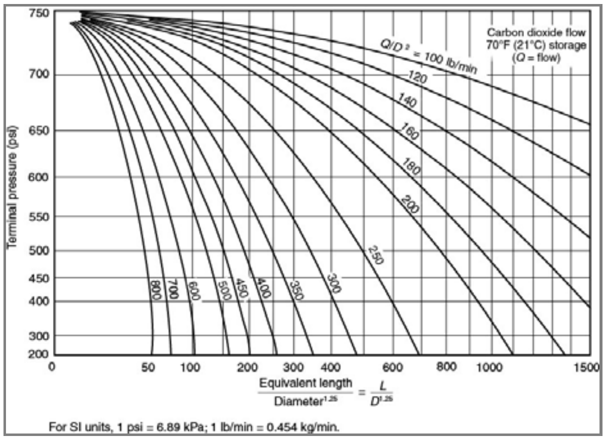
Figure C.1(a) Pressure Drop in Pipeline for 300 psi (2068 kPa) Storage Pressure.



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

Units for Q/D^2 are incorrect in both Figure C.1(a) and C.1(b) along the topmost curves. Units should read lb/min/in^2 or lb/(min-in^2).

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



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

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

Pipe Size	**Inside Diameter**		
and Type	**(in.)**	$D^{1.25}$	D^2
1/2 Std.	0.622	0.5521	0.3869
3/4 Std.	0.824	0.785	0.679
1 Std.	1.049	1.0615	1.100
1 XH	0.957	0.9465	0.9158
1 1/4 Std.	1.380	1.496	1.904
1 1/4 XH	1.278	1.359	1.633
1 1/2 Std.	1.610	1.813	2.592
1 1/2 XH	1.500	1.660	2.250
2 Std.	2.067	2.475	4.272
2 XH	1.939	2.288	3.760
2 1/2 Std.	2.469	3.09	6.096
2 1/2 XH	2.323	2.865	5.396
3 Std.	3.068	4.06	9.413
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:

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

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

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:

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

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:

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

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

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 or grooved fittings . 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.

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

Pipe Size	Elbow Std.	Elbow Std.	Elbow	Tee	
(in.)	45 Degrees	90 Degrees	90 Degrees Long Radius and Tee Thru Flow	Side	Union Coupling or Gate Valve
3/8	0.6	1.3	0.8	2.7	0.3
1/2	0.8	1.7	1.0	3.4	0.4
3/4	1.0	2.2	1.4	4.5	0.5
1	1.3	2.8	1.8	5.7	0.6
1 1/4	1.7	3.7	2.3	7.5	0.8
1 1/2	2.0	4.3	2.7	8.7	0.9
2	2.6	5.5	3.5	11.2	1.2
2 1/2	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	Elbow Std. 45 Degrees	Elbow Std. 90 Degrees	Elbow	Tee	Gate Valve

(in.)			90 Degrees Long Radius and Tee Thru Flow	Side	
3/8	0.2	0.7	0.5	1.6	0.3
1/2	0.3	0.8	0.7	2.1	0.4
3/4	0.4	1.1	0.9	2.8	0.5
1	0.5	1.4	1.1	3.5	0.6
1 1/4	0.7	1.8	1.5	4.6	0.8
1 1/2	0.8	2.1	1.7	5.4	0.9
2	1.0	2.8	2.2	6.9	1.2
2 1/2	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	

Statement of Problem and Substantiation for Public Input

Two issues addressed in this submittal: 1) The units for Q/D^2 in Figures C.1(a) and C.1(b) are incomplete. 2) It is unclear which table for equivalent lengths (C.1(d) or C.1(e)) should be used when using grooved fittings, like those from Victaulic. These fittings are fairly commonly used for ease of installation and maintenance, especially for larger bore piping. We have seen different integrators use different tables for these fittings. It would help if the standard included guidance on which is appropriate. For reference, I believe at least one manufacturer's version of low pressure CO2 flow calculation software includes an option for grooved fittings and selects one of these tables for the calculations.

Related Public Inputs for This Document

Related Input	Relationship
Public Input No. 13-NFPA 12-2018 [Section No. C.1]	Unrelated recommendation in the same section.

Submitter Information Verification

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Submittal Date:	Fri Dec 28 15:16:27 EST 2018
Committee:	GFE-AAA

Committee Statement

Resolution: FR-9-NFPA 12-2019

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.

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

Physical Properties of CO2

Type your content here ...Add tables and graphs excerpted from ch 45 in the SFPE Handbook

Additional Proposed Changes

File Name	Description	Approved
image001.png	Properties of CO2	
image002.png	Saturation Properties of CO2	
image004.png	Properties of superheated CO2	
image005.png	Solubility of CO2 in water	
image006.png	Material compatibility of CO2	

Statement of Problem and Substantiation for Public Input

NFPA 12-18 currently does not include basic physical property information for CO2. This is at odds with NFPA 12A,12B and 2001 which do include that information for the subject agent(s). The proposed change seeks to add physical property information for CO2 in line with what is done for related NFPA Standards. The proposed added information are extracts from ch 45 in teh SFPE Handbook.

Submitter Information Verification

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Submittal Date:	Fri Dec 07 08:47:48 EST 2018
Committee:	GFE-AAA

Committee Statement

Resolution: FR-10-NFPA 12-2019

Statement: The information provided in the SFPE Handbook can be useful for users of the standard.