NFPA® 68

Standard on Explosion Protection by Deflagration Venting

2023 Edition

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NFPA® 68

Standard on

Explosion Protection by Deflagration Venting

2023 Edition

This edition of NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, was prepared by the Technical Committee on Explosion Protection Systems. It was issued by the Standards Council on November 29, 2022, with an effective date of December 19, 2022, and supersedes all previous editions.

This document has been amended by one or more Tentative Interim Amendments (TIAs) and/or Errata. See "Codes & Standards" at www.nfpa.org for more information.

This edition of NFPA 68 was approved as an American National Standard on December 19, 2022.

Origin and Development of NFPA 68

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* started out as a tentative standard in 1945, titled NFPA 68T, *Explosion Venting Standard*. In 1954, the temporary standard was replaced with NFPA 68, *Guide for Explosion Venting*, which brought together all the best available information on the fundamentals and parameters of explosions, the data developed by small-scale tests, the interpretation of the results of those tests, and the use of vents and vent closures that were current at the time. The information was then related to "rules of thumb" vent ratio recommendations, which were used for many years. Some of the vents that were designed using those rules of thumb functioned well, while others were never put to the test.

Beginning in 1954, extensive experimentation was carried out in Great Britain and Germany and added to the existing information. The U.S. Bureau of Mines also did some work in this area. However, the work was not completed because the group involved was reassigned to different programs.

In 1974, NFPA 68 was revised, and the work done in Great Britain and Germany was included with the hope that the new information would provide a means for calculating vent ratios with a greater degree of accuracy than that provided by the rules of thumb. The 1978 revision included substantial data that were more valuable in designing explosion relief vents.

In 1979, the committee began a major effort to rewrite the guide in order to incorporate the results of the test work done in Germany. In addition, the 1988 edition, titled *Guide for Venting of Deflagrations*, contained rewritten text that more clearly explained the various parameters that affect the venting of deflagrations.

The 1994 edition of NFPA 68 was completely rewritten to more clearly explain the principles of venting deflagrations. Revisions to each chapter improved the organization of information within the document without changing the venting methodology. The thrust of this revision was to improve the user friendliness and adoptability of the guide and to clarify this complex technology.

The 1998 edition introduced updated terminology to be consistent with current industrial practice. New information was added on the effects of vent ducts, calculation methods for evaluating those effects, and the effects of vent discharge. The revision also incorporated the "weak roof-to-shell" joint design as a means of venting silos and bins and provided new information on explosions in elongated vessels. It also clarified the provisions for securing restraint panels.

The 2002 edition represented a complete revision of the guide and included updated and enhanced treatment for deflagration venting design for dusts and hybrid mixtures. The revision also included new vent design equations based upon the methodology developed by Factory Mutual Research Corporation. In addition to the generalized correlation for dusts were new methods to evaluate the effects of vent ducts, partial volumes, vent panel inertia, and initially elevated pressures.

All design guidelines for gas mixtures were combined into a single chapter, and the document was revised in accordance with the NFPA *Manual of Style for NFPA Technical Committee Documents*.

The 2007 edition represented a complete revision, including a change from guide to standard. The new standard, titled *Standard on Explosion Protection by Deflagration Venting*, provided mandatory requirements for the design, location, installation, maintenance, and use of devices and systems to vent combustion gases and pressures from deflagrations.

The Committee incorporated a new chapter on performance-based design that enabled users to present alternative design methods to satisfy the requirements for gas and mist mixtures, for dusts, and for hybrid mixtures. The Committee also revised the generalized correlation for dusts on the basis of a review of additional experimental data. That review enabled the Committee to support revisions to the basic equation, along with changes to the equations for low-inertia vent closures, panel inertia, partial volume, initially elevated pressures, and vent ducts. The Committee also added a new chapter on inspection and maintenance.

The 2013 edition introduced a revised calculation method for venting of deflagrations of gas mixtures. The chapter on venting of deflagrations in dust mixtures was revised to address differences between translating vent panels and hinged vent panels, to permit sub atmospheric initial pressures, and to incorporate new research on the entrainment of accumulated dust in a building. New sections addressed bucket elevators and grain silos, and new annex material provided guidance on designing vent ducts and estimating the fundamental burning velocity of a fuel.

In the 2018 edition, a requirement was added to adjust the K_{St} values for certain metal dusts if the K_{St} value was obtained in a vessel smaller than 1 m^3. An equation was added to determine the hydraulic diameter for rectangular enclosures. The chapter on venting gas mixture and mist deflagrations was reorganized to clarify the order and applicability of the various adjustments and corrections to required vent area. A new annex was added to implement the equations and calculation procedures, including partial volume effects. The requirements for determining K_G were replaced with requirements for determining P_{max}, and the equations to determine the turbulent flame enhancement factor were revised.

The chapter on venting dust and hybrid mixture deflagrations was also reorganized in order of intended execution. The equation for determining the vent area for elevated or subatmospheric pressure was revised, and an example calculation was added to the annex. The method of determining enclosure volume for dust collectors was revised, and a definition for *flexible filter* was added. Requirements for the use of plastic buckets in bucket elevators were moved from the annex to the body of the standard.

For the 2023 edition, the fireball and hazard distance requirements for gases and dusts have been combined and moved into Chapter 6 for consistency in application. The partial volume calculations for both gases and dusts have been revised to account for solid objects reducing the open-air volume available for mixing and to account for possible dust concentrations below the worst case concentrations. The fundamental burning velocity values in the annex have been updated based on current available data, and an annex on vent sizing for hydrogen mixtures has been added.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced publications can be found in Chapter 2 and Annexes H, L, and M.

Chapter 1 Administration

1.1* Scope. This standard applies to the design, location, installation, maintenance, and use of devices and systems that vent the combustion gases and pressures resulting from a deflagration within an enclosure so that structural and mechanical damage is minimized.

1.2* Purpose. The purpose of this standard is to provide the user with criteria for design, installation, and maintenance of deflagration vents and associated components.

1.3* Application. This standard applies where the need for deflagration venting has been established.

1.3.1 This standard does not apply to detonations, bulk autoignition of gases, or unconfined deflagrations, such as open-air or vapor cloud explosions.

1.3.2* This standard does not apply to devices that are designed to protect storage vessels against excess internal pressure due to external fire exposure or to exposure to other heat sources.

1.3.3 This standard does not apply to emergency vents for pressure generated during runaway exothermic reactions, self-decomposition reactions, internal vapor generation resulting from electrical faults, or pressure generation mechanisms other than deflagration.

1.3.4 This standard does not apply to venting of deflagrations in oxygen-enriched atmospheres or other oxidants unless supported by specific test data.

1.4 Retroactivity.

1.4.1 The provisions of this standard reflect a consensus of what is necessary to provide an acceptable degree of protection from the hazards addressed in this standard at the time the standard was issued.

1.4.1.1 Unless otherwise specified, the provisions of this standard shall not apply to facilities, equipment, structures, or installations that existed or were approved for construction or installation prior to the effective date of the standard. Where specified, the provisions of this standard shall be retroactive.

1.4.1.2 In those cases where the authority having jurisdiction determines that the existing situation presents an unacceptable degree of risk, the authority having jurisdiction shall be permitted to apply retroactively any portions of this standard deemed appropriate.

1.4.1.3 The retroactive requirements of this standard shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction, and only where it is clearly evident that a reasonable degree of safety is provided.

1.4.2 This standard shall apply to facilities on which construction is begun subsequent to the date of publication of the standard.

1.4.3 When major replacement or renovation of existing facilities is planned, provisions of this standard shall apply.

1.5 Equivalency. Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard.

1.5.1 Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

1.5.2 The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

1.6 Conversion Factors. The conversion factors in Table 1.6 are useful for understanding the data presented in this standard.

Table 1.6 Conversion Factors

Parameter	Unit	Equivalent
Length	1 m	3.28 ft
		39.4 in.
	1 in.	25.4 mm
	1 ft	305 mm
	1 μm	1.00×10^{-6} m
Area	1 m^2	10.8 ft^2
	1 $in.^2$	6.45 cm^2
Volume	1 L	61.0 $in.^3$
	1 ft^3	7.48 U.S. gal
	1 m^3	35.3 ft^3
		264 U.S. gal
	1 U.S. gal	3.78 L
		231 $in.^3$
		0.134 ft^3
Pressure	1 atm	760 mm Hg
		101 kPa
		14.7 psi
		1.01 bar
	1 psi	6.89 kPa
	1 N/m^2	1.00 Pa
	1 bar	100 kPa
		14.5 psi
		0.987 atm
	1 kg/cm^2	14.2 psi
	1 kg/m^2	0.205 lb/ft^2 (psf)
Energy	1 J	1.00 W-s
	1 Btu	1055 J
	1 J	0.738 ft-lb
K_{St}	1 bar-m/s	47.6 psi-ft/s
conversion	1 psi-ft/s	0.021 bar-m/s
Concentration	1 oz avoirdupois/ft^3	1000 g/m^3

Key to abbreviations:
atm = atmosphere
Btu = British thermal unit
cm = centimeter
ft = foot
g = gram
gal = gallon
Hg = mercury
in. = inch
J = joule
kg = kilogram
kPa = kilopascal
L = liter
lb = pound
m = meter
mm = millimeter
N = newton
oz = ounce
Pa = pascal
psf = pounds per square foot
psi = pounds per square inch
s = second
W = watt
μm = micron (micrometer)

1.7 Symbols. The following symbols are defined for the purpose of this standard:

A = area (m^2, ft^2, or $in.^2$)
A_S = internal surface area of enclosure (m^2 or ft^2)
A_v = vent area (m^2 or ft^2)
C = constant used in venting equations as defined in each specific use
dP/dt = rate of pressure rise (bar/s or psi/s)
F_r = reaction force constant (lb)
K_{St} = deflagration index for dusts (bar-m/s)
L_n = linear dimension of enclosure [m or ft (n = 1, 2, 3)]
L_x = distance between adjacent vents
L/D = length to diameter ratio (dimensionless)
LFL = lower flammable limit (percent by volume for gases, weight per volume for dusts and mists)
MEC = minimum explosible concentration (g/m^3 or oz/ft^3)
MIE = minimum ignition energy (mJ)
p = perimeter of duct cross-section (m or ft)
P = pressure (bar-g or psig)
P_{es} = enclosure strength (bar-g or psig)
P_{ex} = explosion pressure (bar-g or psig)
P_{max} = maximum pressure developed in an unvented vessel (bar-g or psig)
P_0 = initial pressure (bar-g or psig)
P_{red} = reduced pressure [i.e., maximum pressure actually developed during a vented deflagration (bar-g or psig)]
P_{stat} = static activation pressure (bar-g or psig)
dP = pressure differential (bar or psi)
S_u = fundamental burning velocity (cm/s)
S_f = flame speed (cm/s)
t_f = duration of pressure pulse (s)
UFL = upper flammable limit (percent by volume)
V = volume (m^3 or ft^3)

1.8 Pressure. All pressures are gauge pressure unless otherwise specified.

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 69, *Standard on Explosion Prevention Systems,* 2019 edition.

NFPA 70®, National Electrical Code®, 2023 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2020 edition.

NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response,* 2022 edition.

2.3 Other Publications.

2.3.1 API Publications. American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

API STD 650, *Welded Tanks for Oil Storage*, 13th edition, 2020.

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

ASME *Boiler and Pressure Vessel Code*, 2021.

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

ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds,* 2019.

2.3.4 ISO Publications. International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 6184-1, *Explosion protection systems — Part 1: Determination of explosion indices of combustible dust in air,* 1985.

2.3.5 Other Publications.

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

Δ **2.4 References for Extracts in Mandatory Sections.**

NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres,* 2021 edition.

NFPA 652, *Standard on the Fundamentals of Combustible Dust,* 2019 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary,* 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.4* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.2.7 Standard. An NFPA standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA manuals of style. When used in a generic sense, such as in the phrases "standards development process" or "standards development activities," the term "standards" includes all NFPA standards, including codes, standards, recommended practices, and guides.

3.3 General Definitions.

3.3.1 Burning Velocity. The rate of flame propagation relative to the velocity of the unburned gas that is ahead of it.

3.3.1.1 *Fundamental Burning Velocity.* The burning velocity of a laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas.

Δ **3.3.2 Combustible Dust.** A finely divided combustible particulate solid, including combustible fibers/flyings, that presents a flash-fire hazard or explosion hazard when suspended in air or the process-specific oxidizing medium over a range of concentrations. [**652,** 2019]

3.3.3 Combustion. A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light in the form of either a glow or flame.

3.3.4 Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

3.3.5 Deflagration Index. Value indicated by the use of the variable *K*. *(See 3.3.20, K_{St}.)*

3.3.6 Detonation. Propagation of a combustion zone at a velocity greater than the speed of sound in the unreacted medium.

3.3.7* Enclosure. A confined or partially confined volume.

3.3.8 Equivalent Diameter. See 3.3.19, Hydraulic Diameter.

3.3.9 Explosible. A material with a pressure ratio (maximum pressure/pressure at ignition, in absolute units) equal to or greater than 2.0 in any test when tested using the explosibility or Go/No-Go screening test described in Section 13 of ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds.*

3.3.10 Explosion. The bursting or rupturing of an enclosure or a container due to the development of internal pressure from a deflagration.

3.3.11* Flame Speed. The speed of a flame front relative to a fixed reference point.

3.3.12 Flammable Limits. The minimum and maximum concentrations of a combustible material, in a homogeneous mixture with a gaseous oxidizer, that will propagate a flame.

3.3.12.1* ***Lower Flammable Limit (LFL).*** The lowest concentration of a combustible substance in a gaseous oxidizer that will propagate a flame, under defined test conditions.

3.3.12.2 ***Upper Flammable Limit (UFL).*** The highest concentration of a combustible substance in a gaseous oxidizer that will propagate a flame.

3.3.13 Flammable Range. The range of concentrations between the lower and upper flammable limits.

3.3.14* Flash Point. The minimum temperature at which a liquid or a solid emits vapor sufficient to form an ignitible mixture with air near the surface of the liquid or the solid.

3.3.15 Flexible Filter. A filter that is rigidly mounted and deflects a distance at least equal to the distance between adjacent outer perimeters when subjected to a lateral force of 89 N (20 lb_f) or greater at the free end of a filter that is supported at only one end or the midpoint of a filter that is supported at both ends, or a filter that is not rigidly mounted and can swing freely with very little force.

3.3.16* Friction Factor, f_D. A dimensionless factor relating pressure drop in a straight duct to velocity and wetted surface area.

3.3.17 Fundamental Burning Velocity. See 3.3.1.1.

3.3.18 Gas. The state of matter characterized by complete molecular mobility and unlimited expansion; used synonymously with the term *vapor.*

3.3.19* Hydraulic Diameter. A diameter for noncircular cross sections that is determined by $4(A/p)$, where A is the cross-sectional area normal to the longitudinal axis of the space and p is the perimeter of the cross section.

3.3.20* K_{St}. The deflagration index of a dust cloud.

3.3.21 Maximum Pressure (P_{max}). See 3.3.27.1.

3.3.22 Minimum Explosible Concentration (MEC). The minimum concentration of a combustible dust cloud that is capable of propagating a deflagration through a uniform mixture of the dust and air under the specified conditions of test.

3.3.23* Minimum Ignition Energy (MIE). The minimum amount of energy released at a point in a combustible mixture that causes flame propagation away from the point, under specified test conditions.

3.3.24 Mist. A dispersion of fine liquid droplets in a gaseous medium.

3.3.25 Mixture.

3.3.25.1* ***Hybrid Mixture.*** An explosible heterogeneous mixture, comprising gas with suspended solid or liquid particulates, in which the total flammable gas concentration is ≥10 percent of the lower flammable limit (LFL) and the total suspended particulate concentration is ≥10 percent of the minimum explosible concentration (MEC).

3.3.25.2* ***Optimum Mixture.*** A specific mixture of fuel and oxidant that yields the most rapid combustion at a specific measured quantity or that yields the lowest value of the minimum ignition energy or that produces the maximum deflagration pressure.

3.3.25.3 ***Stoichiometric Mixture.*** A balanced mixture of fuel and oxidizer such that no excess of either remains after combustion. [**53,** 2021]

3.3.26* Oxidant. Any gaseous material that can react with a fuel (either gas, dust, or mist) to produce combustion.

3.3.27 Pressure.

3.3.27.1 ***Maximum Pressure (P_{max}).*** The maximum pressure developed in a contained deflagration of an optimum mixture.

3.3.27.2 ***Reduced Pressure (P_{red}).*** The maximum pressure developed in a vented enclosure during a vented deflagration.

3.3.27.3 ***Static Activation Pressure (P_{stat}).*** Pressure that activates a vent closure when the pressure is increased slowly [with a rate of pressure rise less than 0.1 bar/min (1.5 psi/min)].

3.3.28 Rate of Pressure Rise *(dP/dt)*. The increase in pressure divided by the time interval necessary for that increase to occur.

3.3.28.1* ***Maximum Rate of Pressure Rise [$(dP/dt)_{max}$].*** The slope of the steepest part of the pressure-versus-time curve recorded during deflagration in a closed vessel.

3.3.29 Reduced Pressure (P_{red}). See 3.3.27.2.

3.3.30 Replacement-in-Kind. A replacement that satisfies the design specifications of the replaced item. [**652,** 2019]

3.3.31 Static Activation Pressure (P_{stat}). See 3.3.27.3.

3.3.32 Strength.

3.3.32.1 ***Enclosure Strength (P_{es}).*** Up to two-thirds the ultimate strength for low-strength enclosures; for high-strength enclosures the enclosure design pressure sufficient to resist P_{red}.

3.3.32.2 ***Ultimate Strength.*** The pressure that results in the failure of the weakest structural component of an enclosure.

3.3.33 Vapor. See 3.3.18, Gas.

3.3.34 Vent. An opening in an enclosure to relieve the developing pressure from a deflagration.

3.3.34.1* ***Hinge Vent.*** Vent closure that is hinged on one or more sides.

3.3.34.2* ***Translating Vent.*** Vent closure that detaches from the vent opening during a vent actuation and travels downstream as one or more pieces with the venting flow.

3.3.35 Vent Closure. A pressure-relieving cover that is placed over a vent.

Chapter 4 General Requirements

4.1 Goal. The goal of this standard shall be to provide effective deflagration venting for enclosures where there is the potential for a deflagration.

4.2 Objectives.

4.2.1 Life Safety.

4.2.1.1* Deflagration venting for occupied enclosures shall prevent the structural failure of the enclosure and minimize injury to personnel in adjacent areas outside of the enclosure.

4.2.1.2 Deflagration venting for unoccupied enclosures shall prevent the rupture of the enclosure.

4.2.1.3 Deflagration venting shall be arranged to avoid injury to personnel by the vent discharge.

4.2.1.4* If the process material has a degree of health hazard (health hazard rating) of 3 or 4 according to NFPA 704, deflagration venting directed inside buildings shall not be permitted even when flame-arresting and particulate retention devices are used.

4.2.1.5 Where explosion protection is required and the process material has a degree of health hazard (health hazard rating) of 3 or 4 according to NFPA 704, alternative protection measures described in NFPA 69 shall be applied unless deflagration venting is supported by a risk assessment suitable to the authority having jurisdiction.

4.2.2 Property Protection.

4.2.2.1 Deflagration venting shall be designed to limit damage of the vented enclosure.

4.2.2.2* Deflagration venting shall be arranged to avoid ignition of adjacent property.

4.2.2.3 Deflagration venting shall be arranged to avoid blast damage to adjacent property.

4.2.2.4 Deflagration venting shall be arranged to avoid projectile damage to adjacent property.

4.2.3 Hazard Analysis.

4.2.3.1 The design basis deflagration hazard scenario shall be identified and documented.

4.2.3.2 A documented risk evaluation acceptable to the authority having jurisdiction shall be permitted to be conducted to determine the level of protection to be provided.

4.3 Compliance Options.

4.3.1 Options. Deflagration venting meeting the goals and objectives of Sections 4.1 and 4.2 shall be provided in accordance with either of the following:

(1) Performance-based provisions of 4.3.2
(2) Prescriptive-based provisions of 4.3.3

4.3.2 Performance-Based Design. A performance-based design shall be in accordance with Chapter 5 of this standard.

4.3.3 Prescriptive-Based Design. A prescriptive-based design shall be in accordance with Chapters 6 through 11 of this standard.

Chapter 5 Performance-Based Design Option

5.1 General Requirements.

5.1.1* Qualifications. The performance-based design shall be prepared by a person with qualifications acceptable to the authority having jurisdiction.

5.1.2 Design Documentation. The design methodology and data sources shall be documented and maintained for the life of the protected enclosure.

5.1.3 Maintenance of Design Features.

5.1.3.1 To continue meeting the performance goals and objectives of this standard, the design features required for each deflagration vent shall be maintained for the life of the protected enclosure.

5.1.3.2 Any changes to the design shall require approval of the authority having jurisdiction prior to the actual change.

5.2 Performance Criteria.

5.2.1 Deflagration vent design shall be based on the documented hazard scenario.

5.2.2 Deflagration vents shall limit the reduced pressure (P_{red}) within an enclosure and any attached vent ducts to meet the objectives in 4.2.1.1 and 4.2.1.2.

5.2.3 Deflagration Vent Discharge.

5.2.3.1 Combustible materials outside the enclosure shall not attain their ignition temperature from flame or hot gases discharged from a deflagration vent.

5.2.3.2* Blast load from deflagration vent discharge shall limit the risk of damage to exposed structures.

5.2.3.3* Access to spaces into which deflagration vents discharge shall be restricted so as to minimize, to a level acceptable to the authority having jurisdiction, the risk of injury from flame, hot gases, hot particles, or projectiles.

5.2.4 Inspection and Maintenance.

5.2.4.1 Deflagration venting shall be regularly inspected and maintained to confirm the ability of the venting to perform as designed.

5.2.4.1.1 If no guidance is given from the performance-based design documents, the requirements of Chapter 11 of this standard shall apply.

5.2.4.2 Inspection and maintenance shall be documented and retained for at least 1 year or the last three inspections.

Chapter 6 Fundamentals of Venting of Deflagrations

6.1* Basic Concepts.

6.1.1* The deflagration index, *K*, shall be computed from the maximum rate of pressure rise attained by combustion in a closed vessel with volume, *V*, and shall be defined by the following equation:

[6.1.1]

$$K = \left(\frac{dP}{dt}\right)_{max} \cdot V^{1/3}$$

6.1.2* For dusts, K_{St} and P_{max} shall be determined in approximately spherical calibrated test vessels of at least 20 L capacity per ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*.

6.1.2.1* It shall be permitted to determine K_{St} and P_{max} per ISO 6184-1, *Explosion protection systems — Part 1: Determination of explosion indices of combustible dusts in air*.

6.1.2.2 The owner/user shall be permitted to test the dust with moisture content and particle size that deviates from the recommended conditions established by the method described in 6.1.2 or 6.1.2.1, provided a documented assessment acceptable to the authority having jurisdiction has been performed prior to using these K_{St} and P_{max} values to determine vent sizing.

6.1.2.3* For aluminum, hafnium, magnesium, tantalum, titanium, zirconium, and similar alloys or mixtures with adiabatic flame temperature higher than 3300°C, unless K_{St} and P_{max} are determined in nominal 1 m^3 or larger calibrated test vessels, the K_{St} value shall be multiplied by a factor of 2 for application of the design methods.

6.1.3 For gases, P_{max} shall be determined in approximately spherical calibrated test vessels of at least 5 L (1.3 gal) capacity with initially quiescent mixture with low energy ignition source (i.e., less than 100 J).

6.2 Mixtures.

6.2.1 Gas Mixtures.

6.2.1.1 Where the hazard consists of a flammable gas mixture, the vent size shall be based on the fundamental burning velocity of the mixture.

6.2.1.2 Where the gas mixture composition is not certain, the vent size shall be based on the component having the highest fundamental burning velocity.

6.2.2 Dust Mixtures.

6.2.2.1 Where the hazard consists of a dust mixture, the vent size shall be based on the K_{St} and P_{max} of the mixture.

6.2.2.2 Where the dust mixture composition is not certain, the vent size shall be based on the highest K_{St} of all components and the highest P_{max} of all components.

6.2.3* Hybrid Mixtures.

6.2.3.1 For hybrid mixtures, the vent size shall be based on the equivalent mixture K_{St} as determined by test.

6.2.3.2 Where test data are not available for hybrid mixtures with gases that have combustion characteristics similar to those of propane (fundamental burning velocity ≤1.3 times that of propane) and St-1 and St-2 dusts, the design shall be permitted to be based upon P_{max} = 10 bar-g and K_{St} = 500 bar-m/s.

6.2.4* Foams of Combustible Liquids. Design of deflagration venting for foams of combustible liquids shall be based on tests performed on the specific foam.

6.3 Enclosure Design and Support.

6.3.1 Enclosure Design Pressure Selection Criteria.

6.3.1.1* P_{red} shall not exceed two-thirds of the ultimate strength for the vented enclosure, provided deformation of the equipment can be tolerated.

6.3.1.2* Where deformation cannot be tolerated, P_{red} shall not exceed two-thirds of the yield strength for the vented enclosure.

6.3.1.3* For enclosures designed using the ASME *Boiler and Pressure Vessel Code* or similar codes, the maximum allowable working pressure, herein designated as P_{mawp}, shall be determined by calculation.

6.3.1.3.1 Such determinations shall include an allowable stress for the enclosure material of construction, which is less than the measured yield stress and the measured ultimate stress for the material of construction.

6.3.1.3.2 Given a P_{mawp}, P_{red} shall be selected based on the following conditions as defined by Equation 6.3.1.3.2a or Equation 6.3.1.3.2b:

(1) Permanent deformation, but not rupture, of the enclosure can be accepted:

[6.3.1.3.2a]

$$P_{red} \le \left(\tfrac{2}{3}\right) \cdot F_u \cdot P_{mawp}$$

(2) Permanent deformation of the enclosure cannot be accepted:

[6.3.1.3.2b]

$$P_{red} \le \left(\tfrac{2}{3}\right) \cdot F_y \cdot P_{mawp}$$

where:

P_{red} = maximum pressure developed in a vented enclosure [bar-g (psig)]

F_u = ratio of ultimate stress of the enclosure to the allowable stress of the enclosure per the ASME *Boiler and Pressure Vessel Code*

P_{mawp} = enclosure design pressure [bar-g (psig)] according to ASME *Boiler and Pressure Vessel Code*

F_y = ratio of the yield stress of the enclosure to the allowable stress of the materials of construction of the enclosure per the ASME *Boiler and Pressure Vessel Code*

6.3.1.4 Ductile design considerations shall be used for materials subject to brittle failure, such as cast iron.

6.3.1.4.1 Special reinforcing shall be considered.

6.3.1.4.2 If such reinforcing is not used, the maximum allowable design stress shall not exceed 25 percent of the ultimate strength.

6.3.2* Venting shall be sufficient to prevent the maximum pressure that develops within the enclosure, P_{red}, from exceeding the enclosure strength, P_{es}, including the dynamic effect of the rate of pressure rise, as expressed by a dynamic load factor (DLF):

[6.3.2]

$$P_{red} \le \frac{P_{es}}{DLF}$$

where:
P_{red} = maximum pressure developed during venting [bar-g (psig)]
P_{es} = enclosure strength evaluated based on static pressure calculations for either deformation or burst [bar-g (psig)]
DLF = X_m/X_s
X_m = maximum dynamic deflection
X_s = static deflection or, in other words, the displacement produced in the system when the peak load is applied statically

6.3.2.1 In the absence of detailed structural response analysis, it shall be permitted to assume a worst-case value of DLF = 1.5 and design based on the weakest structural element of the enclosure.

6.3.2.2* It shall be permitted to modify the value of DLF based on a documented analysis of the vented explosion pressure profile and enclosure structural response.

6.3.3 All structural elements and supports shall be included in the design calculations.

6.3.3.1* The weakest structural element, as well as any equipment or other devices that can be supported by structural elements, shall be identified.

6.3.3.2 Where designing an enclosure to prevent catastrophic failure while still allowing permanent deformation, the normal dead and live loads shall not be relied on to provide restraint.

6.3.3.3 Structural members shall be designed to support the total load.

6.3.3.4 Doors, windows, ducts, or other openings in walls that are intended to be pressure resistant shall also be designed to withstand P_{red}.

6.3.4 Relieving Walls or Roof.

6.3.4.1 Nothing in this standard shall prohibit the use of an enclosure with relieving walls, or a roof, provided the potential for damage and injury is addressed.

6.3.4.2 A lightweight roof shall be permitted to be used as a vent, provided its movement can be tolerated and provided its movement is not hindered by ice or snow.

6.3.5 Enclosure Support Criteria.

6.3.5.1* The supporting structure for the enclosure shall be strong enough to withstand any reaction forces that develop as a result of operation of the vent, including the dynamic effect of the rate of force application, as expressed by a DLF.

6.3.5.2* The following equation shall be used to determine the reaction force applicable to enclosures without vent ducts:

[6.3.5.2]

$$F_r = a \cdot DLF \cdot A_v \cdot P_{red}$$

where:
F_r = maximum reaction force resulting from combustion venting [kN (lbf)]
a = units conversion [100 (1)]
DLF = 1.2
A_v = vent area [m^2 (in.^{2})]
P_{red} = maximum pressure developed during venting [bar-g (psig)]

6.3.5.3* Modification of the value of DLF based on a documented analysis of the vented explosion pressure profile and the supporting structure's response shall be permitted.

6.3.5.4* The total reaction force shall be applied at the geometric center of the vent.

6.3.5.4.1 The calculation of reaction forces on the enclosure shall be permitted to be eliminated when all of the following conditions are satisfied:

(1) Vent panels are of the rupture diaphragm type.
(2) Vent panels are located at opposing positions on the enclosure.
(3) The P_{stat} of each vent panel is equal and less than or equal to 0.1 bar-g.
(4) Vent panels are of equal area.

6.3.5.5* The duration of the reaction force shall be calculated according to Equation 6.3.5.5, which is shown to represent the available duration data within a minus 37 percent and a plus 118 percent:

[6.3.5.5]

$$t_f = b \cdot \left(\frac{P_{max}}{P_{red}}\right)^{0.5} \cdot \left(\frac{V}{A_v}\right)$$

where:
t_f = duration of pressure pulse after vent opening (s)
b = $4.3 \cdot 10^{-3} (1.3 \cdot 10^{-3})$
P_{max} = maximum pressure developed in an unvented explosion [bar-g (psig)]
P_{red} = maximum pressure developed during venting [bar-g (psig)]
V = enclosure volume [m^3 (ft^3)]
A_v = area of vent (without vent duct) [m^2(ft^2)]

6.3.5.6* The total impulse that a structure supporting a vented enclosure experiences during deflagration venting shall be expressed by the following equation:

[6.3.5.6]

$$I = 0.52 \cdot F_r \cdot t_f$$

where:
I = total impulse experienced by supporting structure [kN-s (lbf-s)]
F_r = maximum reaction force resulting from combustion venting [kN (lbf)]
t_f = duration of pressure pulse after vent opening (s)

6.4* Enclosure Length-to-Diameter Ratio and Vent Variables.

6.4.1 For silos and other enclosures that can be vented at only one end, the maximum effective vent area to use to determine the expected P_{red} shall be the enclosure cross section.

6.4.2 For enclosures that can be vented at more than one point along the major axis, the vents shall be permitted to be distributed along the major axis and sized based on the length to diameter (*L/D*) between vents.

6.4.2.1 The maximum effective vent area at any point along the major axis shall be the enclosure cross section.

6.4.3* *L/D* of Elongated Enclosures.

6.4.3.1 The *L/D* of an elongated enclosure shall be determined based upon the general shape of the enclosure, the location of the vent, the shape of any hopper extensions, and the farthest distance from the vent at which the deflagration could be initiated.

6.4.3.2 The maximum flame length along which the flame can travel, *H*, shall be determined based on the maximum distance, taken along the central axis, from the farthest end of the enclosure to the opposite end of the vent.

6.4.3.2.1 When multiple vents are provided, a single value of *H*, and *L/D,* shall be permitted to be determined for the enclosure based on the farthest vent.

6.4.3.2.2 When multiple vents are located along the central axis, the value of *H*, and *L/D*, shall be permitted to be determined for each section using the maximum distance from the closest end of one vent to the opposite end of the next vent.

6.4.3.3 The effective volume of the enclosure, V_{eff}, shall be determined based on the volume of that part of the enclosure through which the flame can pass as it travels along the maximum flame length, *H.*

6.4.3.3.1 Partial volume *(see Section 8.4)* shall not be considered in the determination of effective volume per this section.

6.4.3.3.2 When multiple vents are provided, a single value of V_{eff} shall be permitted to be determined for the enclosure based upon the farthest vent.

6.4.3.3.3 When multiple vents are located along the central axis, V_{eff} shall be permitted to be determined for each section using the maximum distance from the closest end of one vent to the opposite end of the next vent.

6.4.3.3.4 When V_{eff} is less than the total volume of the enclosure, only those vents located within the effective volume shall be considered as providing venting for the event.

6.4.3.4 It shall be permitted to conservatively determine both *H* and V_{eff}, or *H* alone, but not V_{eff} alone, based on the total enclosure, irrespective of vent location.

6.4.3.5 The effective area, A_{eff}, shall be determined by dividing V_{eff} by *H.*

6.4.3.6 The effective hydraulic diameter, D_{he}, for the enclosure shall be determined based on the general shape of the enclosure taken normal to the central axis:

[6.4.3.6]

$$D_{he} = 4 \cdot \left(\frac{A_{eff}}{p} \right)$$

where:
p = perimeter of the general shape.

6.4.3.6.1 Where the enclosure and any hopper extension are generally cylindrical, the perimeter, p, shall be permitted to be determined based on a circular cross section, given the following:

[6.4.3.6.1]

$$D_{he} = \left(\frac{4 \cdot A_{eff}}{\pi} \right)^{0.5}$$

6.4.3.6.2 Where the enclosure and any hopper extension are generally rectangular or square, and the aspect ratio of the largest cross section is between 1 and 1.2, the perimeter shall be permitted to be determined based on a square cross section, given the following:

[6.4.3.6.2]

$$D_{he} = \left(A_{eff} \right)^{0.5}$$

6.4.3.6.3 Where the enclosure and any hopper extension are generally rectangular, and the aspect ratio, *R*, of the largest cross section is greater than or equal to 1.2, the perimeter shall be permitted to be determined based on the aspect ratio of the largest cross section, given the following:

[6.4.3.6.3]

$$D_1 = \left(\frac{A_{eff}}{R} \right)^{0.5}$$
$$p = 2 \cdot (R + 1) \cdot D_1$$
$$D_{he} = 4 \cdot \frac{A_{eff}}{p}$$

6.4.3.7 *L/D* for use in this standard shall be set equal to H/D_{he}.

6.4.4* The vent areas shall be permitted to be reduced from those specified in Chapters 7 and 8 if large-scale tests show that the resulting damage is acceptable to the user and the authority having jurisdiction.

6.4.5* The owner/user shall be permitted to install vents that are larger in area, are lower in density, or relieve at lower pressure than the minimum requirements determined from application of Chapter 7 or Chapter 8, as appropriate.

6.5 Vent Closure Operation.

6.5.1* The vent opening shall be free and clear.

6.5.2 Vent closure operation shall not be hindered by deposits of snow, ice, paint, corrosion, or debris, or by the buildup of deposits on their inside surfaces.

6.5.2.1* The materials that are used shall be chosen to minimize corrosion from process conditions within the enclosure and from ambient conditions on the nonprocess side.

6.5.2.2 Clear space shall be maintained on both sides of a vent to enable operation without restriction and without impeding a free flow through the vent.

6.5.2.3 To prevent snow and ice accumulation, where the potential exists, and to prevent entry of rainwater and debris, the vent or vent duct exit shall not be installed in the horizontal position, unless any of the alternative methods in 6.5.2.3.1 are followed.

6.5.2.3.1 Any of the following alternative methods of protection for horizontal vent or vent duct exits shall be permitted:

(1) Fixed rain hats where P_{red} effects on vent area are included in accordance with Section 8.5 and restraint design includes maximum force from P_{red} applied over the area
(2) Weather covers mounted at an angle sufficient to shed snow, with restraints designed and tested to prevent the cover from becoming a free projectile, where inertia effects of the additional weather cover mass and P_{stat} of the cover are included
(3) Deicing provisions such as a heated vent closure

6.5.3 Restraining devices shall not impede the operation of the vent or vent closure device. *(See Chapter 10.)*

6.5.4 A vent closure shall release at its P_{stat} or within a pressure range specified by the vent closure manufacturer.

6.5.5 A vent closure shall reliably withstand pressure fluctuations that are below P_{stat}.

6.5.6 A vent closure shall withstand vibration or other mechanical forces to which it can be subjected.

6.5.7* P_{stat}, including the manufacturer's negative tolerance, shall be greater than the anticipated loading equivalent to the local design wind speed such that wind load will not cause the vent to open.

6.5.7.1 The area calculation shall be performed using the nominal value of P_{stat}.

6.5.8* P_{stat}, including the manufacturer's positive tolerance, shall be less than the intended P_{red}.

6.5.8.1 The area calculation shall be performed using the nominal value of P_{stat}.

6.5.9* Vent closures shall be maintained in accordance with Chapter 11.

6.6* Consequences of a Deflagration.

6.6.1 The material discharged from an enclosure during the venting of a deflagration shall be directed outside to a safe location.

Δ **6.6.2** Property damage and injury to personnel due to material ejection during venting shall be minimized or avoided by locating vented equipment outside of buildings and away from normally occupied areas. *(See 6.8.2 and 6.8.3 for gases and dusts, respectively.)*

Δ **6.6.2.1** Deflagration vents shall not be located in positions closer to air intakes than the distances prescribed by the fireball length *(see 6.8.2 and 6.8.3)*.

Δ **6.6.2.2** Deflagration vents shall be permitted to be located closer to buildings and normally occupied areas than the distances determined by 6.8.2 or 6.8.3, provided a documented risk assessment acceptable to the authority having jurisdiction has been performed.

6.6.2.3* Where a deflector is provided in accordance with 6.6.2.4 and 6.6.2.5, it shall be permitted to reduce the axial (front-centerline) hazard distance to 50 percent of the value calculated in 6.8.2 or 6.8.3. This method shall not be used to reduce the radial hazard distance as defined in 6.8.2 and 6.8.3 [115].

6.6.2.4* A deflector design shall meet all of the following criteria:

(1) The deflector for a rectangular vent shall be geometrically similar to the vent and sized with a linear scale factor of at least 1.75. For a round vent, the deflector shall be square shaped and at least 1.75 times the vent's hydraulic diameter.
(2) The deflector shall be inclined 45 degrees to 60 degrees from the vent axis, as shown in Figure 6.6.2.4.
(3) The centerline of the deflector shall be coincident with the vent axis.
(4) The distance from the vent opening to the deflector on the vent axis shall be $1.5D_{hv}$, where D_{hv} is the vent's hydraulic diameter.
(5) The deflector plate shall be mounted so as to withstand the force exerted by the vented explosion, calculated as P_{red} times the deflector area.
(6) The deflector location shall not interfere with the operation of hinged vent closures.

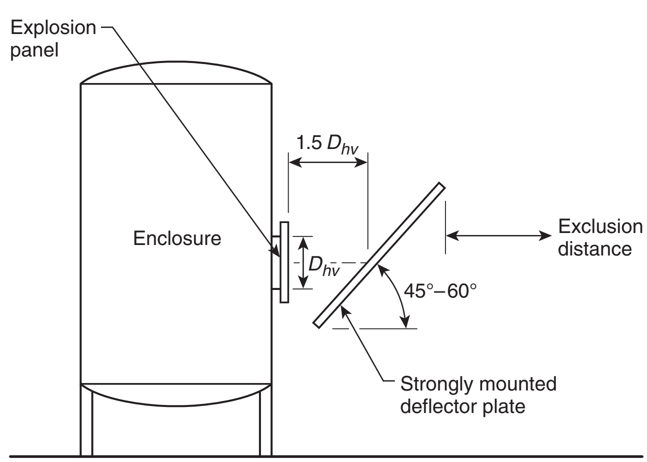
6.6.2.5* A deflector to limit flame length shall not be used as follows:

(1) For enclosure volume greater than 20 m^3 (706 ft^3)
(2) With a tethered or translating vent closure

6.6.3 Warning signs shall be posted to indicate the location of a vent.

6.7 Effects of Vent Inertia.

6.7.1* Counterweights and insulation added to panels shall be included in the total mass.



Δ **FIGURE 6.6.2.4 Design for an Installation of a Blast Deflector Plate.**

6.7.2* A vent closure shall have low mass to minimize inertia, thereby reducing opening time.

6.7.3 If the total mass of a closure divided by the area of the vent opening does not exceed the panel densities calculated by Equation 7.4.2 and Equation 8.3.2 (for gas and dust, respectively), all vent area correlations presented in this standard shall be permitted to be used without correction [111].

6.7.4* Hinged closures shall be permitted to be used, provided the following conditions are met:

(1) There are no obstructions in the path of the closure that prevent it from opening.
(2) Operation of the closure is not restrained by corrosion, sticky process materials, or paint.

N **6.8* Fireball Dimensions.** Measures shall be taken to reduce the risk to personnel and equipment from the effects of fireball temperature and pressure.

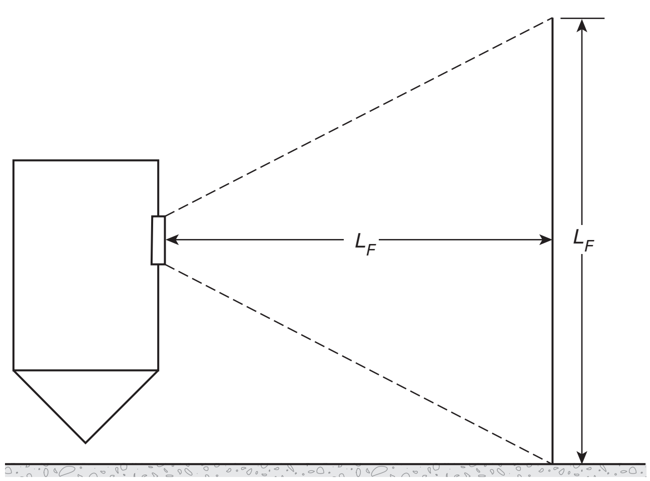
N **6.8.1** A documented risk assessment shall be permitted to be used to reduce the hazard distances calculated in 6.8.2, 6.8.3, and 6.8.7.

N **6.8.2* Gas Deflagration Fireball Dimensions.** In the case of gas deflagration venting, L_F, the maximum axial length, width, and height of the fireball hazard zone distributed around the centerline of each vent discharge *(see Figure 6.8.2)* shall be expressed by Equation 6.8.2:

Δ **[6.8.2]**

$$L_F = 3.1 \cdot \left(\frac{V}{n}\right)^{0.402}$$

where:
L_F = axial length, width, and height of fireball hazard zone distributed around the centerline of the vent (m)
V = volume of vented enclosure (m^3)
n = number of independent vents, with vent centers spaced at least 4 times the hydraulic diameter of the largest vent *(see 6.8.4)*



N **FIGURE 6.8.2 Fireball Dimensions**

N **6.8.3* Dust Deflagration Fireball Dimensions.** In the case of dust deflagration venting, L_F, the maximum axial length, width, and height of the fireball hazard zone distributed around the centerline of each vent discharge *(see Figure 6.8.2)* shall be expressed by Equation 6.8.3:

Δ **[6.8.3]**

$$L_F = K \cdot \left(\frac{V}{n}\right)^{1/3}$$

where:
L_F = axial length, width, and height of fireball hazard zone distributed around the centerline of the vent (m)
K = flame length factor: 10 for metal dusts, 8 for chemical and agricultural dusts
V = volume of vented enclosure (m^3)
n = number of independent vents,with vent centers spaced at least 4 times the hydraulic diameter of the largest vent *(see 6.8.4)*

N **6.8.4* Definition of Independent Vents.** Independent vents shall meet the requirements in 6.8.4.

N **6.8.4.1*** For vents located at a single elevation and spaced around the circumference of a cylindrical vessel, the normal to the adjacent vents shall be separated by at least 60 degrees or 4 hydraulic diameters of the largest vent.

N **6.8.4.2** Vents located on different sides of a rectangular enclosure shall be considered independent.

N **6.8.4.3*** For vents located along the axis of a cylindrical vessel or on the same side of a rectangular enclosure, the center of the vents shall be separated by at least four times the hydraulic diameter of the largest vent.

N **6.8.4.4** Vents that do not meet the requirements of 6.8.4 are allowed but shall not be counted separately to calculate n in 6.8.2 or 6.8.3.

N **6.8.5** Axial distance, calculated by Equation 6.8.3, shall be limited to 60 m [104].

N **6.8.6*** Axial distance calculated by Equation 6.8.2 shall not be limited for gases.

N **6.8.7*** Where venting is from a cubic vessel, the $P_{max,a}$ value shall be indicated approximately by Equation 6.8.7 [108]:

[6.8.7]

$$P_{max,a} = 0.2 \cdot P_{red} \cdot A_v^{0.1} \cdot V^{0.18}$$

where:
$P_{max,a}$ = external pressure (bar-g)
P_{red} = reduced pressure (bar-g)
A_v = vent area (m^2)
V = enclosure volume (m^3)

N **6.8.8** For distances longer than $\alpha \cdot L_F$, the maximum external pressure, $P_{max,r}$, shall be indicated approximately by Equation 6.8.8:

Δ **[6.8.8]**

$$P_{max,r} = P_{max,a}\left(\alpha \cdot L_F / r\right)$$

where:

$P_{max,r}$ = maximum external pressure
$P_{max,a}$ = external pressure (bar-g)
α = 0.20 for horizontal vents and 0.25 for vertical (upward directed) vents
L_F = maximum length of fireball (m)
r = distance from vent (m)

N **6.8.9** Equation 6.8.3, Equation 6.8.7, and Equation 6.8.8 shall be valid for the following conditions:

(1) Enclosure volume: $0.3\ m^3 \leq V \leq 10{,}000\ m^3$
(2) Reduced pressure: $P_{red} \leq 1$ bar-g
(3) Static activation pressure: $P_{stat} \leq 0.1$ bar-g
(4) Deflagration index: $K_{St} \leq 300$ bar-m/s for Equation 6.8.3, $K_{St} \leq 200$ bar-m/s for Equation 6.8.7 and Equation 6.8.8
(5) $P_{max} \leq 9$ bar-g

6.9 Effects of Vent Discharge Ducts.

6.9.1 If it is necessary to locate enclosures with deflagration vents inside of buildings, vent ducts shall be used to direct vented material from the enclosure to the outdoors.

6.9.2 A vent duct shall have a cross-sectional area at least as great as that of the vent itself but shall be limited to no more than 150 percent of the vent itself at any point in the vent duct.

6.9.3 When either a single enclosure or multiple close-coupled modular enclosures with a common inlet duct are protected by multiple deflagration vents, it shall be permitted to manifold multiple vent discharges within a single vent discharge duct under the following conditions:

(1) Each vent closure has the same nominal shape, area, inertia, and P_{stat}.
(2) Each vent discharge duct connects individually to a safe discharge location.
(3) The vent discharge duct has a single continuous inlet perimeter without branch connections.
(4) The vent discharge duct cross-sectional area is everywhere less than or equal to 1.5 times the total manifolded vent area *(see Figure 6.9.3)*.

6.9.4 When either a single enclosure or multiple close-coupled modular enclosures with a common inlet duct are protected by multiple deflagration vents, it shall be permitted to provide individual vent discharge ducts for each vent under the following conditions:

(1) Each vent closure has the same shape, area, inertia, and P_{stat}.

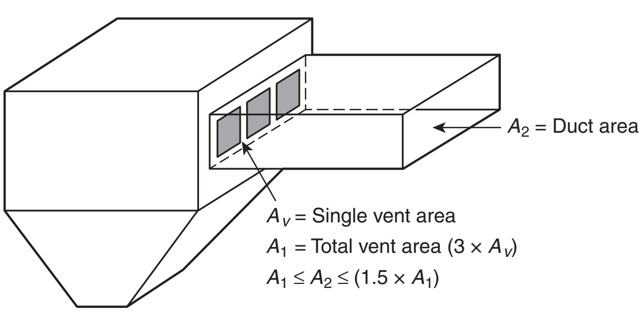


FIGURE 6.9.3 Example Range of Vent Duct Area for Manifolded Vent Duct.

(2) Each vent discharge duct connects individually to a safe discharge location.
(3) Each vent discharge duct cross-sectional area is everywhere less than or equal to 1.5 times the vent area.
(4) Each vent discharge duct has the same nominal cross-sectional area and configuration.
(5) Corrections for vent discharge duct effects use the longest duct length for all ducts.

6.9.5* Vent area calculations shall include the effects of vent ducts. *(See Sections 7.5 and 8.5 for gases and dusts, respectively.)*

6.9.6 Vent ducts and nozzles with total lengths of less than one hydraulic diameter, relative to the calculated installed vent area, irrespective of the duct area, shall not require a correction to increase the vent area.

6.9.7 Ducts that are used to direct vented gases from the vent to the outside of a building shall be of noncombustible construction and shall be strong enough to withstand the expected P_{red}.

6.9.7.1 When vent ducts include bends, the support calculations shall include reaction forces based on the expected P_{red}.

6.9.7.2* Where vent ducts include bends, they shall be long radius.

6.10* Venting with Flame Arresting and Particulate Retention.

6.10.1* Where external venting is not feasible or desirable, such as where the location of equipment outdoors or adjacent to exterior walls is impractical, or where ducting is too long to be effective, a device that operates on the principles of flame arresting and particulate retention shall be permitted to be used.

6.10.2 These devices shall be listed or approved and shall be considered only for use within the tested range of K_{St}, dust loading, dust type, enclosure volume, and P_{red}.

N **6.10.3** When these devices are being used with metal dusts, in addition to the requirements of 6.10.2, the listing or approval shall specify the maximum metal adiabatic flame temperature.

6.10.4* The deflagration venting area provided for the protected enclosure shall be increased to compensate for the reduction in venting efficiency due to the presence of the device.

6.10.5* Limitations. The following limitations shall apply:

(1) Where a flame-arresting vent system and a particulate retention vent system are used inside a building, a documented risk analysis shall be performed to ensure safe installation. Considerations shall include, but are not limited to, the following:
  (a) Proximity of personnel
  (b) Volume of room
  (c) Possibility of combustible mixtures exterior to the equipment
  (d) Possible toxic gaseous and particulate emissions
(2) A flame-arresting vent system and a particulate retention vent system shall be sized to ensure that P_{red} remains within the enclosure design limits.

6.10.6* The areas adjacent to the discharge point shall be clear of combustible dusts.

6.10.7* All devices shall be equipped with an indicating sensor that shall notify the user upon activation of the device.

6.10.8* Flame-arresting vent devices without particulate retention shall be used only where a restricted area around the device has been identified and access during operation of the protected equipment is prohibited.

6.10.8.1 The restricted area shall be based on the external volume that can be filled with an explosible dust-air cloud during the venting process.

6.10.8.2 The restricted area shall be identified as an electrically classified (hazardous) area in accordance with *NFPA 70*.

6.10.8.3 There shall be no normally present ignition sources in the restricted area, including, but not limited to, hot surfaces exceeding the auto-ignition temperature and open flames.

6.10.9* Devices without particulate retention elements that reset after relieving pressure shall be inspected after a deflagration to ensure that the design performance has not been affected.

Chapter 7 Venting Deflagrations of Gas Mixtures and Mists

7.1 Introduction.

7.1.1* This chapter shall apply to the design of deflagration vents for enclosures that contain a flammable gas or combustible mist and that have an *L/D* of ≤5.

7.1.1.1 This chapter shall be used in conjunction with the information contained in the rest of this standard.

7.1.1.2 Chapter 6 and 3.3.32.1 shall be reviewed before using this chapter.

7.2 Venting by Means of Low Inertia Vent Closures.

Δ **7.2.1 Low Inertia Vent Closure Equations for Low P_{red}.** When $P_{red} \leq 0.5$ bar-g, the minimum required vent area, A_{v0}, shall be determined by Equation 7.2.1a and Equation 7.2.1b:

[7.2.1a]

$$A_{v0} = \frac{A_s C}{\sqrt{P_{red}}}$$

[7.2.1b]

$$C = \frac{S_u \rho_u \lambda}{2 G_u C_d}\left[\left(\frac{P_{max}+1}{P_0+1}\right)^{1/\gamma b} - 1\right](P_0+1)^{1/2}$$

where:

A_{v0} = the vent area calculated from Equation 7.2.1a (m^2)
A_s = the enclosure internal surface area determined according to 7.2.5 (m^2)
P_{red} = the maximum pressure developed in a vented enclosure during a vented deflagration (bar-g)
S_u = fundamental burning velocity of gas-air mixture (m/s)
ρ_u = mass density of unburned gas-air mixture (kg/m^3)
λ = ratio of gas-air mixture burning velocity accounting for turbulence and flame instabilities in vented deflagration to the fundamental (laminar) burning velocity, determined according to 7.2.6
G_u = unburned gas-air mixture sonic flow mass flux (kg/m^2-s)
C_d = vent flow discharge coefficient, determined according to 7.2.4
P_{max} = the maximum pressure developed in a contained deflagration by ignition of the same gas-air mixture (bar-g)
P_0 = the enclosure pressure prior to ignition (bar-g)
γ_b = ratio of specific heats for burned gas-air mixture

7.2.1.1 The *C* value for flammable gases and vapors with a P_{max} value less than 9 bar-g and a stoichiometric (near worst case) fuel concentration no greater than about 10 percent shall be permitted to be calculated using Equation 7.2.1.1 for use in Equation 7.2.1a:

[7.2.1.1]

$$C = 0.0223 \lambda S_u \text{ bar}^{1/2} \text{ for } S_u \text{ in m/s}$$

7.2.1.2 When applying Equation 7.2.1a, the value of P_{stat} shall be less than P_{red} as specified for the following conditions:

(1) For $P_{red} \leq 0.1$ bar-g (1.5 psig), $P_{stat} \leq P_{red} - 0.024$ bar-g (50 psf).
(2) For $P_{red} > 0.1$ bar-g (1.5 psig), $P_{stat} < 0.75\ P_{red}$.

Δ **7.2.2 Low Inertia Vent Closure Equations for High P_{red}.** When $P_{red} > 0.5$ bar-g, the minimum required vent area, A_{v0}, shall be determined from Equation 7.2.2a and Equation 7.2.2b:

[7.2.2a]

$$A_{v0} = A_s \frac{\left[1 - \left(\frac{P_{red}+1}{P_{max}+1}\right)^{1/\gamma b}\right]}{\left[\left(\frac{P_{red}+1}{P_{max}+1}\right)^{1/\gamma b} - \delta\right]} \frac{S_u \rho_u}{G_u} \frac{\lambda}{C_d}$$

[7.2.2b]

$$\delta = \frac{\left(\frac{P_{stat}+1}{P_0+1}\right)^{1/\gamma b} - 1}{\left(\frac{P_{max}+1}{P_0+1}\right)^{1/\gamma b} - 1}$$

where:

A_{v0} = the vent area calculated from Equation 7.2.2a (m^2)
A_s = the enclosure internal surface area determined according to 7.2.5 (m^2)
P_{red} = the maximum pressure developed in a vented enclosure during a vented deflagration (bar-g)
S_u = fundamental burning velocity of gas-air mixture (m/s)
ρ_u = mass density of unburned gas-air mixture (kg/m^3)
λ = ratio of gas-air mixture burning velocity accounting for turbulence and flame instabilities in vented deflagration to the fundamental (laminar) burning velocity, determined according to 7.2.6
G_u = unburned gas-air mixture sonic flow mass flux (kg/m^2-s)

C_d = vent flow discharge coefficient, determined according to 7.2.4
P_{max} = the maximum pressure developed in a contained deflagration by ignition of the same gas-air mixture (bar-g)
P_0 = the enclosure pressure prior to ignition (bar-g)
γ_b = ratio of specific heats for burned gas-air mixture
P_{stat} = nominal vent deployment or burst pressure (bar-g)

7.2.3* Gas-Air Mixture Parameters.

7.2.3.1* The design of a deflagration vent for an enclosure containing a combustible mist shall be based on a value of S_u equal to 0.46 m/s unless a value of S_u applicable to the mist of a particular substance is determined by test.

7.2.3.2* The burning velocity, S_u, shall be the maximum value for any gas concentration unless a documented hazard analysis shows that there is not a sufficient amount of gas to develop such a concentration.

7.2.3.3 It shall be permitted to assume a mass density of unburned gas-air mixture, ρ_u, equal to 1.2 kg/m^3 for flammable gases with stoichiometric concentrations less than 5 vol % and initially at ambient temperature.

7.2.3.4 It shall be permitted to assume an unburned gas-air mixture sonic flow mass flux, G_u, equal to 230.1 kg/m^2-s for an enclosure initially at ambient temperatures.

7.2.3.5 It shall be permitted to assume the ratio of specific heats for burned gas-air mixture, γ_b, equal to 1.15 for flammable gases with stoichiometric concentrations less than 5 vol % and initially at ambient temperatures.

7.2.3.6 It shall be permitted to assume the unburned gas-air mixture dynamic viscosity, μ_u, equal to 1.8 × 10^{-5} kg/m-s for flammable gases with stoichiometric concentrations less than 5 vol % and initially at ambient temperatures.

7.2.3.7 It shall be permitted to assume the unburned gas-air mixture sound speed, a_u, equal to 343 m/s for flammable gases with stoichiometric concentrations less than 5 vol % and initially at ambient temperatures.

7.2.4 Enclosure Parameters.

7.2.4.1 The value of C_d shall be 0.70 unless the vent occupies an entire wall of the enclosure, in which case a value of 0.80 shall be permitted to be used.

7.2.4.2* The value of P_0 shall be greater than or equal to the normal operating pressure and chosen to represent the likely maximum pressure at which a flammable gas mixture can exist at the time of ignition.

7.2.4.3* For initially elevated pressures, the enclosure shall be located to accommodate the blast wave.

7.2.5* Calculation of Internal Surface Area.

7.2.5.1* The internal surface area, A_s, shall include the total area that constitutes the perimeter surfaces of the enclosure that is being protected.

7.2.5.1.1 Nonstructural internal partitions that cannot withstand the expected pressure shall not be considered to be part of the enclosure surface area.

7.2.5.1.2 The enclosure internal surface area, A_S, in Equation 7.2.2 includes the roof or ceiling, walls, floor, and vent area and shall be based on simple geometric figures.

7.2.5.1.3 Surface corrugations and minor deviations from the simplest shapes shall not be taken into account.

7.2.5.1.4 Regular geometric deviations, such as saw-toothed roofs, shall be permitted to be "averaged" by adding the contributed volume to that of the major structure and calculating A_S for the basic geometry of the major structure.

7.2.5.1.5* The internal surface of any adjoining rooms shall be included.

7.2.5.2 The surface area of equipment and contained structures shall be neglected.

7.2.6* Determination of Turbulent Flame Enhancement Factor, λ.

7.2.6.1* The baseline value, λ_0, of λ shall be calculated from Equations 7.2.6.1a through 7.2.6.1f:

[7.2.6.1a]

$$\varphi_1 = \begin{cases} 1, \ if \ \ \mathrm{Re}_f < 4000 \\ \left(\dfrac{\mathrm{Re}_f}{4000}\right)^{\theta}, \ if \ \ \mathrm{Re}_f \geq 4000 \end{cases}$$

[7.2.6.1b]

$$\mathrm{Re}_f = \frac{\rho_u S_u \left(D_{he}/2\right)}{\mu_u}$$

[7.2.6.1c]

$$\varphi_2 = \max\left\{1, \beta_1 \left(\frac{\mathrm{Re}_v}{10^6}\right)^{\left(\frac{\beta_2}{S_u}\right)^{0.5}}\right\}$$

[7.2.6.1d]

$$\mathrm{Re}_v = \frac{\rho_u u_v \left(D_v/2\right)}{\mu_u}$$

[7.2.6.1e]

$$u_v = \min\left\{\sqrt{\frac{2\times10^5 P_{red}}{\rho_u}}, a_u\right\}$$

[7.2.6.1f]

$$\lambda_0 = \varphi_1 \varphi_2$$

where:

ρ_u = mass density of unburned gas-air mixture (kg/m^3)
S_u = fundamental burning velocity of gas-air mixture (m/s)
D_{he} = the enclosure hydraulic equivalent diameter as determined in Chapter 6 (m)
μ_u = the unburned gas-air mixture dynamic viscosity (kg/m-s)
β_1 = 1.23
β_2 = 2.37×10^{-3} m/s
D_v = the vent diameter as determined through iterative calculation (m)
u_v = maximum velocity through vent (m/s)
P_{red} = the maximum pressure developed in a vented enclosure during a vented deflagration (bar-g)
a_u = the unburned gas-air mixture sound speed(m/s)
θ = 0.39

7.2.6.2 The total external surface area, A_{obs}, of the following equipment and internal structures that can be in the enclosure shall be estimated:

(1) Piping, tubing, and conduit with diameters greater than ½ in.
(2) Structural columns, beams, and joists
(3) Stairways and railings
(4) Equipment with a characteristic dimension in the range of 2 in. to 20 in. (5.1 cm to 51 cm)

7.2.6.3 When $A_{obs} < 0.2A_S$, λ_1 shall be equal to λ_0 as determined in 7.2.6.1.

7.2.6.4 When $A_{obs} > 0.2A_S$, λ_1 shall be determined as follows:

[7.2.6.4]

$$\lambda_1 = \lambda_0 \exp\left(\sqrt{\frac{A_{obs}}{A_s} - 0.2}\right)$$

7.2.6.5 The L/D of the enclosure shall be determined according to Section 6.4.

7.2.6.6 For L/D values less than 2.5, λ shall be set equal to λ_1.

7.2.6.7 For L/D values from 2.5 to 5 and for P_{red} no higher than 2 bar-g, λ shall be calculated as follows:

[7.2.6.7]

$$\lambda = \lambda_1 \left[1 + \left(\frac{L/D}{2.5} - 1\right)^2\right]$$

7.2.6.8 Equations for determining λ shall be subject to the following limitations:

(1) $S_u < 3$ m/s (300 cm/s).
(2) $P_{max} < 10$ bar-g.
(3) The maximum air velocity in the enclosure prior to ignition is no greater than 5 m/s.
(4) The enclosure is isolated from possible flame jet ignition and pressures caused by a deflagration in an interconnected enclosure.

7.2.6.9 For long pipes or process ducts where L/D is greater than 5, the requirements of Chapter 9 shall be used.

7.2.6.10 Methods to Reduce Flame Enhancement.

7.2.6.10.1 The value of λ shall be permitted to be reduced for gas deflagrations in relatively unobstructed enclosures by the installation of noncombustible, acoustically absorbing wall linings, provided that large-scale test data confirm the reduction.

7.2.6.10.2 The tests shall be conducted with the highest anticipated turbulence levels and with the proposed wall lining material and thickness.

7.3 Partial Volume Effects.

7.3.1 When a documented hazard analysis demonstrates that there is insufficient gas in the enclosure to form a stoichiometric gas-air mixture occupying the entire enclosure volume, the vent area, A_{v0}, calculated from Equation 7.2.1a or Equation 7.2.2a, as appropriate, shall be permitted to be reduced as described in 7.3.3.

7.3.2* A partial volume fill fraction, X_r, shall be calculated as shown in Equation 7.3.2:

Δ **[7.3.2]**

$$X_r = \frac{V_{gas} / \left(V_{enc} - V_{solid}\right)}{x_{st}}$$

where:

V_{gas} = maximum volume of gas that can be mixed with air in the enclosure
V_{enc} = enclosure volume
V_{solid} = volume of solid objects
x_{st} = stoichiometric volume concentration of gas

7.3.3 If $X_r < 1$, the minimum required vent area, A_{v1}, shall be calculated from the following equation:

[7.3.3]

$$A_{v1} = A_{v0} X_r^{-1/3} \cdot \sqrt{\frac{X_r - \Pi}{1 - \Pi}}$$

where:

A_{v1} = vent area for partial volume deflagration
A_{v0} = vent area for full volume deflagration as determined from Equation 7.2.1a or 7.2.2a
X_r = fill fraction > Π
Π = P_{red}/P_{max}

7.3.4 If $X_r > 1$, A_{v1} shall be set equal to A_{v0}.

7.4 Effects of Panel Inertia.

7.4.1* When the mass of the vent panel ≤40 kg/m^2, Equation 7.4.2 shall be used to determine whether an incremental increase in vent area is needed, and Equation 7.4.3 shall be used to determine the value of that increase.

7.4.2 The vent area determined in Section 7.3 shall be adjusted for vent mass when the vent mass exceeds M_T as calculated in Equation 7.4.2:

[7.4.2]

$$M_T = \left[\frac{P_{red}^{0.2} \cdot n^{0.3} \cdot V}{\left(S_u \cdot \lambda\right)^{0.5}} \right]^{1.67}$$

where:
M_T = threshold mass (kg/m²)
P_{red} = the maximum pressure developed in a vented enclosure during a vented deflagration (bar-g)
n = number of panels
V = enclosure volume (>1 m³)

7.4.3 For $M > M_T$, the required vent area, A_{v2}, shall be calculated as follows:

[7.4.3]

$$A_{v2} = A_{v1} \cdot F_{SH} \left[1 + \frac{(0.05) \cdot M^{0.6} \cdot \left(S_u \cdot \lambda\right)^{0.5}}{n^{0.3} \cdot V \cdot P_{red}^{0.2}} \right]$$

where:
A_{v2} = vent area for panel inertia (m²)
M = mass of vent panel (kg/m²)
A_{v1} = vent area determined in Section 7.3 (m²)
F_{SH} = 1 for translating panels or 1.1 for hinged panels

7.4.4 If $M < M_T$, A_{v2} shall be set equal to A_{v1}.

7.5* Effects of Vent Ducts.

7.5.1* Where vent ducting is used, a lower value, P'_{red}, shall be used in place of the actual P_{red} in all equations in this chapter.

7.5.2 Duct lengths shorter than 3 m (10 ft) and shorter than four duct hydraulic diameters in length shall be treated using Curve A in Figure 7.5.2. For ducts exceeding either of these limitations, Curve B shall be used.

7.5.2.1 For vent ducts with lengths less than 3 m (10 ft) and shorter than four duct hydraulic diameters, the following equation shall be permitted to be used to determine P'_{red}:

[7.5.2.1]

$$P'_{red} = 0.779 \cdot \left(P_{red}\right)^{1.161}$$

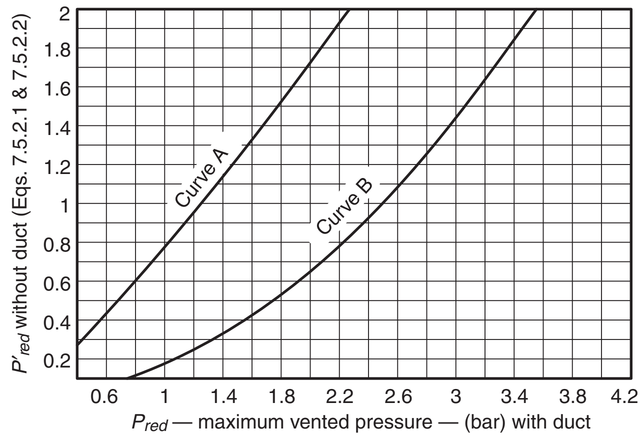
7.5.2.2 For vent ducts with lengths of 3 m to 6 m (10 ft to 20 ft) or shorter vent ducts longer than four duct hydraulic diameters, the following equation shall be permitted to be used to determine P'_{red}:

[7.5.2.2]

$$P'_{red} = 0.172 \cdot \left(P_{red}\right)^{1.936}$$

7.5.3* Duct lengths shorter than 3 m (10 ft) shall be treated as 3 m (10 ft) in length for calculation purposes.

7.5.3.1 If longer ducts are needed, P'_{red} shall be determined by appropriate tests.



Notes:
1. Curve A to be used for duct length < 3 m (10 ft) and less than four duct hydraulic diameters.
2. Curve B to be used for duct length of 3 m to 6 m (10 ft to 20 ft) or of four or more duct hydraulic diameters. Curve B is not valid for duct lengths > 6 m (20 ft).
3. For both Curve A and Curve B: Unlike a piping system described in Chapter 9 where flammable vapor is presumed present, in this situation flammable vapor is not initially present in the vent duct.

Δ **FIGURE 7.5.2 Maximum Pressure Developed During Venting of Gas, with and Without Vent Ducts.**

7.5.3.2 Vent ducts and nozzles with total lengths of less than one hydraulic diameter shall not require a correction.

• **7.6 Deflagration Venting of Enclosures Interconnected with Pipelines.** For interconnected enclosures, explosion isolation or suppression shall be provided in accordance with NFPA 69, unless a documented risk assessment acceptable to the authority having jurisdiction demonstrates that increased vent area prevents enclosure failure. *(See A.8.11.2.)*

Chapter 8 Venting of Deflagrations of Dusts and Hybrid Mixtures

8.1 Introduction.

8.1.1 This chapter shall apply to all enclosures with $L/D \leq 6$ handling combustible dusts or hybrid mixtures.

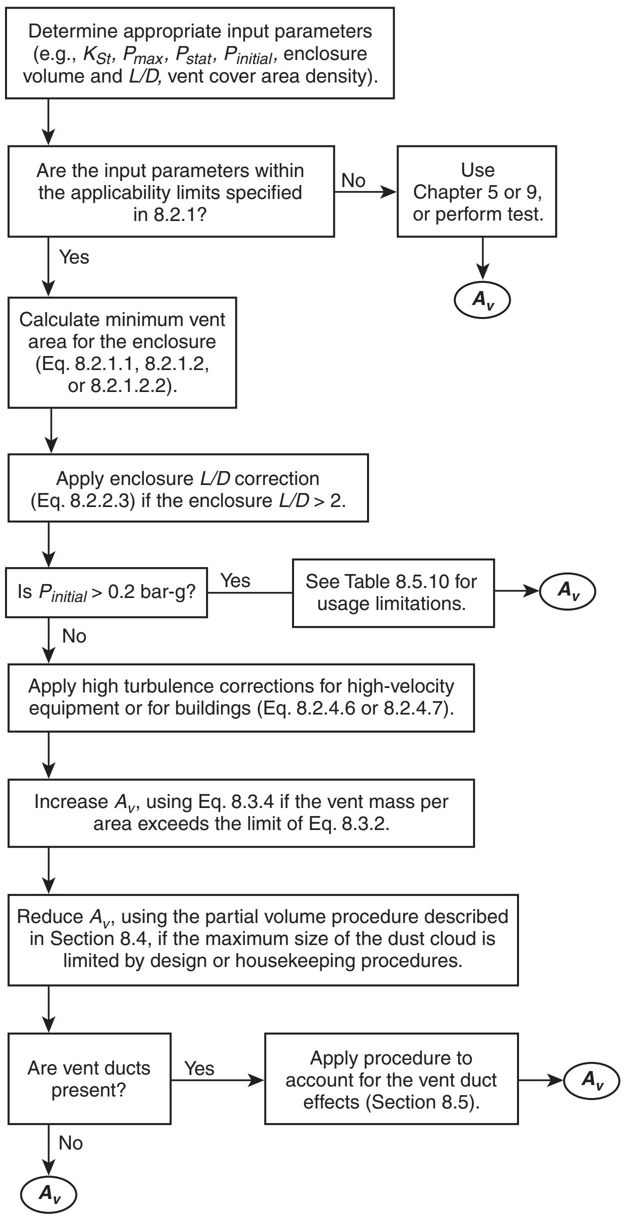
8.1.1.1 This chapter shall be used with the information contained in the rest of this standard.

8.1.1.2 In particular, Chapters 6, 7, 10, and 11 shall be reviewed before the information in this chapter is applied.

8.1.1.3 This chapter provides a number of equations and calculation procedures that shall be used to treat a variety of vent sizing applications.

8.1.1.4 The general flowchart given in Figure 8.1.1.4 shall be permitted to be used to select applicable vent sizing methods.

8.1.2* Where actual material is not available for test, vent sizing shall be permitted to be based on K_{St} values for similar composition materials of particle size no greater than the specified particle size range per the chosen standard: ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds,* or ISO



Δ **FIGURE 8.1.1.4 Dust Explosion Vent Sizing Calculation Flowchart.**

6184-1, *Explosion protection systems — Part 1: Determination of explosion indices of combustible dust in air*.

8.1.2.1 Where the actual material intended to be produced is smaller than the size determined by 8.1.2, tests shall be performed near the intended particle size.

8.1.2.2 When the actual material is available, the K_{St} shall be verified by test.

8.2 Venting by Means of Low-Inertia Vent Closures.

8.2.1 Minimum Vent Area Requirement. Minimum vent area shall be determined per 8.2.1 based on the initial pressure in the enclosure prior to ignition.

8.2.1.1 Minimum Vent Area Requirement for Near Atmospheric Initial Pressure. When enclosure pressure is initially between –0.2 bar-g (–20 kPa) and 0.2 bar-g (20 kPa), A_{v0} shall be determined from Equation 8.2.1.1:

[8.2.1.1]

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1}$$

where:

A_{v0} = vent area (m^2)
P_{stat} = nominal static burst pressure of the vent (bar-g)
K_{St} = deflagration index (bar-m/s)
V = enclosure volume (m^3)
P_{max} = maximum pressure of an unvented deflagration initially at atmospheric pressure (bar-g)
P_{red} = reduced pressure after deflagration venting (bar-g) [115]

8.2.1.2* Minimum Vent Area Requirement for Elevated or Subatmospheric Initial Pressure. When enclosure pressure is initially >0.2 bar-g (20 kPa) or <–0.2 bar-g (–20 kPa), A_{v0} shall be determined from Equation 8.2.1.2:

[8.2.1.2]

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot \left(\frac{P_{stat} - P_{initial}}{1 + P_{effective}}\right)^{4/3}\right] \cdot K_{St} \cdot V^{3/4} \sqrt{\frac{1}{\Pi_{effective}} - 1}$$

where:

A_{v0} = vent area (m^2)
P_{stat} = static burst pressure of the vent (bar-g)
$P_{initial}$ = enclosure pressure at moment of ignition (bar-g)
$P_{effective}$ = $^1/_3 P_{initial}$ (bar-g)
$\Pi_{effective}$ = $(P_{red} - P_{effective})/(P^E_{max} - P_{effective})$
P_{red} = reduced pressure (bar-g)
P^E_{max} = $[(P_{max} + 1)\cdot(P_{initial} + 1)/(1 \text{ bar-abs}) - 1]$ maximum pressure of the unvented deflagration at pressure (bar-g)
P_{max} = maximum pressure of an unvented deflagration initially at atmospheric pressure (bar-g)

8.2.1.2.1* When enclosure pressure is initially <–0.2 bar-g (–20 kPa), the vent area in Equation 8.2.1.2 shall be evaluated over the range between operating pressure and atmospheric pressure and the largest vent area correction applied.

8.2.1.2.2 When enclosure pressure is initially <–0.2 bar-g (–20 kPa), it shall be permitted to determine minimum vent area per Equation 8.2.1.2.2.

[8.2.1.2.2]

$$A_{v0} = 1.1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot P_{stat}^{4/3}\right] \cdot K_{St} \cdot V^{3/4} \sqrt{\frac{P_{max}}{P_{red}} - 1}$$

8.2.1.2.3 When enclosure pressure is initially > 0.2 bar-g (20 kPa), deflagration vents shall be permitted only when the following conditions are met:

(1) Vent duct length $L/D \leq 1$
(2) Panel density $M \leq M_T$ and $\leq 40\ kg/m^2$

(3) v_{axial} and $v_{tan} < 20$ m/s
(4) No allowance for partial volume

8.2.1.3 The following limitations shall be applicable to 8.2.1:

(1) 5 bar-g ≤ P_{max} ≤ 12 bar-g
(2) 10 bar-m/s ≤ K_{St} ≤ 800 bar-m/s
(3) 0.1 m^3 ≤ V ≤ 10,000 m^3
(4) $P_{stat} \leq P_{initial} + 0.75(1 + P_{effective})$ bar-g when $P_{initial}$ is >0.2 bar-g
(5) $P_{stat} < 0.75$ bar-g when $P_{initial}$ is <0.2 bar-g

8.2.2 Effects of Elevated *L/D*.

8.2.2.1 The *L/D* of the enclosure shall be determined according to Section 6.4.

8.2.2.2 When $L/D \leq 2$, A_{v1} shall be set equal to A_{v0}.

8.2.2.3 For $2 < L/D \leq 6$, the required vent area, A_{v1}, shall be calculated as follows (where exp $(A) = e^A$, e is the base of the natural logarithm [114]):

[8.2.2.3]

$$A_{v1} = A_{v0} \cdot \left[1 + 0.6 \cdot \left(\frac{L}{D} - 2\right)^{0.75} \cdot \exp\left(-0.95 \cdot \left(\frac{P_{red}}{1 + P_{initial}}\right)^2\right)\right]$$

where:
A_{v0} = vent area as calculated by 8.2.1
L/D = length-to-diameter ratio
P_{red} = reduced pressure after deflagration venting (bar-g)
$P_{initial}$ = enclosure pressure at moment of ignition (bar-g)

8.2.2.4 When initial pressure in the enclosure is less than 0.2 bar-g (20 kPa), $P_{initial}$ in Equation 8.2.2.3 shall be set to zero.

8.2.2.5* It shall be permitted to extend Equation 8.2.2.3 to values of *L/D* of 8 for top-fed bins, hoppers, and silos, provided the calculated required vent area, after application of all correction factors, does not exceed the enclosure cross-sectional area.

8.2.2.6 For situations where vents can be distributed along the major axis of the enclosure, Equation 8.2.1.1 and Equation 8.2.2.3 shall be permitted to be applied where *L* is the spacing between vents along the major axis.

8.2.3 Reserved.

8.2.4 Effects of Additional Turbulence.

8.2.4.1* For this application, average air axial velocity shall be calculated according to the following equation:

[8.2.4.1]

$$v = \frac{Q}{A}$$

where:
v = average axial gas velocity (m/s)
Q = volumetric air flow rate (m^3/s)
A = average cross-sectional area of the flow path (m^2) [118, 119]

8.2.4.2* If a circumferential (i.e., tangential) air velocity is in the equipment, v_{tan} shall be given by 0.5 v_{tan_max}, where v_{tan_max} is the maximum tangential air velocity in the equipment.

8.2.4.3 Values of Q, v_{axial}, v_{tan_max}, and v_{tan} shall be measured or calculated by engineers familiar with the equipment design and operation.

8.2.4.4 The measurements or calculations shall be documented and made available to vent designers and the authority having jurisdiction.

8.2.4.5 When the maximum values derived for v_{axial} and v_{tan} are less than 20 m/s, A_{v2} shall be set equal to A_{v1}.

8.2.4.6* When either v_{axial} or v_{tan} is larger than 20 m/s, A_{v2} shall be determined from the following equation where *max* (*A*, *B*) = maximum value of either *A* or *B* [118, 119]:

[8.2.4.6]

$$A_{v2} = \left[1 + \frac{max(v_{axial}, v_{\tan}) - 20}{36} \cdot 0.7\right] \cdot A_{v1}$$

where:
v_{axial} = axial air velocity (m/s)
v_{tan} = tangential air velocity (m/s)
A_{v1} = vent area calculated by 8.2.2

8.2.4.7* Vent areas for buildings in which there is a dust explosion hazard shall be determined from Equation 8.2.4.7 [118, 119]:

[8.2.4.7]

$$A_{v2} = 1.7 \cdot A_{v1}$$

where:
A_{v1} = vent area calculated by 8.2.2

8.2.4.8 The required vent areas for these buildings shall be permitted to be reduced through use of the partial volume Equation 8.4.3.

8.3* Effects of Panel Inertia.

8.3.1 When the mass of the vent panel ≤40 kg/m^2, Equation 8.3.2 shall be used to determine whether an incremental increase in vent area is needed and the requirements of 8.3.4 shall be used to determine the value of that increase.

8.3.2 The vent area shall be adjusted for vent mass where the vent mass exceeds M_T as calculated in Equation 8.3.2:

[8.3.2]

$$M_T = \left[6.67 \cdot \left(P_{red}^{0.2}\right) \cdot \left(n^{0.3}\right) \cdot \left(\frac{V}{K_{St}^{0.5}}\right)\right]^{1.67}$$

where:
M_T = threshold mass (kg/m^2)
P_{red} = reduced pressure after deflagration venting (bar-g)
n = number of panels
V = volume (m^3)
K_{St} = deflagration index (bar-m/s)

8.3.3 Where M> 40 kg/m^2, it shall be permitted to use the procedure provided in Annex G.

8.3.4 For $M > M_T$, the required vent area A_{v3}, shall be calculated as follows:

[8.3.4]

$$A_{v3} = F_{SH}\left[1+(0.0075)\cdot M^{0.6}\cdot\left(\frac{K_{St}^{0.5}}{n^{0.3}VP_{red}^{0.2}}\right)\right]\cdot A_{v2}$$

where:
F_{SH} = 1 for translating panels or 1.1 for hinged panels
M = mass of vent panel (kg/m^2)
K_{St} = deflagration index (bar-m/s)
n = number of panels
V = volume (m^3)
P_{red} = reduced pressure after deflagration venting (bar-g)
A_{v2} = vent area calculated by 8.2.4.5, Equation 8.2.4.6, or Equation 8.2.4.7, as applicable

8.3.5 If K_{St} < 75 bar-m/s, K_{St} = 75 shall be used in Equation 8.3.4.

8.3.6 Where $M \leq M_T$, A_{v3} shall be set equal to A_{v2}.

8.4* Effects of Partial Volume.

N **8.4.1*** It shall be permitted to calculate the partial volume fill fraction X_r as follows:

Δ **[8.4.1]**

$$X_r = \frac{M_e/\left(V_{enc}-V_{solid}\right)}{c_r}$$

where:
M_e = total mass of combustible dust that could be suspended inside the enclosure (g)
V_{enc} = enclosure volume (m^3)
V_{solid} = volume of solid objects (m^3)
c_r = 0.5 · c_w
c_w = worst case dust concentration (g/m^3)

N **8.4.2** The value of c_w shall be based upon $(dP/dt)_{max}$ versus concentration test data using ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds.*

N **8.4.2.1** If a measured value of c_w is available, the lowest value of c_w for the various samples shall be used to determine c_r.

N **8.4.2.2** If a measured value of c_w is not available, a value of 200 g/m^3 shall be permitted to be used to determine c_r.

8.4.3 When the volume fill fraction, X_r, can be determined for a worst-case explosion scenario, the minimum required vent area shall be permitted to be calculated from the following equation:

[8.4.3]

$$A_{v4} = A_{v3}\cdot X_r^{-1/3}\cdot\sqrt{\frac{X_r-\Pi}{1-\Pi}}$$

where:
A_{v4} = vent area for partial volume deflagration
A_{v3} = vent area for full volume deflagration as determined from Equation 8.3.4 or from 8.3.6
X_r = fill fraction > Π
Π = P_{red} / P_{max}

8.4.3.1* If $X_r \leq \Pi$, deflagration venting shall not be required.

8.4.3.2 Where partial volume is not applied, A_{v4} shall be set equal to A_{v3}.

8.4.4* Process Equipment Partial Volumes. Process equipment involving nonsolvent drying shall be permitted to use partial volume venting in accordance with Equation 8.4.3.

8.4.4.1 In applications involving dryers with recirculation of dry product, the fill fraction shall be taken as 1.0.

8.4.4.2 If the solvent is flammable, hybrid deflagration K_{St} values shall be determined.

8.4.4.3 In applications such as a spray dryer or fluidized bed dryer, the specific fill fraction to be used for vent design shall be based on measurements with representative equipment and process materials.

8.4.4.4 In applications involving spray dryers where a partial volume venting is calculated in accordance with Equation 8.4.3, the vent shall be mounted within the chosen partial volume zone of the dryer that contains the driest fraction of material.

8.4.4.5 In these applications, the determination of X_r shall be documented and submitted to the authority having jurisdiction for review and concurrence.

8.4.5 Building Partial Volumes. *(See Annex J.)*

8.4.5.1 This subsection shall apply to large process buildings in which a dust explosion hazard is associated with combustible material deposits on the floor and other surfaces, and with the material contained in process equipment.

8.4.5.2 The minimum required deflagration vent area for the building dust explosion hazard shall be based either on the full building volume or on a partial volume determined as follows:

(1) Collect at least three representative samples of the floor dust from either the actual building or a facility with similar process equipment and materials. The samples shall be obtained from measured floor areas, A_{fs}, that are each 0.37 m^2 (4 ft^2) or larger.
(2) Weigh each sample and calculate the average mass, $\bar{M}_f$ (grams), of the floor samples.
(3) Collect at least two representative samples from measured sample areas, A_{ss}, on other surfaces with dust deposits. These surfaces on any plane could include beams, shelves, and external surfaces of process equipment and structures. Calculate the total area, A_{sur}, of these surfaces with dust deposits.
(4) Weigh each sample and calculate the average mass, $\bar{M}_f$ (grams), of the surface samples.
(5) Determine the total mass, M_e, of combustible dust that could be released from the process equipment in the building.
(6) Test the dust samples per ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds,* to determine P_{max}, K_{St}, and the worst-case concentration, c_w, corresponding to the largest value of K_{St}.
(7) Using the highest values of P_{max} and K_{St}, the building volume, V, and $\Pi = P_{red}/P_{max}$, use Equation 8.3.4 or 8.3.6 to calculate the vent area, A_{v3}, needed if the full building volume were filled with combustible dust.

(8) Calculate the worst-case building partial volume fraction, X_r, in accordance with 8.4.5.3.1.

(9) If the calculated $X_r > 1$, the minimum required vent area is equal to A_{v3} .

(a) If $X_r \leq \Pi$, no deflagration venting is needed.

(b) If $1 > X_r > \Pi$, the minimum required vent area, A_{v4}, is calculated from Equation 8.4.3 as follows:

[8.4.5.2]

$$A_{v4} = A_{v3} \cdot X_r^{-1/3} \cdot \sqrt{\frac{X_r - \Pi}{1 - \Pi}}$$

where:

A_{v4} = vent area for partial volume deflagration

A_{v3} = vent area for full volume deflagration as determined from Equation 8.3.4 or from 8.3.6

X_r = fill fraction > Π

Π = P_{red}/P_{max}

8.4.5.3 The worst-case building partial volume fraction, X_r, shall be calculated from the following equation:

Δ **[8.4.5.3]**

$$X_r = \frac{\overline{M}_f \cdot A_{f\text{-}dusty} \cdot \eta_{Dfloor}}{A_{fs} \cdot (V - V_{solid}) \cdot c_r} + \frac{\overline{M}_s \cdot A_{sur} \cdot \eta_{Dsur}}{A_{ss} \cdot (V - V_{solid}) \cdot c_r} + \frac{M_e}{(V - V_{solid}) \cdot c_r}$$

where:

X_r = worst-case building partial fraction

$\bar{M}_f$ = average mass of floor samples (g)

$A_{f\text{-}dusty}$ = total area of floor with dust deposits (m²)

η_{Dfloor} = entrainment factor for floor accumulations

A_{fs} = measured floor areas (m²)

V = building volume (m³)

V_{solid} = volume of solid objects (m³)

c_w = worst-case dust concentration (g/m³)

c_r = $0.5 \cdot c_w$

$\bar{M}_s$ = average mass of surface samples (g)

A_{sur} = total area of surfaces with dust deposits (m³)

η_{Dsur} = entrainment factor for surface accumulations

A_{ss} = measured sample areas of surfaces with dust deposits (m²)

M_e = total mass of combustible dust that could be released from the process equipment in the building (g)

8.4.5.3.1 If a measured value of c_w is available, the lowest value of c_w for the various samples shall be used to determine c_r in Equation 8.4.5.3.

8.4.5.3.2 If a measured value of c_w is not available, a value of 200 g/m³ shall be permitted to be used to determine c_r in Equation 8.4.5.3.

8.4.5.3.3* If measured values of $\bar{M}_f / A_f$ and $\bar{M}_s / A_{ss}$ are not available, and if the facility is to be maintained with dust layer thickness in accordance with NFPA 654, an approximate value for these ratios shall be permitted to be used, based on a dust layer bulk density of 1200 kg/m³ and a layer thickness of 0.8 mm (1⁄32 in.) over the entire floor area and other surfaces defined in 8.4.5.3.4.

8.4.5.3.4 The total mass of dust that could be released from process equipment in the building/room M_e, shall be determined as follows:

(1) Evaluate equipment with exposed dust accumulations, such as but not limited to screeners, open-top conveyors or conveyor belts, open packaging or shipping containers, and enclosureless dust collectors

(2) Evaluate anticipated episodic spills from equipment in light of current housekeeping procedures and practices

(3) Do not include material in closed packaging or shipping containers, material in enclosed silos or storage bins, or in otherwise explosion-protected equipment

8.4.5.3.5 The entrainment factor, η_D, for each representative area shall be determined by one of the following methods:

(1) Assume an entrainment factor of 1

(2) Calculate the entrainment factor as follows:

(a) Determine the average particle density, ρ_p for each sampled dust layer

(b) Determine the entrainment threshold velocity using the following equation:

[8.4.5.3.5a]

$$U_t = 0.46 \cdot \rho_p^{1/3}$$

where:

U_t = threshold velocity (m/s)

ρ_p = particle density (kg/m³)

(c) Assume a maximum free-stream velocity, U, of 50 m/s or establish a different free-stream velocity calculated from a maximum credible initiating event

(d) Determine a maximum entrainment rate using the following equation:

[8.4.5.3.5b]

$$m'' = 0.002 \cdot \rho \cdot U \cdot \left(U^{1/2} - U_t^2 / U^{3/2}\right)$$

where:

m'' = entrained mass flux (kg/m²-s)

ρ = gas density (kg/m³)

U = free-stream velocity (m/s) > U_t

U_t = threshold velocity (m/s)

(e) Determine initiating event time, t, by dividing the building's or enclosure's longest dimension by ½ the maximum free-stream velocity

(f) Using the appropriate surface area, A, determine the maximum mass, M_{max}, from the presumed initiating event using the following equation:

[8.4.5.3.5c]

$$M_{max} = m'' \cdot A \cdot t$$

where:

m'' = entrained mass flux (kg/m²-s)

A = surface area (m²)

t = initiating event time(s)

(g) Determine the entrainment factor using the following equation:

[8.4.5.3.5d]

$$\eta_D = \begin{Bmatrix} \dfrac{M_{max}}{M}, \text{ if } \dfrac{M_{max}}{M} < 1 \\ 1, \text{ if } \dfrac{M_{max}}{M} \geq 1 \end{Bmatrix}$$

where:
M = average accumulation mass (kg)
M_{max} = maximum entrained mass (kg)

8.5* Effects of Vent Ducts.

Δ **8.5.1*** If there is no vent duct, $A_{vf} = A_{v4}$; otherwise, the effect of vent ducts shall be calculated from the following equations:

[8.5.1a]

$$A_{vf} = A_{v4} \cdot \left(1 + 1.18 \cdot E_1^{0.8} \cdot E_2^{0.4}\right) \cdot \sqrt{\frac{K}{K_0}}$$

[8.5.1b]

$$E_1 = \frac{A_{vf} \cdot L_{duct}}{V}$$

[8.5.1c]

$$E_2 = \frac{10^4 \cdot A_{vf}}{\left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4}}$$

[8.5.1d]

$$K \equiv \frac{\Delta P}{\frac{1}{2} \cdot \rho \cdot U^2} = K_{inlet} + \frac{f_D \cdot L_{duct}}{D_h} + K_{elbows} + K_{outlet} + \cdots$$

where:
A_{vf} = vent area required when a duct is attached to the vent opening (m^2)
A_{v4} = vent area after adjustment for partial volume (m^2), per Equation 8.4.3
K = overall resistance coefficient of the vent duct application
K_0 = 1.5, the resistance coefficient value assumed for the test configurations that generated the data used to validate 8.2.1 and 8.2.2
L_{duct} = vent duct overall length, including centerline length through elbows and fittings (m)
V = enclosure volume (m^3)
P_{stat} = nominal static opening pressure of the vent cover (bar-g)
ΔP = static pressure drop from the enclosure to the duct exit at average duct slow velocity, U (bar)
ρ = gas density (kg/m^3)
U = fluid velocity (m/s)
K_{inlet}, K_{elbows}, K_{outlet} = resistance coefficients for fittings
f_D = D'Arcy friction factor for fully turbulent flow; see Equation A.8.5c for typical formula [114]
D_h = vent duct hydraulic diameter (m)

8.5.2 Under certain circumstances, in which there are two solutions for vent area, the smaller vent area shall be used.

8.5.3 Where these equations do not produce a solution for vent area, the design shall be modified by decreasing the vent duct length, strengthening the vessel to contain a higher P_{red}, or both.

8.5.4 Equation 8.5.1a shall not be used if the vent cover is not located at the entrance of the duct.

8.5.5 Equation 8.5.1a shall not be used if the initial pressure exceeds 0.2 bar-g.

8.5.6 Equation 8.5.1a shall not be used if the vent duct cross-sectional area varies by more than 10 percent anywhere along the length.

8.5.7 It shall be permitted to use Equation 8.5.1a for vent ducts equipped with elbows, bird screens, and rain covers as long as the obstructions are properly accounted for through the duct resistance coefficient *K*.

8.5.8 It shall be permitted to use vent ducts outside the limitations of Equation 8.5.1a if designed in accordance with full-scale test data.

8.5.9 The maximum length of the duct shall be limited to obey the following inequality, where min(A, B) = the minimum value of either A or B:

[8.5.9]

$$L_{eff} \leq \min\left[\frac{10{,}000 \cdot D}{K_{St}}, \frac{11{,}000}{K_{St}}\right]$$

where:
L_{eff} = min(L_{duct}, L_{dusty})
L_{dusty} = $(P_{max} - P_{red}) \cdot V/A_v$

8.5.10 Table 8.5.10 shall be reviewed to determine the combination rules and limitations for application of various dust models in this chapter.

8.6 Bins, Hoppers, and Silos.

8.6.1 Deflagration venting for bins, hoppers, and silos shall be from the top or the upper side, above the maximum level of the material contained, and shall be directed to a safe outside location *(see Section 6.8)*.

8.6.1.1* Deflagration venting shall be permitted to be through vent closures located in the roof or sidewall or by making the entire enclosure top a vent.

8.6.1.2 In all cases, the total volume of the enclosure shall be assumed to contain a suspension of the combustible dust in question.

8.6.1.3 No credit shall be taken for the enclosure being partly full of settled material.

8.6.1.4 For a multiple application, the closures shall be placed symmetrically to minimize the effects of potential reaction forces *(see 6.3.5)*.

8.6.1.5 Care shall be taken not to fill the enclosure above the bottoms of the vent panels, because large amounts of dust can blow out into the atmosphere, ignite, and form a large fireball.

Δ Table 8.5.10 Combination Rules and Limitations for NFPA 68 Dust Models

Vent ducts	$P_{initial} \leq 1.2$ bar-abs $1 \leq L/D \leq 6$ Allow turbulence Panel density ≤ 40 kg/m² Allow partial volume No elevated pressure (calculate vent duct effect last)
Partial volume	$P_{initial} \leq 1.2$ bar-abs $1 \leq L/D \leq 6$ Allow turbulence Panel density ≤ 40 kg/m² Allow vent ducts No elevated pressure (calculate vent duct effect last)
Panel inertia	$P_{initial} \leq 1.2$ bar-abs $1 \leq L/D \leq 6$ Allow turbulence Allow partial volume Allow vent ducts No elevated pressure (calculate vent duct effect last)
Elevated pressure	$1.2 < P_{initial} \leq 5$ bar-abs $1 \leq L/D \leq 6$ Turbulence (v_{axial} and v_{tan}) < 20 m/s Panel density ≤ M_T and ≤ 40 kg/m² Full volume, no partial volume No vent ducts (calculate elevated pressure effect last)
Subatmospheric pressure	$P_{initial} \leq 0.8$ bar-abs $1 \leq L/D \leq 6$ Allow turbulence Panel density ≤ 40 kg/m² Allow partial volume Allow vent ducts (calculate vent duct effect last)

8.6.2 Deflagration venting shall be permitted to be accomplished by means of vent closures located in the roof of the enclosure.

8.6.2.1 The vent operation procedures outlined in Section 6.5 shall be followed.

8.6.3* The entire enclosure top shall be permitted to be used to vent deflagrations.

8.6.3.1 Roof panels shall be as lightweight as possible and shall not be attached to internal roof supports.

8.6.3.2 API STD 650, *Welded Steel Tanks for Oil Storage*, shall be referenced for guidelines for the design of a frangible, welded roof joint.

8.6.3.3 Equipment, piping, and other process connections shall not restrict the roof's operation as a vent closure.

8.6.3.3.1 Equipment, piping, and other process connections shall be included in the vent panel inertia evaluation per Section 8.3.

8.6.3.4 The entire enclosure rooftop shall be labeled as an explosion vent in accordance with 11.3.4.

8.6.3.5 Access to the rooftop shall be restricted during operation of the protected enclosure.

8.6.3.6 Initial inspection shall include the roof-wall connections.

8.6.3.7 The remaining portions of the enclosure, including anchoring, shall be designed to resist the calculated P_{red}, based on the vent area provided. *(See Section 6.3.)*

8.7 Venting of Dust Collectors Using Bags, Filters, or Cartridges.

8.7.1* Determination of *V* and *L/D* for Dust Collectors.

8.7.1.1* Unlike the general approach of 6.4.3.2, the maximum flame length, *H*, shall be the longest distance, taken on the dirty side of the tube sheet, parallel to the major axis of the enclosure, either horizontal or vertical, and ignoring the location of explosion vents.

8.7.1.2* Both the enclosure volume, *V*, and the effective volume of the enclosure, V_{eff}, shall be determined based on the total dirty volume of the enclosure on the dirty side of the tube sheet, including the volume occupied by the filters and ignoring the location of the explosion vents.

8.7.1.3 The effective area of the enclosure, A_{eff}, shall be determined by dividing V_{eff} by *H*.

8.7.1.4 The effective hydraulic diameter, D_{he}, for the enclosure shall be determined based on the general shape of the enclosure taken normal to the maximum flame path. *(See 6.4.3.6.)*

8.7.1.5 *L/D* for dust collectors shall be set equal to H/D_{he} as determined above.

8.7.2* In applications involving flexible filters where vents are located totally above the free end of the filter and a free vent path inside the dust collector is not maintained with internal restraint, the otherwise required minimum vent area shall be increased by 25 percent.

8.7.3 If the clean air plenum contains dust, or if the material entering the dust collector is a hybrid mixture, one of the following protection measures shall be applied:

(1) A separate vent shall be provided on the clean air side, calculated based on the clean air side volume using the methodology in Chapter 7 or Chapter 8, as applicable.
(2) The clean air side gas concentration shall be evaluated for flammability and protected in accordance with NFPA 69.

8.8 Bucket Elevators.

8.8.1* Bucket elevators shall be classified as single-casing (single leg) or double-casing (twin leg) design.

8.8.2* Head and Boot Vents.

8.8.2.1 Vent areas shall be not less than the cross-sectional area of each leg and at a minimum shall be fitted both at the head and as close to the boot as practicable.

8.8.2.2 Where a vent is not installed directly on the boot, a vent shall be installed on each casing at a distance from the boot less than or equal to the smaller of 6 m or the additional vent spacing distance per Table 8.8.3.3.

8.8.3 Additional Casing Vents.

8.8.3.1 The owner/operator shall be permitted to choose a design strength based on a P_{red} of 0.2, 0.5, or 1.0 bar-g.

8.8.3.2 The casing(s), head, and boot shall all be designed for the same P_{red} chosen from 8.8.3.1.

8.8.3.3 Additional vents shall be installed in each casing at center-to-center spacing distance along the elevator axis based on the bucket elevator classification, the K_{St} of the material being handled, and the design strength based on P_{red}, as given in Table 8.8.3.3.

N **8.8.3.4** For a P_{red} that falls between one of the P_{red} values on Table 8.8.3.3, interpolation between numerical values on the table, but not extrapolation, shall be permitted.

Δ **8.8.3.5*** Where plastic buckets are used, the corresponding anticipated elevator P_{red} of 0.2, 0.5, or 1.0 bar-g shall be increased by the factors given in Table 8.8.3.5 before applying the spacing requirements in 8.8.3.3.

8.8.3.6* At each vent location, the total vent area shall be not less than the cross-sectional area of each leg.

8.8.3.7 For K_{St} values less than 100 bar-m/s where a P_{red} of 0.2 bar-g is selected, vents shall be placed at an interval not exceeding 6 m on the leg(s).

8.8.4* Vent closures shall have P_{stat} less than or equal to 0.1 bar-g.

•

Table 8.8.3.3 Additional Vent Spacing

Bucket Elevator Classification	K_{St} (bar-m/s)	Spacing (m) P_{red} 0.2 bar-g	P_{red} 0.5 bar-g	P_{red} 1.0 bar-g
Double-casing (twin leg)	<100	6	None required	None required
	100–150	3	10	19
	151–175	N/A	4	8
	176–200	N/A	3	4
	>200	N/A	N/A	3
Single-casing (single leg)	<100	N/A*	None required	None required
	100–150	N/A	7	14
	151–175	N/A	4	5
	176–200	N/A	3	4
	>200	N/A	N/A	3

N/A: Not allowed.
*For P_{red} = 0.3 bar-g, vent spacing of 6 m is appropriate.
Source: [120]

Δ **Table 8.8.3.5 P_{red} Increase for Plastic Buckets**

K_{St} (bar-m/s)	Percent Increase in P_{red}
<100	20
100–150	35
151–200	50

Source: [120, 124].

8.9* Venting Internal to a Building with Flame-Arresting and Particulate Retention Device.

8.9.1 Expected overpressure shall be compared to the building design, and building venting shall be considered to limit overpressures.

8.9.1.1 The resulting pressure increase in an unvented building shall be permitted to be estimated from the following:

(1) $\Delta P = 1.74\ P_0\ (V_1/V_0)$
(2) V_0 = free volume of building
(3) V_1 = volume of protected equipment
(4) P_0 = ambient pressure [14.7 psia (1.013 bar-abs)]
(5) ΔP = pressure rise in the building (in same units as P_0)

8.9.1.2 It shall be permitted to use a lower value of the coefficient than that shown in 8.9.1.1(1) where experimental data are available to substantiate the lower value.

8.9.2 The deflagration venting area provided for the protected enclosure shall be adjusted to compensate for the venting efficiency as determined by test for the device.

8.10* Venting Silos or Other Storage Vessel Provided with Integral Bin Vents.

8.10.1 Where bin vents (air material separators) are installed in common with a silo or any other storage vessel, they shall be protected as follows:

(1) The protected volume shall be calculated as the sum of the volume of the silo and the volume of the collector in accordance with Section 8.7.
(2) The *L/D* of the combination shall be calculated based on the dimensions of the silo alone in accordance with Section 6.4.
(3) Vent panels shall be located on the silo top surface or on the side walls above the maximum level of the contents of the silo.
(4) It shall be permitted to locate a portion of the venting on the bin vent surface in accordance with the following proportions:

[8.10.1a]

$$A_{v,bin\ vent} = A_{v,\ total} - A_{v,silo\ min}$$

[8.10.1b]

$$A_{v,silo\ min} = \left(\frac{V_{silo}}{V_{total}}\right)^{2/3} A_{v,\ total}$$

where:

$A_{v,bin\ vent}$ = vent area of the bin vent/collector
$A_{v,\ total}$ = total vent area calculated for the bin vent–silo combination
$A_{v,\ silo\ min}$ = minimum explosion venting area required to be on the silo
$A_{v,\ silo}$ = actual explosion venting area installed on the silo

8.10.2 Where the open area of the connection between the bin vent and the silo is greater than or equal to the vent area required for the combined volume, it shall be permitted to locate all or any portion of the venting on the bin vent surface.

8.10.2.1 When 8.10.2 is applied, the clear path requirements of Section 8.7 shall apply.

8.11* Deflagration Venting of Enclosures Interconnected with Pipelines.

Δ **8.11.1*** For interconnecting pipelines with inside diameters no greater than 0.3 m (1 ft) and lengths no greater than 6 m (20 ft), the following requirements shall apply [104]:

(1) The venting device for the enclosure shall be designed for P_{stat} < 0.2 bar-g.
(2) Enclosures of volumes within 10 percent of each other shall be vented as determined by 8.2.1 and 8.2.2.
(3) If enclosures have volumes that differ by more than 10 percent, the vents for both enclosures shall be designed as if P_{red} were equal to 1 bar-g or less. The enclosure shall be designed with P_{es} equal to a minimum of 2 bar-g.
(4) If it is not possible to vent the enclosure with the smaller volume in accordance with this standard, the smaller enclosure shall be designed for the maximum deflagration pressure, P_{max}, and the vent area of the larger enclosure with the larger volume shall be doubled.
(5) The larger enclosure shall be vented or otherwise protected as described in NFPA 69 in order for the deflagration venting of smaller enclosures to be effective.

8.11.2* For enclosures outside the scope of 8.11.1, explosion isolation or suppression shall be provided in accordance with NFPA 69 unless a documented risk assessment acceptable to the authority having jurisdiction demonstrates that increased vent area prevents enclosure failure.

Chapter 9 Venting of Deflagrations of Gases and Dusts in Pipes and Ducts Operating at or Near Atmospheric Pressure

9.1* Introduction.

9.1.1 This chapter applies to systems handling gases or dusts operating at pressures up to 0.2 bar-g (3 psi).

9.1.2 This chapter shall apply to pipes, ducts, and elongated vessels with length-to-diameter ratios of 5 or greater for gases and 6 or greater for dusts.

9.1.3 This chapter shall not apply to vent discharge ducts.

9.1.4 This chapter shall not apply to oxidants other than air or to mixtures at elevated initial temperatures that are greater than 57°C (134°F).

9.2* Design.

9.2.1 Each vent location along a pipe, duct, or elongated vessel shall have a vent area equal to the total cross-sectional area at each vent location.

9.2.2 The vent area needed at a vent location shall be permitted to be accomplished by using one, or more than one, vent at each location.

9.2.3 For noncircular cross sections, the diameter shall be the hydraulic diameter that is equal to $4(A/p)$, where A is the cross-sectional area and p is the perimeter of the cross section.

9.2.4* Pipes or ducts connected to a vessel in which a deflagration can occur shall have a vent located on the pipe or duct at a location no more than two pipe or duct diameters from the point of connection to the vessel.

9.2.5 For systems that handle gases, vents shall be provided on each side of turbulence-producing devices at a distance of no more than three diameters of the pipe or duct.

9.2.6 The weight of deflagration vent closures shall not exceed 12.2 kg/m^2 (2.5 lb/ft^2) of free vent area.

9.2.7 Deflagration vents shall discharge to a location that cannot endanger personnel.

9.2.8 The static burst pressure of the vent closures shall be less than 0.3 bar-g (4.4 psi).

9.2.9 Transition to Detonation.

9.2.9.1 Vents shall be placed on pipes and ducts to prevent a deflagration from transitioning into a detonation.

9.2.9.2* If L/D ratios are greater than those shown in Figure 9.2.10.1, multiple vents shall be installed in accordance with Section 9.3.

9.2.10 Use of a Single Deflagration Vent on a Pipe or Duct.

9.2.10.1* Figure 9.2.10.1 shall be used to determine the maximum allowable length of a smooth, straight pipe, duct, or vessel that is closed on one end and vented on the other where no additional deflagration vents are required.

9.2.10.2 The maximum pressure during deflagration venting, P_{red}, in a pipe or duct shall be no greater than 50 percent of the yield strength of the pipe or duct.

9.2.10.2.1 Flammable Gas Systems with a Flow Velocity of 2 m/s or Less.

9.2.10.2.1.1 The maximum pressure during deflagration venting, P_{red}, in a pipe or duct that conveys propane or gases that have a fundamental burning velocity of less than 60 cm/s shall be determined from Figure 9.2.10.2.1.1.

9.2.10.2.1.2 For other pipe diameters, P_{red} shall be determined by interpolation using Figure 9.2.10.2.1.1.

9.2.10.2.2 Dust Systems with a Flow Velocity of 2 m/s or Less.

9.2.10.2.2.1* The maximum pressure during deflagration venting, P_{red}, in a pipe or duct that conveys dusts shall be estimated from Figure 9.2.10.2.2.1.

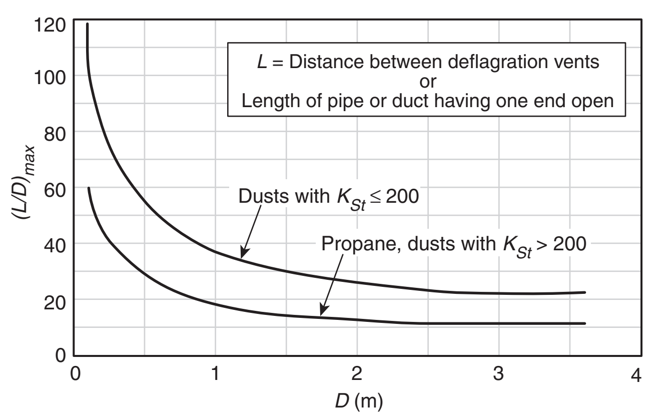


FIGURE 9.2.10.1 Maximum Allowable Distance, Expressed as Length-to-Diameter Ratio, for a Smooth, Straight Pipe or Duct.

9.2.10.2.2.2 For dusts having other values of K_{St}, P_{red} shall be determined by interpolation.

9.2.11 For system flow velocities greater than 2 m/s and for gases with fundamental burning velocities greater than 60 cm/s (2 ft/s), additional vent area shall be provided in accordance with Section 9.3.

9.2.12 For systems having an initial flow velocity greater than 20 m/s, for gases having a burning velocity more than 1.3 times that of propane, or for dusts with K_{St} > 300, vent placement shall be determined by tests.

9.3 Multiple Deflagration Vents on a Pipe or Duct.

9.3.1* Figure 9.3.1 shall be used to determine the maximum distance between each vent for a maximum pressure during deflagration venting of 0.17 bar-g (2.5 psig).

9.3.1.1 Figure 9.3.1 shall apply to system flow velocities up to 20 m/s (66 ft/s).

9.3.1.2 Figure 9.3.1 shall also apply to dusts with a K_{St} less than or equal to 300 bar-m/s and to propane.

9.3.2 For gases other than propane, the maximum pressure during deflagration and the distances between vents shall be calculated using Equations 9.3.2a and Equation 9.3.2b, which

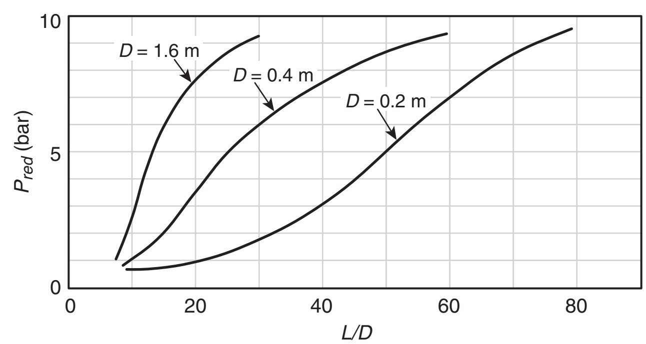


FIGURE 9.2.10.2.1.1 Maximum Pressure Developed During Deflagration of Propane/Air Mixtures Flowing at 2 m/s or Less in a Smooth, Straight Pipe Closed at One End.

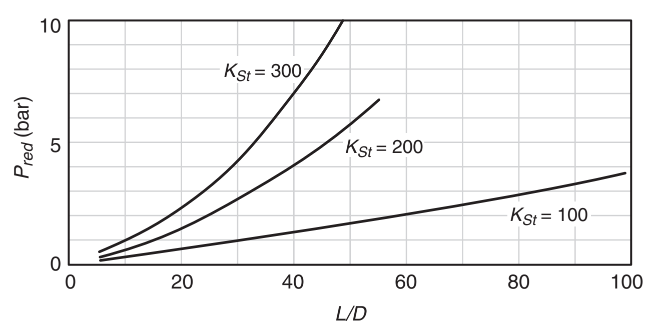


FIGURE 9.2.10.2.2.1 Maximum Pressure Developed During Deflagration of Dust/Air Mixtures Flowing at 2 m/s or Less in a Smooth, Straight Pipe Closed at One End.

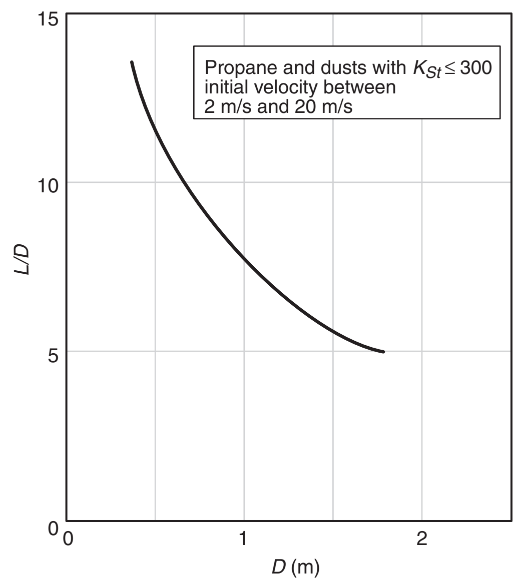


FIGURE 9.3.1 Vent Spacing Needed to Keep P_{red} from Exceeding 0.17 bar-g for Propane and Dusts with a K_{St} Less Than 300 bar-m/s.

are limited to fundamental burning velocities below 60 cm/s (2 ft/s):

[9.3.2a]

$$P_{red,x} = P_{red,p} \cdot \left(\frac{S_{u,x}}{S_{u,p}} \right)^2$$

[9.3.2b]

$$L_x = L_p \cdot \left(\frac{S_{u,p}}{S_{u,x}} \right)^2$$

where:

$P_{red,x}$ = maximum pressure predicted for gas [bar-g (psig)]
$P_{red,p}$ = 0.17 bar-g (2.5 psig)— maximum pressure for propane
$S_{u,x}$ = fundamental burning velocity of gas
$S_{u,p}$ = fundamental burning velocity of propane
L_x = distance between vents for gas [m (ft)]
L_p = distance between vents for propane [m (ft)]

Chapter 10 Details of Deflagration Vents and Vent Closures

10.1* Normally Open Vents.

10.1.1 Louvered Openings.

10.1.1.1 Increases in P_{red} due to louvered openings shall be accounted for in a documented system design.

10.1.1.2 The pressure drop through the louvered vent shall be determined by gas flow calculations, and P_{red} shall be adjusted.

N **10.1.1.3** The louvered vent shall be designed to withstand no less than 10 percent above the maximum intended P_{red} and documented via design calculations or a test report.

10.1.2 Hangar-Type Doors. Large hangar-type or overhead doors shall be permitted to be installed in the walls of rooms or buildings that contain a deflagration hazard.

10.1.2.1 The doors shall be permitted to be opened to provide sizable unobstructed vents during the operation of a process or of equipment in which there is an inherent deflagration hazard.

10.1.2.2 The opening shall be considered to be a vent only when the door is not in place.

10.1.2.3 Interlocks with process systems that create a deflagration hazard shall be provided to ensure that the doors are open when the process is in operation.

10.2 Normally Closed Vents.

Δ **10.2.1 Manufactured Vent Design Documentation.**

N **10.2.1.1** The vent closure manufacturer or designer shall be responsible for documenting the value and tolerance of the P_{stat} of a vent closure as well as the maximum P_{red}, where installed according to the manufacturer's recommendation in the intended application.

N **10.2.1.2*** Where non-fragmenting operation is desired, the evaluation of maximum P_{red} shall include all accessories, external release mechanisms, and insulation.

10.2.2 Testing shall be carried out to establish the P_{stat} for any closure release mechanism, with the mechanism installed on the vent closure and tested as a complete assembly.

10.2.2.1 The requirement in 10.2.2 shall apply to all types of closure mechanisms, including pull-through fasteners; shear bolts; spring-loaded, magnetic, and friction latches; and rupture diaphragms.

10.2.2.2 For field-fabricated vent closures, the designer shall document that the entire assembly releases at the P_{stat} specified.

10.2.2.2.1 The documentation shall include the design P_{red}, P_{stat}, enclosure surface area, closure area, panel mass per unit area, types of fasteners, spacing, and quantity.

10.2.2.2.2 The design records and installation drawings shall be maintained by the building owner and operator.

10.2.2.3 Where vent closure mechanisms or fasteners are used, they shall be listed for the application.

10.2.3 The vent closure shall be designed to release at the calculated pressure and shall be compatible with the service conditions to which it is to be exposed.

10.2.3.1 Vent closures shall be designed for their expected temperature range.

10.2.4 The closure shall be designed to withstand natural forces such as wind or snow loads, operating conditions such as internal pressure fluctuations and internal temperature, and the effects of corrosion.

10.3 Types of Building or Room Vent Closures. The following types of vent closures shall be permitted to be used with low-strength enclosures such as those covered by Chapter 7.

10.3.1 Hinged Doors, Windows, and Panel Closures. Hinged doors, windows, and panel closures shall be designed to swing outward and have latches or similar hardware that automatically release under the calculated release pressure.

10.3.1.1 Friction, spring-loaded, or magnetic latches of the type used for doors on industrial ovens shall be permitted to be used.

10.3.1.2 For personnel safety, the door or panel shall be designed to remain intact and to stay attached.

10.3.1.3 Materials that tend to fragment and act as shrapnel shall not be used.

10.3.2* Shear and Pull-Through Fasteners. Listed shear and pull-through fasteners shall be permitted to be used where the vent design calls for large vent areas, such as the entire wall of a room.

10.3.2.1 At locations where personnel or equipment can be struck by flying vent closures, tethering of the vent closure or other safety measures shall be required.

10.3.2.2* Where restraint is required, any vent restraint design shall be documented by the designer.

10.3.2.3 No restraint for any vent closure shall result in restricting the required vent area or slowing the response time of the closure.

10.3.2.4 Any hardware added to a vent closure shall be included when determining the total mass of the closure, subject to Section 6.7.

10.4* Restraints for Large Panels. Any vent restraint design shall be documented by the designer.

10.4.1 No restraint for any vent closure shall result in restricting the vent area.

10.4.2 Any hardware added to a vent closure shall be included when determining the total mass of the closure, subject to Section 6.7.

10.5 Equipment Vent Closures.

10.5.1* Hinged Devices. Hinged doors or covers shall be permitted to be designed to function as vent closures.

10.5.1.1* The hinge shall be designed to ensure that the closure device remains intact during venting.

10.5.1.2* Hinged devices shall be permitted to be used on totally enclosed mixers, blenders, dryers, and similar equipment.

10.5.1.3 Charging doors or inspection ports shall be permitted to be designed to serve this purpose where their action does not endanger personnel.

10.5.1.4 Regular maintenance of hinge and spring-loaded mechanisms shall be performed to ensure proper operation.

10.5.1.5 If a hinged vent closure is followed by a vent duct, special consideration shall be given to the clearance between the front edge of the closure panel and the duct wall throughout the course of the opening arc.

10.5.1.5.1 The clearance shall not hinder flow during the venting while the vent closure is swinging open.

10.5.1.5.2 The amount of clearance needed from the front edge of the hinged closure, in the closed position, to the wall of the vent duct shall be approximately half the length of the hinged closure from the hinge to the front edge.

10.5.1.6* Vacuum breakers shall be permitted to be designed according to Figure 10.5.1.6 and installed to prevent inward deformation, provided they either are built strongly enough to withstand the P_{red} during venting or open to leave a clear path.

10.5.2* Rupture Diaphragm Devices. Only rupture diaphragms with controlled opening patterns that ensure full opening on initial rupture shall be utilized.

Chapter 11 Inspection and Maintenance

11.1 General.

11.1.1 This chapter covers the installation, inspection, and maintenance procedures necessary for the proper functioning and operation of vent closures for venting deflagrations.

11.1.2 Sections 11.4 through 11.11 shall be applied retroactively.

11.2* Design Parameters and Documentation. Data sheets, installation details, and design calculations shall be developed and maintained for each vent closure application, suitable for review by an authority having jurisdiction that verifies the vent area is sufficient to prevent deflagration pressure from exceeding the enclosure strength and identifies areas exposed to potential overpressure, event propagation, and fireball effects during venting. Documentation shall include all of the following:

(1) Manufacturer's data sheets and instruction manuals
(2) Design calculations
(3) General specifications
(4) Vent closure specifications
(5) End user inspection/maintenance forms
(6) User documentation of conformity with applicable standards
(7) Vent closure identification
(8) Combustible material properties test report
(9) Copy of vent identification label
(10) Process plan view
(11) Process elevation view
(12) Vent relief (pressure and fireball) path
(13) Proximity of personnel to vent relief path
(14) Mechanical installation details
(15) Electrical supervision (if provided) installation details
(16) Vent restraint installation and design documentation (if required)
(17) Process interlocks (if provided)
(18) Event deflagration isolation requirements (if required)
(19) Employee training requirements

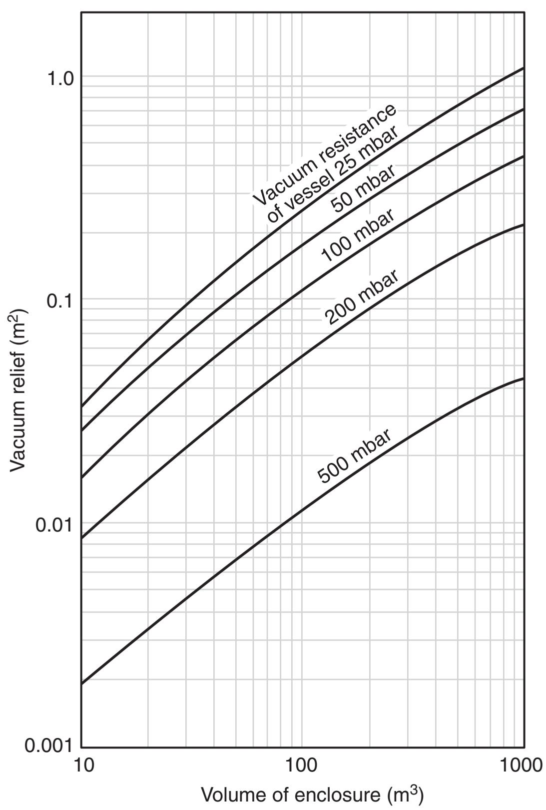


FIGURE 10.5.1.6 Graph to Determine the Vacuum Relief Area for Vacuum Vents on Enclosures [104].

11.3 Installation.

11.3.1 Mounting frames shall be fabricated and mounted so that the vent closure is not stressed in any way that will contribute to fatiguing the vent closure.

11.3.2 Vent closures shall be installed in accordance with the manufacturer's requirements.

11.3.3 The final installation shall be inspected to verify its conformance to the design.

11.3.4* Vent closures shall be clearly marked as follows:

WARNING: Explosion relief device.

11.4* Inspection.

11.4.1 Vent closures shall be inspected according to 11.4.4 at least annually.

11.4.2* The frequency of the inspection described in 11.4.4 shall be permitted to be increased or decreased based on documented operating experience.

11.4.3 The owner/operator of the facility in which the deflagration vent closures are located shall be responsible for inspecting and maintaining such devices after they are installed.

11.4.4 The inspector shall verify, as applicable, that the vent inspection determines the following:

(1) The opening is free and clear of any obstructions on both sides.
(2) The discharged material and fireball pathway does not extend into an area normally occupied by personnel or critical process equipment.
(3) The closure has been properly installed according to manufacturer's instructions.
(4) The closure is not corroded or mechanically damaged.
(5) The closure is clearly identified with manufacturer's information.
(6) The closure is clearly labeled as an explosion relief device.

(7) The closure has no damage and is protected from the accumulation of water, snow, ice, or debris after any act of nature.
(8) The closure has not been painted or coated other than by manufacturer.
(9) The closure has no buildup of deposits on the inside surfaces or between layers of the vent.
(10) The closure has not been tampered with.
(11) The closure shows no fatigue and has not released.
(12) The closure hinges (if provided) are lubricated and operate freely.
(13) The closure restraints (if provided) are in place and operational.
(14) The closure seals, tamper indicators, or vent rupture indicators (e.g., breakwire switches), if provided, are in place.
(15) The flame-arresting and particulate-retention device is being maintained, is clean, and is unobstructed in accordance with the manufacturer's listing.
(16) The closure has no conditions that would hinder its operation.

11.4.5 The owner/operator shall verify by signature on the inspection form that the production process material has not changed since the last inspection.

11.5 Procedures Following Vent Closure Actuation.

11.5.1 In the event of vent closure actuation, inspection and maintenance as specified in Sections 11.4 and 11.10, respectively, shall be performed before the system is placed back into service.

11.5.2 An investigation and a review of the cause of the actuation shall be made.

11.6* Vent Closure Design Parameters. The vent closure design parameters shall be maintained and made available for management of change review, employee training information, inspection, and reordering purposes.

11.7 Inspection Reports. Deficiencies found during inspections shall be reported to the owner/operator.

11.8 Recordkeeping.

11.8.1 A record shall be maintained that indicates the date and the results of each inspection and the date and description of each maintenance activity.

11.8.2 The records of inspections shall be retained for a minimum of 3 years.

11.9 Management of Change. Management shall implement and maintain written procedures to evaluate proposed changes to facility and processes, both physical and human, for the impact on safety, loss prevention, and control.

11.9.1 Management of change procedures shall be followed for any change to process, materials, technology, equipment, process flow, exposure, or procedures affecting equipment protected by requirements in this document.

11.9.2* Management of change documentation shall be available for review by the relevant authority having jurisdiction.

11.9.3 The management of change procedures shall ensure that the following issues are addressed prior to any change:

(1) The technical basis for the proposed change
(2) Safety and health implications
(3) Review of fire and explosion prevention systems
(4) Whether the change is permanent or temporary
(5) Personnel exposure changes
(6) Modifications to operating maintenance procedures
(7) Employee training requirements
(8) Authorization requirements for the proposed change

11.9.4 Implementation of the management of change procedures shall not be required for replacements-in-kind.

11.9.5 Design documentation as required by Section 11.2 shall be updated to incorporate the change.

11.10 Maintenance.

11.10.1 Vent closure maintenance shall be performed after every act of nature or process upset condition to ensure that the closure has not been physically damaged and there are no obstructions, including but not limited to snow, ice, water, mud, or process material, that could lessen or impair the efficiency of the vent closure.

11.10.2 An inspection shall be performed in accordance with 11.4.4 after every process maintenance turnaround.

11.10.3 If process material has a tendency to adhere to the vent closure, the vent closure shall be cleaned periodically to maintain vent efficiency.

11.10.4 Process interlocks, if provided, shall be verified.

11.10.5 Known potential ignition sources shall be inspected and maintained.

11.10.6 Records shall be kept of any maintenance and repairs performed.

11.11 Employee Training.

11.11.1 Initial and refresher training shall be provided and training records maintained for employees who are involved in operating, maintaining, and supervising facilities that utilize devices for venting of deflagrations.

11.11.2 Initial and refresher training shall ensure that all employees are knowledgeable about the following:

(1) Hazards of their workplace
(2) General orientation, including plant safety rules
(3) Process description
(4) Equipment operation, safe startup and shutdown, and response to upset conditions
(5) The necessity for proper functioning of related fire and explosion protection systems
(6) Deflagration vent(s) location, vent relief path, and maintenance requirements and practices
(7) Housekeeping requirements
(8) Emergency response and egress plans

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1 A deflagration can result from the ignition of a flammable gas, mist, or combustible dust. This standard is a companion document to NFPA 69, which covers explosion prevention measures and can be used in place of, or in conjunction with, NFPA 68. The choice of the most effective and reliable means for explosion control should be based on an evaluation that includes the specific conditions of the hazard and the objectives of protection. Venting of deflagrations only minimizes the damage that results from combustion.

A.1.2 It is important to note that venting does not prevent a deflagration; venting can, however, minimize the destructive effects of a deflagration.

A.1.3 Vents act as a system in conjunction with the strength of the protected enclosure. However, some lightweight structures, such as damage-limiting buildings, can be considered to be totally self-relieving and require no specific vents.

NFPA 30, NFPA 30B, NFPA 33, NFPA 35, NFPA 52, NFPA 58, NFPA 61, NFPA 69, NFPA 400, NFPA 484, NFPA 652, and NFPA 654 specify under which conditions deflagration venting (explosion protection measures) is required.

A.1.3.2 For further information, see NFPA 30.

Δ **A.3.2.1 Approved.** The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment, or materials, the "authority having jurisdiction" may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The "authority having jurisdiction" may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA standards in a broad manner because jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.7 Enclosure. Examples of enclosures include a room, building, vessel, silo, bin, pipe, or duct.

A.3.3.11 Flame Speed. Flame speed is dependent on turbulence, the equipment geometry, and the fundamental burning velocity.

A.3.3.12.1 Lower Flammable Limit (LFL). LFL is also known as minimum explosible concentration (MEC). See ASTM E681, *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases).*

A.3.3.14 Flash Point. See ASTM E502, *Standard Test Method for Selection and Use of ASTM Standards for the Determination of Flash Point of Chemicals by Closed Cup Methods,* to determine the appropriate test method to use.

A.3.3.16 Friction Factor, f_D. The D'Arcy friction factor, relating pressure drop in a straight duct to velocity and wetted surface area, is dimensionless:

[A.3.3.16a]

$$f_D = \frac{2D_h \cdot \Delta P}{\rho \cdot U^2 \cdot L}$$

where:
D_h = hydraulic diameter
ΔP = pressure loss across the duct
ρ = fluid density
U = fluid velocity (shown here as U to avoid confusion with volume)
L = duct length

At least two friction factors are in common usage: the D'Arcy friction factor, as used in this document, and the Fanning friction factor (f_F). The two forms differ by a factor of 4, as seen here:

[A.3.3.16b]

$$f_F = \frac{D_h \cdot \Delta P}{2\rho \cdot U^2 \cdot L}$$, the Fanning friction factor

[A.3.3.16c]

$$f_D = \frac{2 \cdot D_h \cdot \Delta P}{\rho \cdot U^2 \cdot L}$$, the D'Arcy friction factor

[A.3.3.16d]

$$f_D = 4 f_F$$

The equivalent velocity head loss for straight duct is expressed as follows:

[A.3.3.16e]

$$K = \frac{4 \cdot f_F \cdot L}{D_h}$$ when using the Fanning friction factor

[A.3.3.16f]

$$K = \frac{f_D \cdot L}{D_h} \text{ when using the D'Arcy friction factor}$$

D'Arcy friction factors are presented in Moody diagrams and can be calculated from equations that represent the diagrams. *(See NFPA 750 for a Moody diagram.)* Similar diagrams are also available to provide Fanning friction factors. To be sure that the appropriate diagram is being used, the user should examine the laminar region. In the laminar region — that is, a low Reynolds number — the D'Arcy friction factor equals 64/Re. The Fanning friction factor in the laminar region equals 16/Re.

Colebrook equations model the friction factor using implicit equations, which must be solved iteratively. The factor of 4 difference can be seen in the following similar equations:

For the Fanning friction factor:

[A.3.3.16g]

$$\frac{1}{\sqrt{f_F}} = -4\log_{10}\left[\frac{\varepsilon}{3.7 \cdot D_h} + \frac{1.255}{\mathrm{Re}\sqrt{f_F}}\right]$$

For the D'Arcy friction factor:

[A.3.3.16h]

$$\frac{1}{\sqrt{f_D}} = -2\log_{10}\left(\frac{\varepsilon}{3.7 \cdot D_h} + \frac{2.51}{\mathrm{Re}\sqrt{f_D}}\right)$$

where:
ε = the absolute roughness
Re = the dimensionless Reynolds number

Note that ε/D is the dimensionless relative roughness.

When applied to venting, the friction factor is evaluated at fully turbulent conditions, meaning a very large Reynolds number. For these conditions, the D'Arcy form of the Colebrook equation is rearranged and simplified as follows to allow a direct solution:

$$\frac{1}{\sqrt{f_D}} = -2\log_{10}\left[\frac{\varepsilon}{3.7 \cdot D_h} + (\approx 0)\right]$$

$$\frac{1}{\sqrt{f_D}} = 1.14 - 2\log_{10}\left(\frac{\varepsilon}{D_h}\right)$$

[A.3.3.16i]

$$f_D = \left\{\frac{1}{\left[1.14 - 2\log_{10} \cdot \left(\frac{\varepsilon}{D_h}\right)\right]}\right\}^2$$

A.3.3.19 Hydraulic Diameter. Hydraulic diameters for circles, squares, and rectangular, triangular, and elliptical shapes are given in Darby, Table 7-1.

For circular cross sections, the effective diameter is the standard diameter. For cross sections other than those that are circular, the effective diameter is the hydraulic diameter determined by Equation A.3.3.19a, where A is the cross-sectional area normal to the longitudinal axis of the space and p is the perimeter of the cross section.

[A.3.3.19a]

$$D_h = 4 \cdot \left(\frac{A}{p}\right)$$

The term *equivalent diameter*, D_E, appears in earlier editions of NFPA 68, but based upon the Committee's review of the data, which is based on circular ducts, the use of hydraulic diameter was determined to be more appropriate and has been introduced into this edition of the standard. The definition of equivalent diameter is shown by the following equation:

[A.3.3.19b]

$$D_E = 2\sqrt{\frac{A}{\pi}}$$

Equivalent diameters are not the same as hydraulic diameters.

A.3.3.20 K_{St}. See B.1.2.3.

A.3.3.23 Minimum Ignition Energy (MIE). The lowest value of the minimum ignition energy is found at a certain optimum mixture. The lowest value, at the optimum mixture, is usually quoted as the minimum ignition energy.

A.3.3.25.1 Hybrid Mixture. In certain processes, flammable gases can desorb from solid materials. If the solid is combustible and is dispersed in the gas-oxidant mixture, as can be the case in a fluidized bed dryer, a hybrid mixture can also result. *(See 6.2.3.)*

A.3.3.25.2 Optimum Mixture. The optimum mixture is not always the same for each combustion property that is measured.

A.3.3.26 Oxidant. Oxygen in air is the most common oxidant.

A.3.3.28.1 Maximum Rate of Pressure Rise *[(dP/dt)$_{max}$]*. See Annex B.

A.3.3.34.1 Hinge Vent. This type of vent closure includes hinged doors, as well as rupture panels that petal upon actuation. During vent actuation, the vent petal(s) are retained by the hinge(s).

A.3.3.34.2 Translating Vent. A translating vent closure that fragments into multiple pieces during vent actuation is sometimes termed a *fragmentation vent*.

A.4.2.1.1 The nature of a deflagration event is such that personnel in an enclosure where a deflagration occurs do not have time to exit to a place of safety. Personnel in the space will be subject to flame and pressure effects. General safety guidelines of other standards should be consulted for advice on how to prevent hazardous atmospheres or restrict access.

A.4.2.1.4 Combustible dust is not completely oxidized during a vented deflagration. Vented material comprises unburned dust, oxidized combustion products, plus partially burned "decomposition" products. Vent relief devices open at a small fraction of the 6–10 atmosphere overpressures produced by typical confined dust deflagrations, and the maximum amount of unburned material is released when the ignition source is farthest from the vent. Unburned dust is always released during venting, and a cloud of dust and various other products can travel large distances from the vented enclosure. Even with a flame-arresting and particulate retention device installed on the vent closure, some dust will escape into the surrounding area. Alternative methods of explosion prevention or protection should be applied for highly toxic combustible dusts, taking into consideration the potential for personnel exposure to released material during or after the event. Consideration of the most appropriate means of explosion protection should include environmental impact even if a toxic dust does not meet the criteria of "highly toxic" in this standard.

A.4.2.2.2 Treatment of interconnected enclosures needs to be considered and explained.

A.5.1.1 The person(s) or organization performing these assessments should have experience in the technologies presented in this document, knowledge of explosion dynamics, the effects of explosions on structures, and alternative protection measures.

A.5.2.3.2 For example, information on blast loads or buildings can be found in API RP 752, *Management of Hazards Associated with Location of Process Plant Permanent Buildings*, Table 3.

A.5.2.3.3 Deflagration vents should be located to discharge into spaces where they will not present a hazard. It is acknowledged that it might be impractical to achieve this safety objective in some cases such as existing plants. In these cases, appropriate warning signs should be posted and the risk should be minimized using an "as-low-as-reasonably-practicable" (ALARP) or other acceptable risk mitigation principle.

A.6.1 A deflagration vent is an opening in an enclosure through which material expands and flows, thus relieving pressure. If no venting is provided, the maximum pressures developed during a deflagration of an optimum fuel–air mixture are typically between 6 and 10 times the initial absolute pressure. In many cases, it is impractical and economically prohibitive to construct an enclosure that can withstand or contain such pressures.

In some cases, however, it is possible to design for the containment of a deflagration. For further information, see NFPA 69.

A.6.1.1 The maximum pressure generated and the maximum rate of pressure rise are key factors in the design of deflagration protection systems. The key characteristics of closed-vessel deflagrations are the maximum pressure attained, P_{max}, and the maximum rate of pressure rise, $(dP/dt)_{max}$. A rapid rate of rise means that only a short time is available for successful venting. Conversely, a slower rate of rise allows the venting to proceed more slowly while remaining effective. In terms of required vent area, the more rapid the rate of rise, the greater the area necessary for venting to be effective, with all other factors being equal.

A.6.1.2 Current vent sizing methodology is based on K_{St} as determined by ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds,* or the similar ISO 6184-1, *Explosion protection systems — Part 1: Determination of explosion indices of combustible dust in air*. Determination of K_{St} values by methods other than these would be expected to yield different results. Data from the Hartmann apparatus should not be used for vent sizing. Also, the 20 L test apparatus is designed to simulate results of the 1 m^3 chamber; however, the igniter discharge makes it problematic to determine K_{St} values less than 50 bar-m/s. Where the material is expected to yield K_{St} values less than 50 bar-m/s, testing in a 1 m^3 chamber might yield lower values.

The K_{St} value needs to be verified by specific test of a dust that has been created by the process that created the dust. There are reasons why this needs to be done.

The shape and particle size distribution of the dust is affected by the mechanical abuse that the material has undergone by the process that has created the dust in the first place. An example of this is the polymeric dust created by the suspension polymerization of styrene (in water) that results in spherical particle shapes (resembling small spheres).

A polymeric dust created by sending a bulk polymerized polystyrene block through a hammermill results in a dust that has been fractured and has many sharp edges and points. Even if the sieve size distribution of the two types of particles are similar, the specific surface area of the spherical particles can be much smaller than the particles generated by hammermill. The K_{St} values for these two samples will be different. The rate of pressure rise for the spherical particles will be slower than the dust sample created by the hammermill operation. Guidance for representative particulate sampling procedures can be found in ASTM D5680, *Standard Practice for Sampling Unconsolidated Solids in Drums or Similar Containers,* or in the Center for Chemical Process Safety *Guidelines for Safe Handling of Powders and Bulk Solids,* Section 4.3.1.

A.6.1.2.1 An increase in the moisture content of a dust also can decrease the maximum rate of pressure rise. The quantity of moisture necessary to prevent the ignition of a dust by most common sources normally results in dust so damp that a cloud cannot readily form. Material that contains such a quantity of moisture usually causes processing difficulties. An increase in the moisture content of a dust can increase the minimum energy necessary for ignition, ignition temperature, and flammable limit. Moisture in a dust can inhibit the accumulation of electrostatic charges. Since moisture in the air (humidity) surrounding a dust particle has no significant effect on a deflagration once ignition occurs, a moisture addition process should not be used as the basis for reducing the size of deflagration vents.

A.6.1.2.3 Recent testing has shown that certain metal dusts exhibit K_{St} values that are significantly larger in 1 m^3 tests than in 20 L tests. There is evidence of nonconservative vent area predictions for aluminum, when based on 20 L tests, while silicon vent area is overpredicted. It is currently hypothesized that flame temperature is a significant related parameter and it is therefore considered appropriate to require either testing in the larger 1 m^3 vessel or application of a safety factor to 20 L results for aluminum, hafnium, magnesium, tantalum, titanium, zirconium, and similar alloys or mixtures. These metals all have maximum adiabatic flame temperatures higher than 3300°C, whereas the calculated adiabatic flame temperature for silicon is 2970°C (NFPA 484 Table A.1.3(a)). The factor of 2 adjustment is based on the comparison of optimum K_{St} values for aluminum in 1 m^3 and 20 L tests. Until more information is available, K_{St} results for aluminum, hafnium, magnesium, tantalum, titanium, zirconium, and similar alloys or mixtures in smaller test vessels are adjusted to provide additional confidence in application of the design methods. It is possible that the adjusted 20 L value will exceed the actual K_{St} when measured in the 1 m^3 vessel and, where available, the measured K_{St} should be used. If the adjusted K_{St} value exceeds 800 bar-m/s, testing in a 1 m^3 vessel is recommended because this exceeds the limitations of the dust venting equations. Representative samples should be collected before the metals undergo significant surface oxidation, and the sample should be preserved in suitable inert gas or vacuum packaging until tested. *(See Table A.6.1.2.3.)*

A.6.2.3 The properties of hybrid mixtures are discussed extensively in [3] and [66]. The effective K_{St} value of most combustible dusts is raised by the admixture of a combustible gas, even if the gas concentration is below the lower flammable limit. The equivalent mixture K_{St} can be determined by adapting the ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, method to precharge the test vessel with the combustible gas(es), then inject the dust in the normal way.

A.6.2.4 The foams of combustible liquids can burn. If the foam is produced by air that bubbles through the liquid, the bubbles contain air for burning. Combustion characteristics depend on a number of properties such as the specific liquid, the size of the bubble, and the thickness of the bubble film. A more hazardous case occurs if a combustible liquid is saturated with air under pressure; if the pressure over the liquid phase is then released, foam can form with the gas phase in the bubbles preferentially enriched in oxygen. The enrichment occurs because the solubility of oxygen in combustible liquids is higher than that of nitrogen. The increased oxygen concentration results in intensified combustion. Therefore, it is recommended that combustible foams be tested carefully relative to design for deflagration venting.

A.6.3.1.1 This is also referred to as "explosion pressure shock resistant design" in European documents, such as EN 14460, *Explosion resistant equipment*.

A.6.3.1.2 If the enclosure is intended to be reused following an event, the owner or operator should design the system to prevent permanent deformation of the enclosure. This is also referred to as "explosion pressure resistant design" in European documents such as VDI 3673, *Pressure Venting of Dust Explosions*, and EN 13237, *Potentially explosive atmospheres — Terms and definitions for equipment and protective systems intended for use in potentially explosive atmospheres*.

A.6.3.1.3 Figure A.6.3.1.3 shows a curve that is a general representation of a stress-strain curve for low-carbon steel.

In the context of pressure vessels, the maximum allowable accumulation of pressure, above the maximum allowable working pressure (MAWP), during the postulated relief scenario is used to determine the minimum open area of the relieving device. Stated differently, the maximum pressure in the vessel is allowed to exceed MAWP during the release. Equations 6.3.1.3.2a and 6.3.1.3.2b similarly indicate that for ratios of ultimate stress or yield stress to allowable stress greater than 1.5, P_{red} could be chosen to exceed MAWP during the deflagration.

Table A.6.1.2.3 Determining K_{St} and P_{max} for Aluminum, Hafnium, Magnesium, Tantalum, Titanium, Zirconium, and Similar Alloys or Mixtures

Multiply K_{St} from 20 L sphere tests by a factor of 2 AND use P_{max} from 20 L sphere tests
Or use K_{St}/P_{max} from 1 m^3 vessel tests

A.6.3.2 The maximum pressure that is reached during venting, P_{red}, exceeds the pressure at which the vent device releases, P_{stat}. The amount by which P_{red} exceeds P_{stat} is a complicated function of the rate of pressure development within the enclosure, vent size, and vent mass. Where the ratio of the deflagration vent area to the enclosure volume is large, P_{red} approaches P_{stat}. As the vent area is reduced, P_{red} increases and approaches P_{max} as the vent area goes to zero.

The dynamic load factor (*DLF*) is defined as the ratio of the maximum dynamic deflection to the deflection that would have resulted from the static application of the peak load, P_{red}, which is used in specifying the load-time variation. Thus the *DLF* is given by the following:

[A.6.3.2]

$$DLF = \frac{X_m}{X_s}$$

where:

X_s = static deflection or, in other words, the displacement produced in the system when the peak load is applied statically

X_m = maximum dynamic deflection

For a linear elastic system subjected to a simplified dynamic load, the maximum response is defined by the *DLF* and maximum response time, t_m. T is the duration of the load, called t_f in 6.3.5.5, and T_n is the natural period of the structure. The *DLF* and time ratio t_m/T are plotted versus the time ratio T/T_n in Figure A.6.3.2 and Figure A.6.3.5.1 for A.6.3.2(2) and A.6.3.2(1), respectively.

Two simplified loading curves with a total impulse (force × time) of 1 are discussed as follows:

(1) A triangular load with an initial amplitude of 2 force units and a duration of 1 time unit
(2) A triangular pulse load with an initial amplitude of 0 force units, rising linearly to 2 force units at time of one-half time unit, and falling linearly to 0 force units at a total duration of 1 time unit

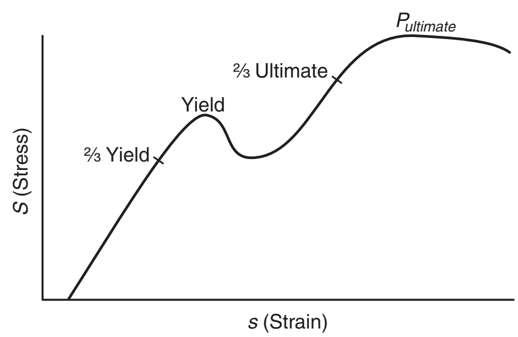


FIGURE A.6.3.1.3 Stress-Strain Curve for Low-Carbon Steel.

For the situation inside a vented enclosure, the deflagration develops in an idealized triangular pulse, A.6.3.2(2). The pressure builds at least to the point the vent closure opens, P_{stat}, and continues to rise to P_{red}. After reaching P_{red}, the pressure in the enclosure falls. In this case the maximum value of *DLF* would be approximately 1.5. Therefore design for a static pressure of two-thirds of yield or burst means that the maximum deflections during the event would reach yield or burst pressure, depending on the design choice. Because deflagration testing is done on supposed worst-case mixtures, this is a reasonable design value. For a stiff enclosure with a small natural period, T_n, and a typical deflagration, $T/T_n > 1$ and *DLF* will be less than the maximum 1.5.

A.6.3.2.2 The dynamic load factor (*DLF*) value of 1.5 is approximately the maximum directly applicable to a linear elastic system with a centrally peaked blast loading. The development of *DLF* values for nonlinear plastic behavior is more complex, and the applicable *DLF* can exceed 1.5. A *DLF* value of 1.5 was adopted in 6.3.1 and 6.3.2 as a reasonable estimate intended to represent a range of conditions but is not bounding for cases where permanent deformation is allowed. If the expected explosion pressure pulse and the response of the enclosure are available, the following references provide guidance on the evaluation of dynamic load factors:

(1) Biggs, *Introduction to Structural Dynamics*
(2) UFC 3-340-02, *Structures to Resist the Effects of Accidental Explosions*
(3) ASCE, *Design of Blast-Resistant Buildings in Petrochemical Facilities*
(4) Yu and Young, "The Dynamic Load Factor of Pressure Vessels in Deflagration Events"

A.6.3.3.1 For example, floors and roofs are not usually designed to be loaded from beneath.

A.6.3.5.1 Equation 6.3.5.2 for the reaction forces in 6.3.5.1 has been established from test results [46]. For the situation outside a vented enclosure, the shape of the load curve, as applied to the supporting structure, could approach a triangular pulse as in A.6.3.2(2) or a triangular wave as in A.6.3.2(1). If P_{red} is not much larger than P_{stat}, the load curve would approach A.6.3.2(1) and the maximum *DLF* would approach 2, as shown in Figure A.6.3.5.1. On the other hand, if P_{red} is significantly greater than P_{stat} and the deflagrating material exhibits a moderate K_{St}, the load curve would approach A.6.3.2(2) with a maximum *DLF* of 1.5.

Both maximum values for the supporting structure are higher than the experimental results by Faber [46], which bound the value of *DLF* as 1.2. Because the actual shape of the load curve is intermediate between the two cases, it is recommended that the experimental limiting value be used instead of either of the theoretical limits.

A.6.3.5.2 An example of the calculation of reaction force, F_r, during venting for a vent area of 1 m² and a P_{red} of 1 bar-g is as follows:

(1) $A_v = 1\ m^2 = 1550\ in.^2$
(2) $P_{red} = 1$ bar-g = 14.5 psig
(3) $F_r = (1) \cdot (1.2) \cdot (1550) \cdot (14.5) = 26{,}970$ lbf

A.6.3.5.3 In the absence of specific test information or combustion modeling results for pressure versus time, a combined collapse failure mechanism for structural supports can be evaluated against both idealized pulse and triangular wave loads and be designed based on the maximum *DLF*.

A.6.3.5.4 The installation of vents of equal area on opposite sides of an enclosure cannot be depended on to prevent thrust in one direction only. It is possible for one vent to open before another. Such imbalance should be considered when designing restraints for resisting reaction forces.

A.6.3.5.5 Knowing the duration of the reaction force can aid in the design of certain support structures for enclosures with deflagration vents. Reference [114] contains several general equations that approximate the duration of the thrust force of a dust deflagration. These equations apply only to enclosures without vent ducts. This material was contained in the NFPA 68 Impulse Task Force Report [113] to the full committee September 15, 1999.

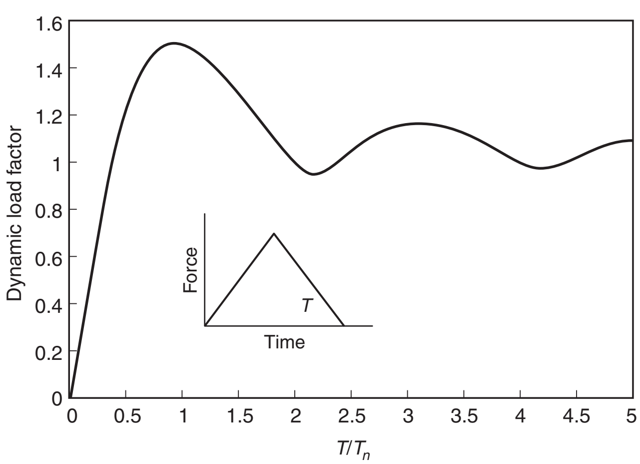


FIGURE A.6.3.2 Maximum Response of Elastic One-Degree-of-Freedom System for Triangular Pulse Load. ***(Courtesy of Department of Defense Explosives Safety Board, from TM 5-1300, Structure to Resist the Effects of Accidental Explosions, Figure 3-52)***

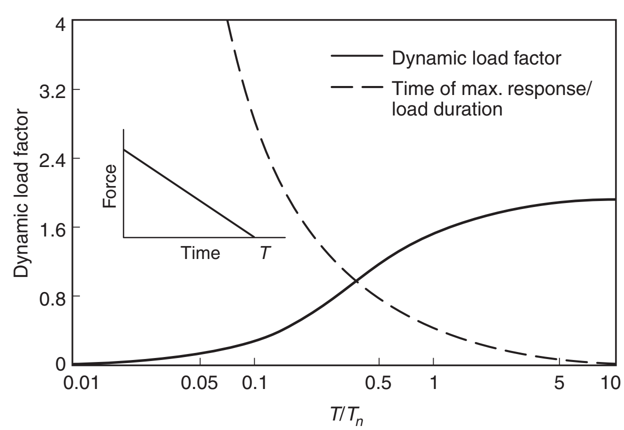


FIGURE A.6.3.5.1 Maximum Response of Elastic One-Degree-of-Freedom System for Triangular Load. ***(Courtesy of Department of Defense Explosives Safety Board, from TM 5-1300, Structure to Resist the Effects of Accidental Explosions, Figure 3-4)***

A.6.3.5.6 The determination of total impulse uses an equivalent static force, which represents the force–time integrated area as a rectangular pulse with height equal to F_s and a width equal to t_f. The equivalent static force, F_s, to be used for calculating total impulse is based on a load factor of 0.52, as established from test results [46]:

[A.6.3.5.6]

$$F_s = 0.52 \cdot (F_r)$$

For additional information on derivation of *DLF* and for use of the total impulse values, refer to textbooks on structural dynamics, such as Biggs, *Introduction to Structural Dynamics*.

An example of the calculation of duration of reaction force, t_f, and total impulse, I, resulting from venting for the following conditions is as follows:

(1) $V = 20$ m^3
(2) $P_{max} = 8$ bar-g
(3) $P_{red} = 0.4$ bar-g
(4) $A_v = 1.4$ m^2
(5) $t_f = (0.0043) \cdot (8/0.4)^{0.5} \cdot (20/1.4)$
(6) $t_f = 0.27$ s
The reaction force is determined as in 6.3.5.2:
(7) $F_r = (100) \cdot (1.2) \cdot (1.4) \cdot (0.4)$
(8) $F_r = 67$ kN
(9) $I = (0.52) \cdot (67) \cdot (0.27)$
(10) $I = 9.4$ kN-s = 9400 N-s

A.6.4 The P_{red} developed in a vented enclosure decreases as the available vent area increases. If the enclosure is small and relatively symmetrical, one large vent can be as effective as several small vents of equal combined area. For large enclosures, the location of multiple vents to achieve uniform coverage of the enclosure surface to the greatest extent practicable is recommended. Rectangular vents are as effective as square or circular vents of equal area.

A.6.4.3 *Example 1.* Cylindrical enclosure with a hopper and vented in the roof:

(1) H equals the vertical height of the enclosure = 6 m.
(2) V_{eff} equals the total free volume of the enclosure.
  (a) The volume of the cylindrical part = $(\pi \cdot D^2 / 4) \cdot h = [\pi \cdot (1.8)^2 / 4] \cdot 4 = 10.18$ m^3.
  (b) The volume of the hopper, with diameters D_1 and $D_2 = \pi \cdot h \cdot [(D_1)^2 + (D_1 \cdot D_2) + (D_2)^2] / 12 = \pi \cdot 2 \cdot [(1.8)^2 + (1.8 \cdot 0.5) + (0.5)^2] / 12 = 2.30$ m^3.
  (c) $V_{eff} = 10.18 + 2.30 = 12.48$ m^3.
  (d) V_{eff} is the shaded region in Figure A.6.4.3(a).
(3) $A_{eff} = V_{eff} / H = 12.48 / 6 = 2.080$ m^2.
(4) $D_{he} = 4 \cdot A_{eff} / p = (4 \cdot A_{eff} / \pi)^{0.5}$, assuming a cylindrical cross section.
(5) $D_{he} = 1.627$ m.
(6) $L/D = H / D_{he} = 6 / 1.627 = 3.69$.

In this example, D_{he} is less than the diameter of the cylindrical portion of the enclosure; thus L/D will be greater than if it had been calculated by taking the actual physical dimensions.

Example 2. Cylindrical enclosure with a hopper and vented at the side:

(1) H equals the vertical distance from the bottom of the hopper to the top of the vent = 4 m.
(2) V_{eff} equals the volume of the hopper plus the volume of the cylinder to the top of the vent.
  (a) The volume of the cylindrical part = $(\pi \cdot D^2 / 4) \cdot h = [\pi \cdot (1.8)^2 / 4] \cdot 2 = 5.09$ m^3.
  (b) The volume of the hopper, with diameters D_1 and $D_2 = \pi \cdot h \cdot [(D_1)^2 + (D_1 \cdot D_2) + (D_2^2)] / 12 = \pi \cdot 2 \cdot [(1.8)^2 + (1.8 \cdot 0.5) + (0.5)^2] / 12 = 2.30$ m^3.
  (c) $V_{eff} = 5.09 + 2.30 = 7.39$ m^3.
  (d) V_{eff} is the shaded region in Figure A.6.4.3(b).
(3) $A_{eff} = V_{eff} / H = 7.39 / 4 = 1.85$ m^2.
(4) $D_{he} = 4 \cdot A_{eff} / p = (4 \cdot A_{eff} / \pi)^{0.5}$, assuming a cylindrical cross section.
(5) $D_{he} = 1.53$ m.
(6) $L/D = H / D_{he} = 4 / 1.53 = 2.61$.

Example 3. Rectangular enclosure with a hopper and a side vent:

(1) H equals the vertical distance from the bottom of the hopper to the top of the vent = 5 m.
(2) V_{eff} equals the volume of the hopper plus the volume of the rectangular vessel to the top of the vent.
  (a) The volume of the rectangular part = $A \cdot B \cdot h = 1.8 \cdot 1.5 \cdot 3 = 8.1$ m^3.
  (b) The volume of the hopper *[see Figure A.6.4.3(c)]* = $(a_1) \cdot h \cdot (b_2 - b_1) / 2 + (b_1) \cdot h \cdot (a_2 - a_1) / 2 + h \cdot (a_2 - a_1) \cdot (b_2 - b_1) / 3 + (a_1) \cdot (b_1) \cdot h = (0.5) \cdot 2 \cdot (1.5 - 0.3) / 2 + (0.3) \cdot 2 \cdot (1.8 - 0.5) / 2 + 2 \cdot (1.8 - 0.5) \cdot (1.5 - 0.3) / 3 + (0.5) \cdot (0.3) \cdot 2 = 2.33$ m^3.
  (c) $V_{eff} = 8.1 + 2.33 = 10.43$ m^3.
  (d) V_{eff} is the shaded region in Figure A.6.4.3(d).
(3) $A_{eff} = V_{eff} / H = 10.43 / 5 = 2.09$ m^2.
(4) $D_{he} = 4 \cdot A_{eff} / p = (A_{eff})^{0.5}$, assuming a square cross section. $D_{he} = 1.44$ m.
(5) $L/D = H / D_{he} = 5 / 1.44 = 3.47$.

Example 4. Rectangular enclosure with a hopper and a side vent located close to the hopper:

(1) H equals the vertical distance from the top of the rectangular vessel to the bottom of the vent. H is the longest flame path possible because the vent is closer to the hopper bottom than it is to the vessel top = 4.5 m.
(2) V_{eff} equals the volume from the top of the rectangular vessel to the bottom of the vent.
  (a) $V_{eff} = A \cdot B \cdot h$
  (b) $V_{eff} = 1.8 \cdot 1.5 \cdot 4.5 = 12.15$ m^3.
  (c) V_{eff} is the shaded region in Figure A.6.4.3(e).
(3) $A_{eff} = V_{eff} / H = 12.1 / 4.5 = 2.7$ m^2.
(4) $D_{he} = 4 \cdot A_{eff} / p = 4 \cdot A_{eff} / [2 \cdot (A + B)]$.
$D_{he} = 4 \cdot 2.7 / [2 \cdot (1.8 + 1.5)] = 1.64$ m.
(5) $L/D = H / D_{he} = 4.5 / 1.64 = 2.74$.

Example 5. General calculation of the volume of a hopper.

(1) Rectangular hopper:

[A.6.4.3a]

$$V = \frac{(a_1)\cdot(h)\cdot(b_2 - b_1)}{2} + \frac{(b_1)\cdot(h)\cdot(a_2 - a_1)}{2} + \frac{(h)\cdot(a_2 - a_1)\cdot(b_2 - b_1)}{3} + (a_1)\cdot(b_1)\cdot h$$

(2) Conical hopper:

[A.6.4.3b]

$$V = \pi \cdot (h)\frac{\left[(D_1)^2 + (D_1 \cdot D_2) + (D_2)^2\right]}{12}$$

where:
D_1 = diameter of the base
D_2 = diameter of the top

Example 6. Two vents, slightly offset vertically but on opposite sides of the enclosure *[see Figure A.6.4.3(f)]*. Because the vents overlap along the vertical axis, V_{eff} equals the volume from the bottom of the rectangular vessel to the top of the highest vent.

Example 7. Two vents located on the same vertical line, offset from each other along the central axis, with the upper vent top located at the top of the enclosure *[see Figure A.6.4.3(g)]*. With multiple vents along the central axis, V_{eff} for the bottom vent is the volume from the bottom of the enclosure to the top of the lowest vent. V_{eff} for the next vent is the volume from the top of the lower vent to the top of the upper vent.

A.6.4.4 The design of deflagration vents and vent closures necessitates consideration of many variables, only some of which have been investigated in depth. The technical literature reports extensive experimental work on venting of deflagrations in large enclosures. Equations have been developed that can be used for determining the necessary vent areas for enclosures [101]. The calculated vent area depends on several factors, including the size and strength of the enclosure, the characteristics of the fuel-oxidant mixture, and the design of the vent itself. The design techniques use one or more empirical factors that allow simplified expressions for the vent area. The design factors are the result of analyses of numerous actual venting incidents and venting tests that have allowed certain correlations to be made. The user of this standard is urged to give special attention to all precautionary statements.

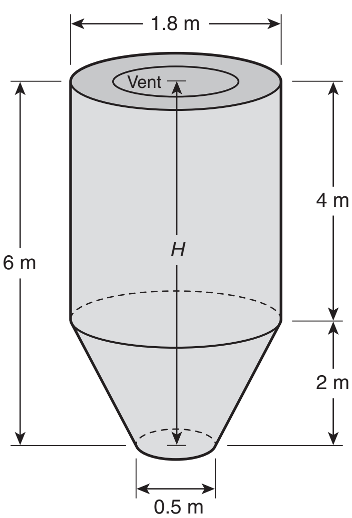


FIGURE A.6.4.3(a) Calculating *L/D* Ratio for a Cylindrical Vessel with a Hopper and a Top Vent.

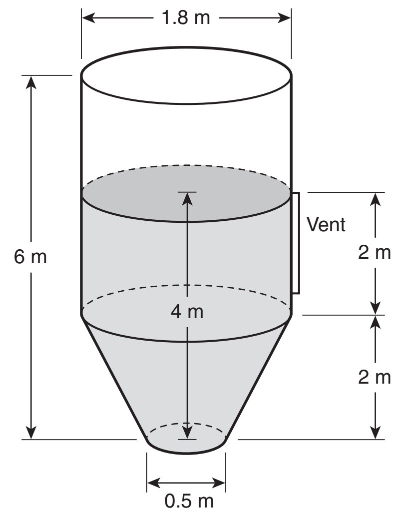


FIGURE A.6.4.3(b) Calculating *L/D* Ratio for a Cylindrical Vessel with a Hopper and a Side Vent.

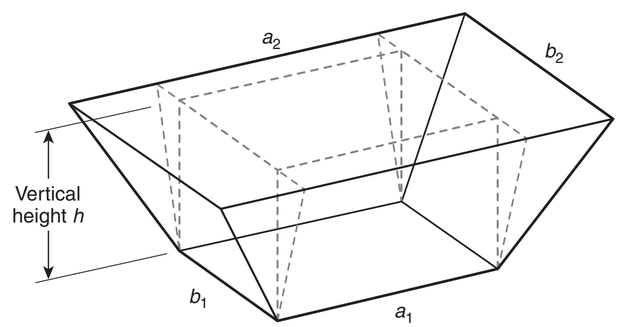


FIGURE A.6.4.3(c) Rectangular Hopper.

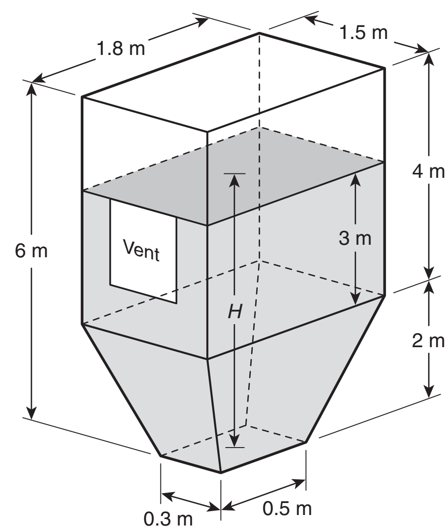


FIGURE A.6.4.3(d) Rectangular Enclosure with a Hopper and a Side Vent.

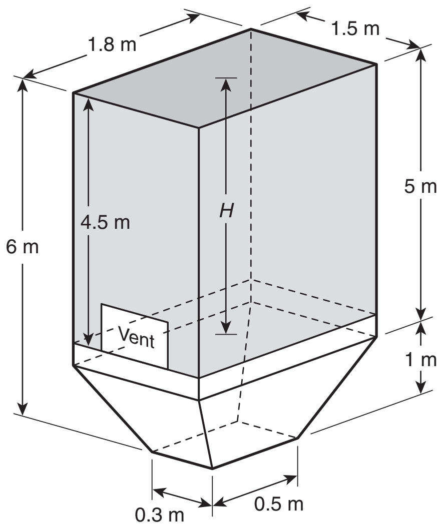


FIGURE A.6.4.3(e) Rectangular Enclosure with a Hopper and a Side Vent Close to the Hopper.

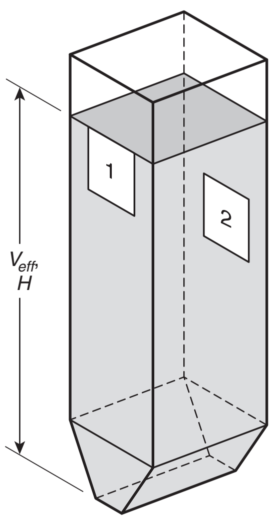


FIGURE A.6.4.3(f) Rectangular Enclosure, with a Hopper and Two Vents on Opposite Sides of the Enclosure.

The reduced pressure, P_{red}, in a vented gas deflagration can be reduced significantly in certain situations by lining the enclosure interior walls with an acoustically absorbing material, such as mineral wool or ceramic fiber blankets. These materials inhibit acoustic flame instabilities that are responsible for high flame speeds and amplified pressure oscillations in deflagrations of initially quiescent gas-air mixtures in unobstructed enclosures.

Data [45] show the effects of using 50 mm (2 in.) thick glass wool linings for propane deflagrations in a 5.2 m^3(184 ft^3) test vessel that is equipped with a 1 m^2(10.8 ft^2) vent for which P_{stat} equals 24.5 kPa (3.6 psi). The value of P_{red} is 34 kPa (4.9 psi) in the unlined vessel and 5.7 kPa (0.8 psi) (that is, a reduction of 83 percent) where the glass wool lining is installed on two of the vessel interior walls.

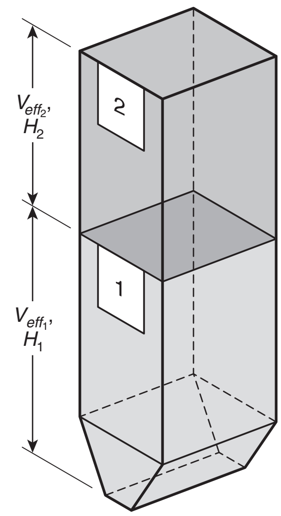


FIGURE A.6.4.3(g) Rectangular Enclosure with a Hopper and Two Vents on the Same Vertical Line.

Data [37] illustrate the effects of a 76 mm (3 in.) thick mineral wool lining for natural gas deflagrations that are centrally ignited in a 22 m^3 (777 ft^3) test vessel that is equipped with a 1.1 m^2 (11.8 ft^2) vent for which P_{stat} equals 8 kPa (1.2 psi). The measured values of P_{red} are approximately 60 kPa (8.7 psi) in the unlined vessel and approximately 8 kPa (1.2 psi) (that is, a reduction of 87 percent) where the lining is placed on the floor and three walls of the vessel.

Similar dramatic reductions in P_{red} have been obtained in propane deflagration tests in a 64 m^3 (2260 ft^3) enclosure using ceramic fiber blankets on three interior walls [102, 103].

A detailed discussion of the role of acoustic flame instabilities in vented gas deflagrations can be found in Solberg, Pappas, and Skramstad [44]. Acoustic flame instabilities and enclosure wall linings are important factors in unobstructed, symmetrical enclosures with ignition near the center of the enclosure. Other types of flame instabilities, such as those described in Solberg, Pappas, and Skramstad [44], that are not influenced by enclosure wall linings can have a greater influence on P_{red} in other situations.

Situations can occur in which it is not possible to provide calculated deflagration venting as described in Chapters 7 and 8. Such situations do not justify the exclusion of all venting. The maximum practical amount of venting should be provided because some venting could reduce the damage potential. In addition, consideration should be given to other protection and prevention methods, as found in NFPA 69.

A.6.4.5 The equations in Chapters 7 and 8 do not precisely predict the necessary vent area for all enclosures under all conditions. Certain data indicate that the gas-venting equations do not provide sufficient venting in every case [44, 98, 99]. Also, tests that involve extreme levels of both congestion and initial turbulence demonstrate that pressures that exceed those indicated by the equations can occur [42, 87]. Currently, however, the use of the equations is recommended based on successful industrial experience.

As the vent area increases, the reduced pressure for a given static activation pressure of the vent closure decreases. Open vents are generally more effective than covered vents. Vents with lightweight closures are more responsive than those with heavy closures.

A.6.5.1 If the vent discharges into a congested area, the pressure inside the vented enclosure increases. A major blast pressure can be caused by the ignition of unburned gases or dusts outside the enclosure.

If vents are fitted with closure devices that do not remain open after activation (i.e., self-closing), it should be recognized that a vacuum can be created where gases within the enclosure cool. Vacuum within the enclosure could result in equipment damage.

A.6.5.2.1 For further information, see *National Association of Corrosion Engineers Handbook*.

A.6.5.7 Explosion vents are produced with a tolerance, as specified by the manufacturer, in pressure terms (e.g., psi, bar) or as a fraction of the P_{stat} (±X%). When P_{stat} minus the manufacturing tolerance is less than the pressure produced by the design wind load, the vent could open if it is on the downwind side of the structure. ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*, and FM Global Property Loss Data Sheet 1-28 are two references for design wind loads. *NFPA 5000*, Section 35.9, references ASCE/SEI 7 to determine appropriate wind loads. When a vent closure for a building or room is constructed by the owner/operator, the manufacturing tolerance is understood to be determined based on the tolerance of the chosen listed shear or pull-through fasteners *(see 10.3.2)*. The nonventing wall sections should be designed to withstand higher pressures than the intended vent closure.

Example: A vent closure is to be located on a side wall section (zone 4) where the outward wind load design pressure, based on the basic wind speed (3-second gust), is 2.0 kPa. Determine the minimum P_{stat} design for a relieving wall section when the shear fasteners employed have a ±10 percent manufacturing tolerance.

Minimum wind load design pressure = 2.0 kPa (42 psf) = 0.02 bar-g

Shear fastener tolerance = ±10%

$P_{stat} \geq 0.022$ bar-g

A.6.5.8 When P_{stat}, including the manufacturing tolerance, is less than P_{red}, there would be no effect on performance. However, when P_{stat}, including the manufacturing tolerance, is higher than P_{red}, the actual P_{red} could be greater than expected. A minimum pressure separation of P_{stat}, including the manufacturing tolerance, from P_{red} prevents that from occurring.

Example:
$P_{stat} = \pm 1.5$ psig
Manufacturing tolerance = ±0.5 psig (±33%)
Vent release range = 1.0 to 2.0 psig
$P_{red} \geq 2.0$ psig

A.6.5.9 In some cases, ensuring dependable operation can necessitate replacing a vent closure.

A.6.6 Deflagration venting is provided for enclosures to minimize structural damage to the enclosure itself and to reduce the probability of damage to other structures. In the case of buildings, deflagration venting can prevent structural collapse. However, personnel within the building can be exposed to the effects of flame, heat, or pressure.

Damage can result if a deflagration occurs in any enclosure that is too weak to withstand the pressure from a deflagration. For example, an ordinary masonry wall [200 mm (8 in.) brick or concrete block 3 m (10 ft) high] cannot withstand a pressure difference from one side to the other of much more than 0.03 bar-g (0.5 psig).

Flames and pressure waves that emerge from an enclosure during the venting process can injure personnel, ignite other combustibles in the vicinity, result in ensuing fires or secondary explosions, and result in pressure damage to adjacent buildings or equipment. The amount of a given quantity of combustible mixture that is expelled from the vent, and the thermal and pressure damage that occurs outside of the enclosure, depends on the volume of the enclosure, the vent opening pressure, and the magnitude of P_{red}. In the case of a given enclosure and a given quantity of combustible mixture, a lower vent opening pressure results in the discharge of more unburned material through the vent, resulting in a larger fireball outside the enclosure. A higher vent opening pressure results in more combustion taking place inside the enclosure prior to the vent opening and higher velocity through the vent. *(See 6.2.3.)* The fireball from vented dust deflagrations is potentially more hazardous than from vented gas deflagrations, because large quantities of unburned dust can be expelled and burned during the venting process.

Deflagration venting generates pressure outside the vented enclosure. The pressure is caused by venting the primary deflagration inside the enclosure and by venting the secondary deflagration outside the enclosure.

A.6.6.2.3 A deflector is considered to be a specific subset of the general concept of a barrier. Walls or three-sided containment constructions are used to minimize the hazard of fragments and flame impingement from a deflagration; however, if the wall is too close or if the containment volume is too small, P_{red} will increase and pressure will build between the barrier and the vent. The effectiveness of the wall is limited to the area immediately behind it. Pressure and flame effects will reform at some point downstream of the wall.

A.6.6.2.4 Other deflector designs are possible, but design information is not available at this time. An alternative could be to use a vent duct consisting of a long radius elbow, accounting for the effect of vent area according to Chapter 8 for dusts. A vertical barrier wall could result in higher P_{red} or larger radial hazard distance than an angled deflector, and no design guidance can be given.

A.6.6.2.5 A deflector inclined at 45 to 60 degrees can be applied to larger vessels to protect personnel as long as it is installed more than $1.5D_{hv}$ from the vent opening so as to not increase P_{red}. The ability of this deflector to limit flame length for these larger vessels is uncertain.

A.6.7.1 Table A.6.7.1 demonstrates the effect of vent mass on P_{red}.

A.6.7.2 The preponderance of the available test data indicates that P_{red} increases with panel density. These data have been used to develop the equations in this document. However, a limited amount of data demonstrates exceptions to this trend,

Table A.6.7.1 Reduced Pressure (Pred) Developed During Deflagration Venting and Influenced by Mass of Vent Closure, 5 Percent Propane in Air, Enclosure Volume = 2.6 m3 [95]

Vent Closure Mass		Static Opening Pressure (P_{stat})	Vent Closure Response	Reduced
kg/m²	lb/ft²	(m-bar-g)	Time (m-s)	P_{red}(m-bar-g)
0.3563	0.073	103	14.5	156
3.32	0.68	96	31.0	199
11.17	2.29	100	42.6	235
20.79	4.26	100	54.0	314

Notes:
(1) L/D = 2.3.
(2) Test series reported = #17, #1, #3, and #4.
(3) A_v = 0.56 m² (6.0 ft²).

especially for initially quiescent gas mixtures where venting-induced turbulence dominates P_{red}.

The greater the mass of the closure, the longer the closure takes to clear the vent opening completely for a given vent opening pressure. Conversely, closures of low mass move away from the vent opening more quickly, and venting is more effective.

A.6.7.4 The free area of a vent does not become fully effective in relieving pressure until the vent closure moves completely out of the way of the vent opening. Until this occurs, the closure obstructs the combustion gases that are issuing from the vent.

In general, a hinged vent closure results in a higher P_{red} than does a rupture diaphragm. The hinged vent closure with its geometric area, A_1, mass, and static relief pressure, P_{stat}, is tested in position on an enclosure under suitable conditions of gas K_G or dust K_{St}, and ignition that closely replicate the intended installation. The P_{red} is determined experimentally under these conditions, and P_{red} is related to a corresponding vent area, A_2, for an inertialess vent closure such as a rupture diaphragm, which relieves at the same P_{stat} and gives the same P_{red}.

The venting efficiency is given by the following equation:

[A.6.7.4]

$$E = \left(\frac{A_2}{A_1}\right) \cdot 100 = \text{percent efficiency}$$

where:
E = venting efficiency
A_2 = vent area for inertialess vent closure
A_1 = vent area for hinged vent closure

For similarly designed hinged closures, the vent area determined by use of equations in Chapter 7 or Chapter 8 should be corrected by dividing by the demonstrated fractional efficiency of the hinged vent closure. This correction would include the otherwise modeled effect of increased inertia. Annex F provides an alternative method to account for hinged closures when dealing with dusts.

A.6.8 The fireball or flame extension from a vented gas or dust deflagration presents a hazard to personnel in the vicinity. People caught in the flame itself will be at obvious risk from burns, but those who are outside the flame area can be at risk from thermal radiation effects. The heat flux produced by the fireball, the exposure time, and the distance from the fireball are important variables to determine the hazard.

When dust deflagrations occur, there can be far more dust present than there is oxidant to burn it completely. When venting takes place, large amounts of unburned dust are vented from the enclosure, and burning continues as the dust mixes with additional air from the surrounding atmosphere. The fireball extent will be a function of the total amount of dust in the enclosure that becomes dispersed and burns in the deflagration. Consequently, a very large and long fireball of burning dust develops that can extend downward as well as upward. The average surface emissive power varies greatly between different types of dusts, with metal dusts tending to be much worse than, for example, agricultural dusts [112].

N **A.6.8.2** If the vented material exits from the vent horizontally, the horizontal length of the fireball or flame extension is anticipated. It is extremely important to note that the fireball can, in fact, extend downward as well as upward [91, 108]. In some deflagrations, buoyancy effects can allow the fireball to rise to elevations well above the distances specified. Equation 6.8.2 and Equation 6.8.3 calculate the fireball dimension, but that is not the only factor to consider in evaluating the hazard from an emerging vented deflagration. Other factors to consider include, but are not limited to, environmental matters such as prevailing wind speed and direction, external nearby structures, particle size, vent configuration and weight, and nearby operations. A safety factor should be considered based on an assessment of the risk elements that are present in or near the anticipated path of travel of the emerging flame and unburned gas or dust.

Δ **A.6.8.3** See A.6.8.2 for additional information.

Equation 6.8.3 is based on Bartknecht [101] and also includes an adjustable value K that reflects the work of Holbrow et al. [112].

Higher panel inertia slows the panel deployment, extending the time during which the projected flame could be deflected off the vent axis direction. This effect can occur with, but is not limited to, one-petal panels with a hinge on one side or translating panels (no hinge). The deflection of the projected flame can be advantageous in some installations, such as directing the flame upwards, assuming upward is the safer venting direction. For hinged panels, the location of the hinge can thus be important. The deflected flame could extend with length equal to the full predicted flame length.

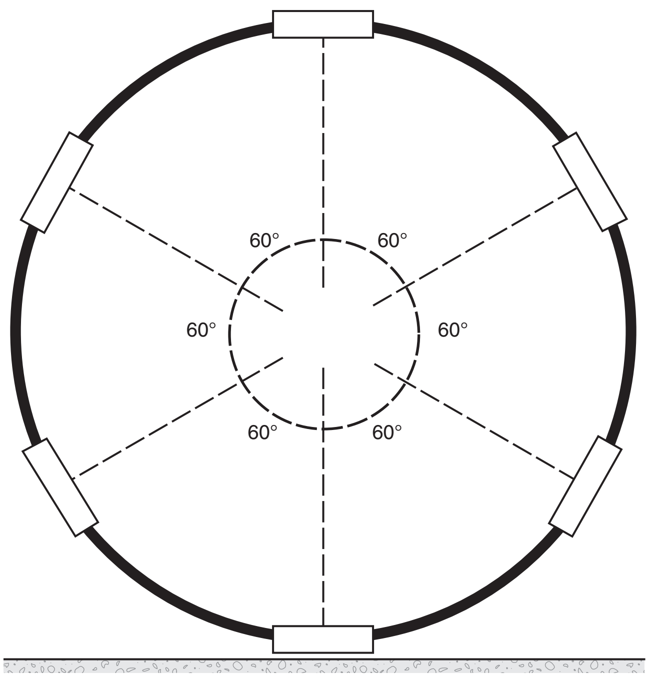
•

N **A.6.8.4** The number of independent vents, n, should be those vents that are spaced sufficiently so that the resulting fireballs do not interact. Multiple independent vents will create separate fireballs with a shorter length than a single vent opening. Vents spaced closely together can create fireballs that interact and create a fireball with a length similar to that calculated for a single vent. If the calculated fireball hazards of vents interact, they should not be counted separately in the calculation of n. If multiple vent panels cover a single vent opening, they should not be counted separately in the calculation of n. Examples of independent vents include vents on the opposite sides of rectangular enclosures or vents with spacing greater than specified in 6.8.4.1.

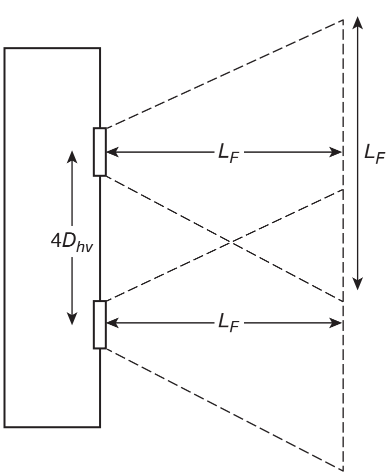
N **A.6.8.4.1** An example of vents spaced around the circumference of a vessel is shown in Figure A.6.8.4.1. Spreading the vents around the enclosure circumference will reduce the fireball length, but can increase the area of the fireball hazard. One example of when this strategy may be useful is when the vents are elevated such that the fireball extent cannot reach potentially occupied areas on the ground.

N **A.6.8.4.3** An example of independent vents spaced on the same side of a rectangular enclosure is shown in Figure A.6.8.4.3.

N **A.6.8.6** There is no maximum limit for the length of the calculated axial distance for gases in contrast to combustible dust fireballs where a maximum axial distance is listed in 6.8.5.



N **FIGURE A.6.8.4.1 Vessel with Vents Around Circumference.**



N **FIGURE A.6.8.4.3 Enclosure with Vents on Side.**

A.6.8.7 Estimates of external pressure effects for gas venting have been made using validated computational fluid dynamics models. A simpler methodology to estimate downstream external pressures for other situations and other locations is described in T. Forcier and R. Zalosh [116].

A.6.9.5 The addition of a vent duct can substantially increase the pressure developed in a vented enclosure.

A.6.9.7.2 A long-radius bend nominally has a minimum radius along the center line of 1.5 duct diameters.

A.6.10 Deflagration venting systems have been developed that have a rupture membrane for venting coupled with flame-arresting and particulate retention elements, as shown in Figure A.6.10. These devices are purposely built with two functional components: flame-arresting elements, which serve to extinguish the flame front, and particulate retention elements, which minimize the passage of particulates. As a deflagration is vented through the system, any burned and unburned dust is retained within the device. Combustion gases are cooled, and no flame emerges from the system. In addition, near-field blast effects (overpressure) are greatly reduced outside the system.

A.6.10.1 Even with complete extinguishment of flame, the area immediately surrounding the vent can experience overpressure and radiant energy. It is not possible to expect absolute retention of burnt and unburnt particulates, as demonstrated by testing. A minimal release is unavoidable and needs to be recognized where toxic or chemically active materials are being processed.

A.6.10.4 The increased flow resistance due to the flame-arresting elements and the retention of particulates could result in decreased venting efficiency. which should be determined by test.

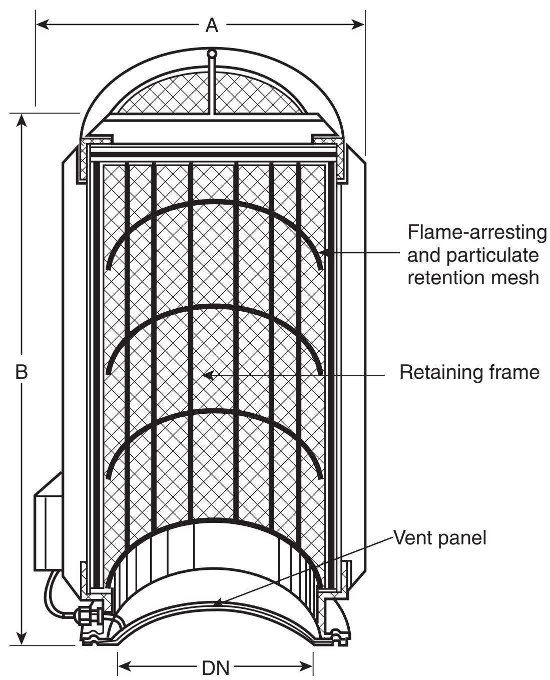


FIGURE A.6.10 Example of Flame-Arresting and Particulate-Retention Vent System.

A.6.10.5 It is essential that the user work closely with the manufacturer to ensure that all the parameters are addressed for a safe, reliable installation.

A.6.10.6 Venting indoors affects the building that houses the protected equipment due to increased pressurization of the surrounding volume *(see also Section 8.9)*. Venting indoors increases the potential for secondary explosions. Particulate deposits in the immediate area can be dislodged by the pressure wave and generate a combustible dust cloud.

A.6.10.7 The presence of flame-arresting elements will prevent direct observation of the condition of the pressure relief elements as required in 11.4.4. It is necessary to know that the venting device has not opened or been exercised. An open vent would permit dust to accumulate within the device and compromise its performance. Likewise, a resetting device would permit dust accumulation if it were to open occasionally due to excess process pressure or other causes. Knowledge that the vent has opened or the resetting device has been exercised would permit corrective actions.

A.6.10.8 The greater release of dust and radiant energy to the surrounding area is the basis for this restriction.

A.6.10.9 Burnt and unburnt fuel might be left in the flame-arresting and pressure-relieving elements, potentially affecting efficiency. Exposure to a deflagration can be expected to affect the performance of the pressure-relieving elements.

A.7.1.1 Examples of enclosures include a room, building, vessel, silo, bin, pipe, or duct *(see A.3.3.7)*. The high pressure equation is not likely to be applicable to buildings since P_{red} is greater than 0.5 bar (7.2 psi). The user is cautioned that fast-burning gas deflagrations can readily undergo transition to detonation. NFPA 69 and NFPA 67 provide alternative measures that should be considered.

Δ **A.7.2.3** Gas-air mixture parameters depend on the properties of the fuel component(s) as well as the temperature and pressure of the enclosure prior to ignition. Thermodynamics programs can be used to determine the necessary mixture parameters. These include Gaseq (http://www.gaseq.co.uk/), Chemical Equilibrium with Applications (https://cearun.grc.nasa.gov/), and STANJAN (https://navier.engr.colostate.edu/code/code-4/index.html).

A.7.2.3.1 The following information is offered to aid the user in determining an appropriate burning velocity to use when dealing with aerosols (mists).

The burning velocity of aerosols varies according to the fuel-to-air ratio, droplet diameter, and vapor fuel–to–total fuel ratio (Ω), as illustrated in Figure A.7.2.3.1(a). The burning velocity ratio is the ratio of the mist fundamental burning velocity to that of the pure vapor. The effect of increased burning velocity in the range of 5 μm to 35 μm is believed to be evident primarily in fluids of relatively low volatility, such as heat transfer fluids, that can be released above their atmospheric boiling point. In those circumstances, they can form an aerosol consisting of very small droplets that can fall into the 5 μm to 35 μm range.

The general effect of burning velocity on liquid mists released below their flash points in the order of 50 μm as compared with dusts of similar particle size and vapors is shown in Figure A.7.2.3.1(b).

The dimensionless Spalding mass transfer number (*B*) is defined as follows:

[A.7.2.3.1]

$$B = \frac{q_{st}H + C_{pa}\left(T_g - T_b\right)}{L + C_p\left(T_b - T_s\right)}$$

where:

q_{st} = mass ratio of fuel to air at stoichiometric concentration
H = heat of combustion
C_{pa} = specific heat of air
T = temperature of the gas (g), boiling point of the fuel (b), surface temperature of the fuel (s)
L = latent heat of vaporization
C_p = specific heat of the fuel

At the time of this writing, the committee is unaware of any aerosol testing that has definitively correlated deflagrations of small droplet diameter (0 μm to 30 μm) aerosols to vent area. This information is provided as a word of warning [117].

A.7.2.3.2 Annex D lists values of S_u for many gases and vapors.

A.7.2.4.2 If pressure excursions are likely during operation, the value of P_0 can be the maximum pressure excursion during operation or the pressure at the relief valve when in the fully open position.

A.7.2.4.3 Venting from enclosures at initially elevated pressures results in severe discharge conditions.

A.7.2.5 Following is a sample calculation of internal surface area:

Step 1. Consider the building illustrated in Figure A.7.2.5(a), for which deflagration venting is needed.

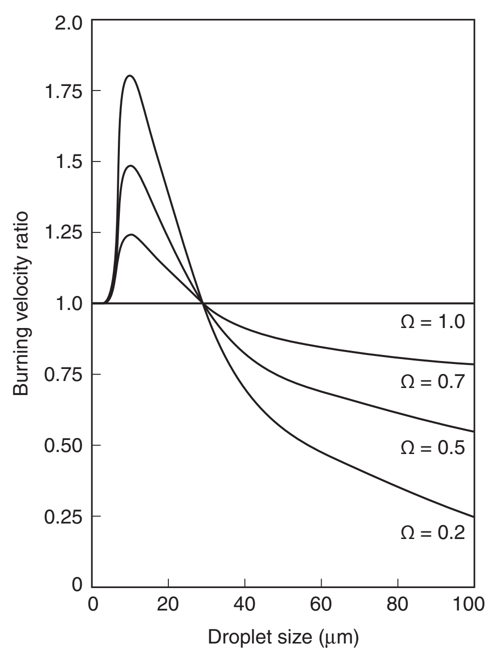


FIGURE A.7.2.3.1(a) Burning Velocity Predictions Versus Aerosol Droplet Size at Different Values of Ω.

Step 2. Divide the building into sensible geometric parts (Parts 1 and 2) as shown in Figure A.7.2.5(b).

Step 3. Calculate the total internal surface area in each part of the building.

Part 1 Surface Area (A_{S1})

Floor	=	51.8 m × 9.15 m = 474 m^2 (170 ft × 30 ft = 5100 ft^2)
Roof	=	51.8 m × 9.65 m = 499 m^2 (170 ft × 31.6 ft = 5372 ft^2)
Rear wall	=	51.8 m × 6.1 m = 316 m^2 (170 ft × 20 ft = 3400 ft^2)
Front wall	=	(36.6 m × 9.15 m) + (15.25 m × 3.05 m) = 381 m^2 [(120 ft × 30 ft) + (50 ft × 10 ft)] = 4100 ft^2
Side walls (rectangular part)	=	2 × 9.15 m × 6.1 m = 111 m^2 (2 × 30 ft × 20 ft = 1200 ft^2)
Side walls (triangular part)	=	9.15 m × 3.05 m = 28 m^2 (30 ft × 10 ft = 300 ft^2)
Total Part 1: A_{S1}	=	1809 m^2 (19,472 ft^2)

Part 2 Surface Area (A_{S2})

Floor	=	15.25 m × 9.15 m = 139 m^2 (50 ft × 30 ft = 1500 ft^2)
Roof	=	15.25 m × 9.15 m = 139 m^2 (50 ft × 30 ft = 1500 ft^2)
Front wall	=	15.25 m × 6.1 m = 93 m^2 (50 ft × 20 ft = 1000 ft^2)
Side walls	=	2 × 9.15 m × 6.1 m = 111 m^2 (2 × 30 ft × 20 ft = 1200 ft^2)
Total Part 2: A_{S2}	=	483 m^2 (5200 ft^2)

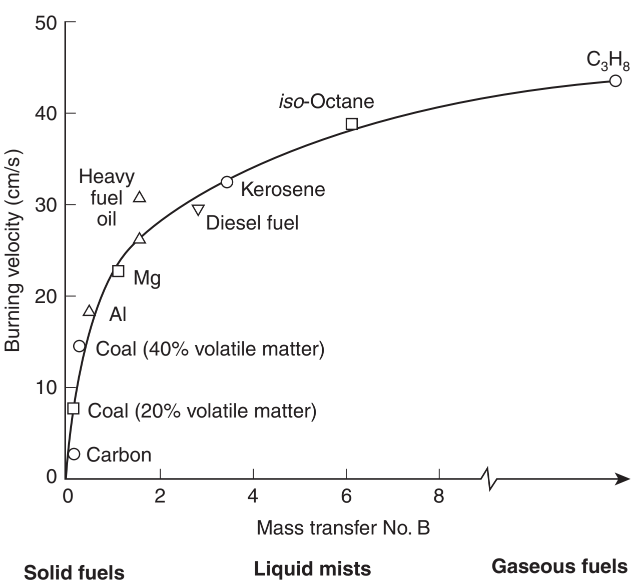


FIGURE A.7.2.3.1(b) Burning Velocity of Mixtures of Air with Flammable Vapors, Aerosols, or Dusts. (Reprinted from Lees, *Lees Loss Prevention in the Process Industries*.)

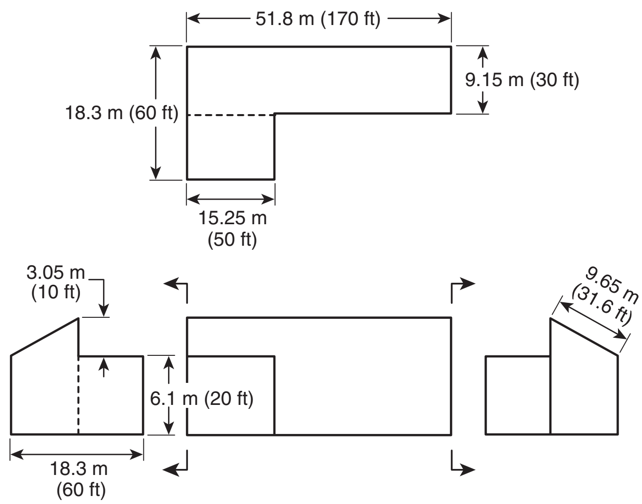


FIGURE A.7.2.5(a) Building Used in Sample Calculation, Version I (Not to Scale).

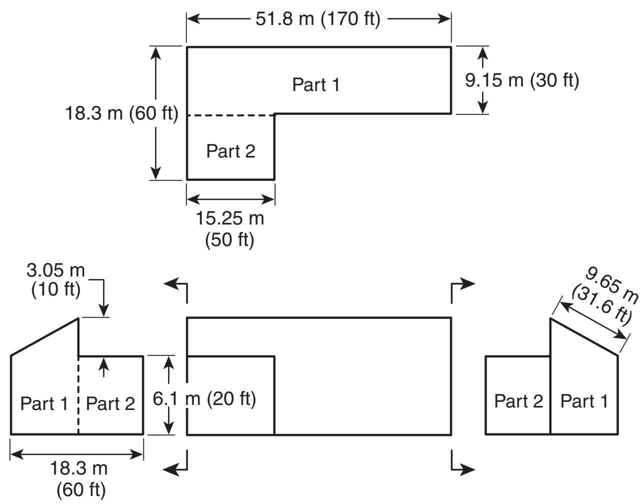


FIGURE A.7.2.5(b) Building Used in Sample Calculation, Version II (Not to Scale).

Step 4. Thus, the total internal surface area for the whole building, A_S, is expressed as follows:

A_S = 1809 m^2 (19,472 ft^2) + 483 m^2 (5200 ft^2) = 2292 m^2 (24,672 ft^2)

A.7.2.5.1 The calculated vent area can be reduced by the installation of a pressure-resistant wall to confine the deflagration hazard area to a geometric configuration with a smaller internal surface area, A_S.

A.7.2.5.1.5 Such rooms include adjoining rooms separated by a partition incapable of withstanding the expected pressure.

A.7.2.6 In many industrial enclosures, the gas phase is present in a turbulent condition. An example is the continuous feed of a flammable gas-oxidant mixture to a catalytic partial oxidation reactor. Normally this mixture enters the reactor head as a high-velocity turbulent flow through a pipe. As the gas enters the reactor head, still more turbulence develops due to the sudden enlargement of the flow cross section. Appurtenances within an enclosure enhance turbulence.

The susceptibility of a turbulent system to detonation increases with increasing values of the fundamental burning velocity. In particular, compounds that have values close to that of hydrogen are highly susceptible to detonation when ignited under turbulent conditions. It should be noted that venting tends to inhibit the transition from deflagration to detonation, but it is not an effective method of protecting against the effects of a detonation once the transition has occurred. Where the likelihood for detonation exists, alternative solutions, such as those in NFPA 69 should be considered.

A.7.2.6.1 The calculation of λ_0 depends, in part, on the diameter or characteristic dimension of the vent, D_v, through the vent Reynolds number. In a large enclosure where the user might decide to divide the total vent area into multiple vents, the characteristic dimension of each vent can be used in the calculation of the vent Reynolds number. The solution of the equations requires an iteration of total vent area, consistent with a characteristic dimension of each vent. Assuming multiple vents, instead of a single vent for the total area, results in a smaller predicted vent area since λ_0 decreases with decreasing D_v.

N **A.7.3.2** The open volume of the enclosure is the total volume of the enclosure less the volume of large solid objects, not the total volume of the enclosure.

Where an object is not gastight, the solid volume of the object might be less than the total volume of the object. Typical electrical or equipment cabinets are not gastight, some are ventilated, and the volume of such cabinets is not the same as the volume of solid objects within the cabinets. There are certain applications, such as battery energy storage systems, where electrical equipment is considered a solid object and would be subtracted from the enclosure volume.

This distinction becomes relevant as the fraction of the enclosure volume filled with solid objects increases, reducing the open-air volume available for mixing. If the partial volume effects were calculated using the total volume of the enclosure, the required vent area would be underpredicted.

A.7.4.1 Where M is greater than 40 kg/m^2, it is necessary to perform testing or apply alternative explosion protection methods per NFPA 69.

A.7.5 The deflagration vent area requirement is increased where a vent discharge duct is used. Where a deflagration is vented through a vent duct, secondary deflagrations can occur in the duct, reducing the differential pressure available across the vent.

A.7.5.1 It should be noted that P_{red} is still the maximum pressure developed in a vented deflagration. P'_{red} is not an actual pressure.

A.7.5.3 Testing has been done with 3 m (10 ft) and 6 m (20 ft) duct lengths. The effect of ducts longer than 6 m (20 ft) has not been investigated.

A.8.1.2 The K_{St} values of dusts of the same chemical composition vary with physical properties such as the size and shape of the dust particle and moisture content. The K_{St} values published in tables are, therefore, examples and represent only the specific dusts tested. *(See Annex B.)* Mechanical processes that increase particle specific surface area, such as grinding, typically increase the K_{St} value. The K_{St} value needs to be verified by specific test of a dust that has been created by the process that created the dust.

A.8.2.1.2 Example Problem

Given the following conditions, calculate A_{v0}:

V = 10 m^3

P_{red} = 5 bar-g

$P_{initial}$ = 2 bar-g

P_{max} = 8.5 bar-g (at atmospheric conditions)

K_{St} = 290 bar-m/s

P_{stat} = 2.6 bar-g

Solution

Starting in Section 8.2 and recognizing that $P_{initial}$ is above the upper atmospheric limit of 0.2 bar-g, 8.2.1.2 should be followed for determination of the minimum vent area requirement (A_{v0}). From Equation 8.2.1.2,

[A.8.2.1.2a]

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot \left(\frac{P_{stat} - P_{initial}}{1 + P_{effective}} \right)^{4/3} \right] \cdot K_{St} \cdot V^{3/4} \sqrt{\frac{1}{\Pi_{effective}} - 1}$$

where:

$P_{effective}$ = 1 / 3$P_{initial}$ (bar-g) = 1 / 3 · (2) = 0.667 bar-g

P^E_{max} = [(P_{max} + 1) · ($P_{initial}$ + 1) / (1 bar-abs) − 1] = [(8.5 + 1) · (2 + 1) / (1) − 1] = 27.5 bar-g

$\Pi_{effective}$ = (P_{red} – $P_{effective}$) / (P^E_{max} – $P_{effective}$) = (5 – 0.666) / (27.5 – 0.667) = 0.161

Δ **[A.8.2.1.2b]**

$$A_{v0} = 1 \cdot 10^{-4} \left[1 + 1.54 \cdot \left(\frac{2.6 - 2}{1 + 0.667} \right)^{4/3} \right] \cdot 290 \cdot 10^{3/4} \sqrt{\frac{1}{0.161} - 1}$$

$$A_{v0} = 0.518 \text{ m}^2$$

Discussion

Where the application would have been based on a $P_{initial}$ within the atmospheric range, Equation 8.2.1.1 would yield a vent area requirement of 0.888 m^2. The resulting reduction of vent area requirement where $P_{initial}$ is above atmospheric, but the rest of the variables remain the same, can be expected as the pressure difference between P_{stat} and $P_{initial}$ is less than in the atmospheric case. Where this is the case, the deflagration is allowed less time to develop prior to the opening of the vent and thus requires less vent area.

A.8.2.1.2.1 Figure A.8.2.1.2.1 shows typical results for evaluation of Equation 8.2.1.2 over a range of initial pressures at the same value of P_{stat}. Such an evaluation is necessary to determine the maximum value of the correction factor over the range between operating pressure and atmospheric pressure. While ignition cannot occur at very low initial pressures, the equation calculates a greatly reduced vent area for these conditions. A maximum value of the vent area correction occurs somewhere in the range of −0.2 and −0.5 bar-g. Since the ignition could occur at any pressure between operating pressure and atmos-

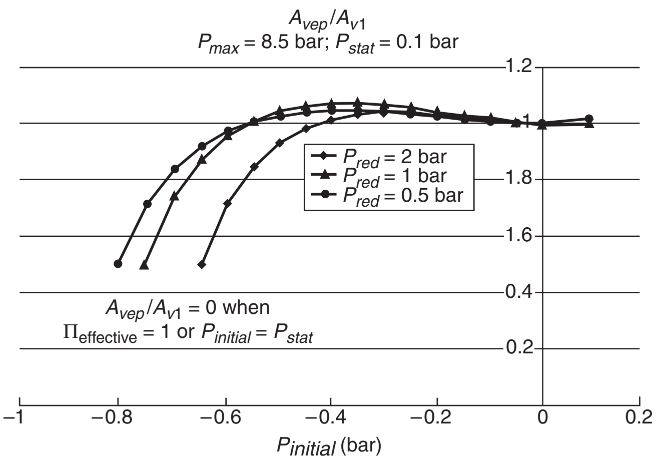


FIGURE A.8.2.1.2.1 Typical Effect of Initial Pressure on Required Vent Area.

pheric pressure, sizing for the maximum correction within this range is appropriate. The form of the equation does not allow evaluation above a positive initial pressure greater than P_{stat}. Similarly, the equation does not allow evaluation when $1/\Pi_{effective}$ is less than 1.

A.8.2.2.5 Conventional top-fed bins, hoppers, and silos are not expected to have large volumes occupied by homogeneous, worst-case dust concentrations. Furthermore, high-turbulence regions in these enclosures are usually limited to the top of the enclosure.

A.8.2.4.1 The equipment cross-sectional area for flow along the vessel axis would be $A = \pi D^2/4$ for round equipment or $A = D_1 \times D_2$ for rectangular equipment. An example is shown in Figure A.8.2.4.1.

For other geometries, the intention is to determine the average velocity in the equipment, ignoring inlet and outlet disturbances.

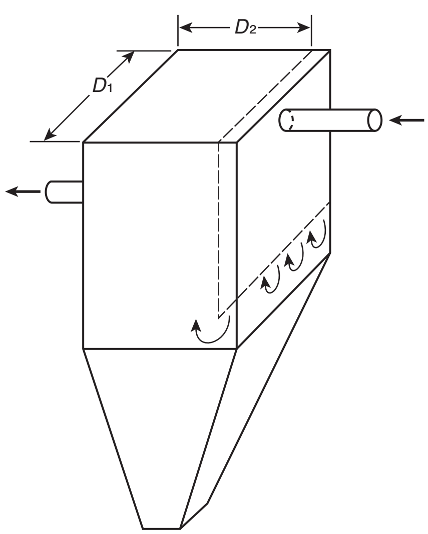


FIGURE A.8.2.4.1 Example of the Cross-Sectional Area of a Complex Enclosure.

A.8.2.4.2 The tangential velocity in particulate processing equipment can be generated either by a tangential inlet flow (as in most cyclone dust collectors) or by internal parts within the equipment (as in blenders, hammermills, etc.). In the case of tangential inlet flow, $v_{tan\_max} = Q/A_{in}$, where Q is the tangential inlet airflow rate (m^3/s), and A_{in} is the inlet cross-sectional area (m^2). In the case of equipment with rotating internal parts,

[A.8.2.4.2]

$$v_{tan\_max} = \frac{2 \cdot (3.14) \cdot N \cdot r}{60}$$

where:
N = number of revolutions per minute of the moving parts
r = radial length (m) of the largest moving part

In the case where the tangential flow is generated by stationary guide vanes and similar internal parts, the determination of v_{tan_max} is more complicated and requires expert analysis or testing.

A.8.2.4.6 The use of a velocity of 20 m/s and 56 m/s to separate the vent area requirements is based on a combination of the data used to derive Equation 8.2.1.1 (the general area correlations) and the Tamanini 1990 data [103] in Figure A.8.2.4.6 showing how the effective K_{St} varies with the root-mean-square (rms) turbulence velocity in the vented enclosure. The figure is based on values of K_{St} calculated from the nomographs in NFPA 68, plotted as a function of the mean turbulence intensity in the time period when the pressure rise is between 20 percent and 80 percent of maximum value. Because it is difficult to measure rms turbulence velocities in operating equipment, a turbulence intensity of 10 percent has been assumed, such that the effective rms turbulence velocity is 10 percent of the average air velocity in the operating equipment. Therefore, most users would be able to calculate the average velocity when deciding which vent area equation to use.

The 20 m/s and 56 m/s delineating velocities were determined by calculating effective K_{St} values that would be consistent with the combinations of A_v, V, and P_{red} from the Tamanini cornstarch data at an rms turbulence intensity of about 2 m/s for Equation 8.2.1.1 and for a higher rms velocity as determined by the correlation between K_{St} and rms velocity in Figure A.8.2.4.6.

A.8.2.4.7 Building-damaging dust explosions are most often secondary dust explosions, where an initial disturbance or smaller ignition causes a high local turbulence, creating the dust cloud with immediate ignition. To provide enough venting to prevent building failure and additional personnel injury, the high-end turbulence correction factor of 1.7 is used for buildings.

A.8.3 Where M is greater than 40 kg/m^2, see Annex G for guidance. For rectangular panels that are not square, a reduction of the required panel area could be gained by calculating the panel inertia effect per Annex G instead of Equation 8.3.4.

A.8.4 Dust concentrations in some process equipment and buildings are inherently limited to only a fraction of the enclosure volume. The effect of this limitation is to reduce the minimum required vent area.

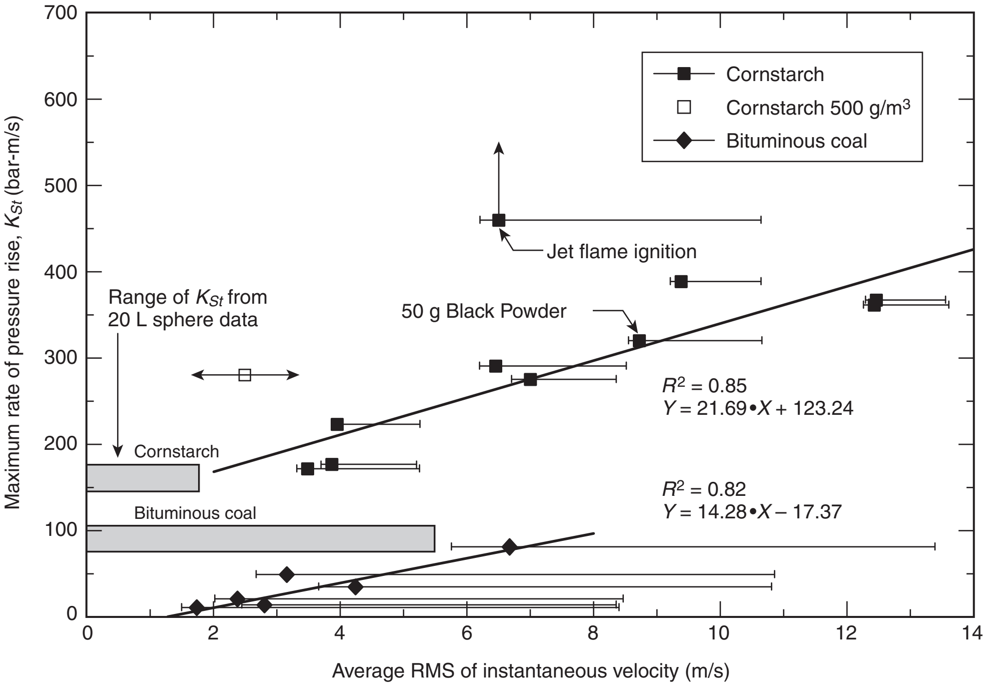


FIGURE A.8.2.4.6 Explosion Severity for Vented Tests in the FMRC 2250 ft³ Chamber.

N **A.8.4.1** Prior editions evaluated fill fractions based on the worst case dust concentration, c_w, corresponding to $(dP/dt)_{max}$, when evaluated in accordance with ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*. A fill fraction is applied along with the pressure ratio, Π, to determine a vent area correction. A smaller fill fraction results in a reduced minimum required vent area. Using the permitted value of $c_r = \frac{1}{2} c_w$ will increase the fill fraction compared to prior editions, and yet the result will not necessarily be the largest appropriate fill fraction. With some materials, the combination of a smaller concentration and its corresponding maximum pressure could produce a larger minimum required vent area. This behavior should be considered when choosing the value of c_r.

A.8.4.3.1 Figure A.8.4.3.1 illustrates the limits of partial volume corrections. At low normalized reduced pressures, Π, the vent ratio approaches the fill fraction to the ⅙ power. When fill fraction approaches Π, both the vent ratio and the necessary vent area approach zero. Subsections 8.4.4 and 8.4.5 provide a method for determining the fill fraction for process vessels and for buildings, respectively.

A.8.4.4 The fill fraction in a spray dryer depends on the dryer design. In the case of a top-loading conical dryer without any recirculation or co-feed of dry product, measurements have indicated that the dry powder concentrations exist only in the bottom portion of the dryer, which typically occupies 20 percent to 35 percent of the total dryer volume.

Process Equipment Example. A 100 m³ spray dryer with a length/diameter ratio of 1.8 is processing a material with a P_{max} of 10 bar-g and a K_{St} of 100 bar-m/s at the dryer operating temperature. The deflagration vent design is to be based on a P_{red} of 0.50 bar-g and a P_{stat} of 0.10 bar-g. Tests by the manufacturer, submitted and approved by the authority having jurisdiction, have shown that the dry material is confined to the conical lower section of the dryer, which has a volume of 33.3 m³. Therefore, $X_r = 0.333$, and $\Pi = 0.50/10 = 0.050$.

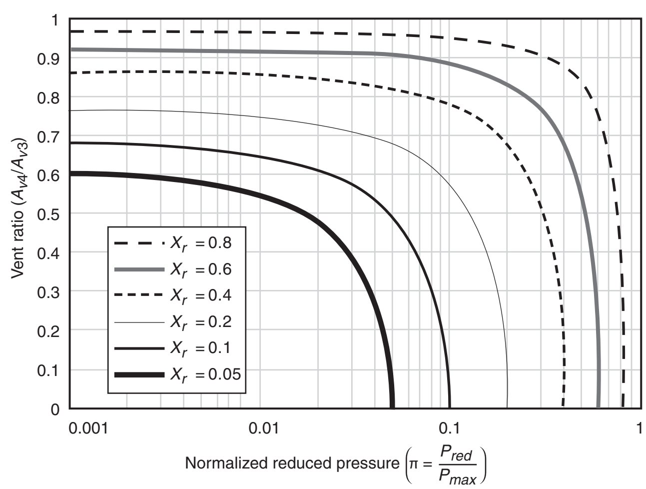


FIGURE A.8.4.3.1 Partial Volume Vent Area Reduction.

Step 1. Using Equation 8.2.1.1, find A_{v0}:

[A.8.4.4a]

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot (0.10)^{4/3}\right] \cdot 100 \cdot (100)^{3/4} \cdot \sqrt{\frac{10}{0.50} - 1}$$

$$A_{v0} = 1.48 \text{ m}^2$$

Step 2. Find the partial volume vent area for this application as follows:

[A.8.4.4b]

$$A_{v4} = (1.48) \cdot (0.333)^{-0.333} \cdot \sqrt{\frac{(0.333 - 0.050)}{1 - 0.050}} = 1.16 \text{ m}^2$$

Step 3. Install vent panels with a total vent area of at least 1.16 m^2 on the conical lower section of the dryer.

A.8.4.5.3.3 The approximate surface density, $\bar{M}/A$, corresponding to these assumed values is 950 g/m^2.

Δ **A.8.5** The flow resistance coefficient K for the vent duct correlation is defined on the static pressure drop, ΔP, from the enclosure to the duct exit at a given average duct flow velocity, U:

[A.8.5a]

$$K \equiv \frac{\Delta P}{\frac{1}{2} \cdot \rho \cdot U^2}$$

Another convention used by some reference books is to define K on the total pressure drop or on another velocity scale. The user should ensure that the loss coefficients used in the calculations are consistent with the definition of K adopted for the vent duct calculations. See Ural [114] for additional information.

The user should note that inlet loss can vary depending on the shape of the vent closure attachment to the vessel; however, most typically a flush inlet would be appropriate. Figure A.8.5(a) shows the loss coefficient for two different inlet designs as well as a plain duct outlet. Rain hats or other outlet covers provide additional resistance as in Figure A.8.5(d).

Figure A.8.5(b) shows a round elbow and loss coefficients for various radii of curvature. Figure A.8.5(c) shows a rectangular elbow and loss coefficients for various duct aspect ratios and radii of curvature. Loss coefficients for 45 degree bends and 30 degree bends are proportionally less than the tabulated 90 degree bends. Figure A.8.5(d) provides loss coefficients for a typical rain hat design. [123]

The equations are nonlinear and, under certain combinations of input values, result in two possible solutions for vent area for a given P_{red}. The lower value of vent area is the meaningful solution, and the upper value is an artifact of the form of the equation set. There are certain combinations of P_{red} and vent duct length where no vent area is large enough and no solution is obtainable. When that occurs, it could be possible to vary P_{red} or vent duct length to converge to a solution. If that solution is not satisfactory, NFPA 69 can provide alternatives.

There is a minimum value for P_{red} as vent area increases, beyond which solutions are not meaningful. That value occurs approximately when the volume of the duct exceeds a fraction of the volume of the vessel. When solving the equations, constraining A_{vf} as follows will typically isolate the smaller root:

Δ **[A.8.5b]**

$$\frac{A_{vf} \cdot L_{duct}}{V} \leq 1$$

For the following input values, Figure A.8.5(e) illustrates the potential solutions:

V = 500 m^3

P_{max} = 8.5 bar-g

K_{St} = 150 bar-m/s

P_{stat} = 0.05 bar-g

P_{red} = 0.5 bar-g

Vessel L/D = 4

ε = 0.26 mm

Straight duct, no elbows, fittings, or rain hats.

Example problem. Given Figure A.8.5(f) and the following conditions, calculate P_{red}:

Enclosure volume, V = 25 (m^3)

Enclosure L/D = 4

Vent diameter, D_v = 1.5 (m)

Duct diameter, D_h = 1.5 (m)

A_v = 1.77 (m^2)

P_{stat} = 0.25 (bar-g)

K_{St} = 200 (bar-m/s)

P_{max} = 8 (bar-g)

L_{duct} = 12 (m)

Duct effective roughness, ε = 0.26 (mm)

Elbows = 2 × 90 degrees, long radius (R/D = 1.5)

Elbow flow resistance = 2 × 0.39 = 0.78 [see Figure A.8.5(b)]

Rain hat flow resistance = 0.73 [H = 0.5D, see Figure A.8.5(d)]

While Section 8.5 provides the equations in a form to calculate the vent area based on an allowable P_{red}, this example shows how to determine the resulting P_{red} for a given vent area. In general, such calculations will be iterative. These input parameters are provided for demonstration purposes. Ural [114] can be referenced for additional discussion on how they were selected.

Solution:

(1) Compute the friction factor for the problem. For practically all vent ducts, the Reynolds number is so large that a fully turbulent flow regime will be applicable. In this regime, the friction factor is only a function of the ratio of the internal duct surface effective roughness (ε) to duct diameter. The duct friction factor can thus be calculated using a simplified form of the Colebrook equation:

[A.8.5c]

$$f_D = \left\{ \frac{1}{\left[1.14 - 2\log_{10}\left(\frac{\varepsilon}{D_h}\right)\right]} \right\}^2$$

The effective roughness for smooth pipes and clean steel pipes is typically 0.0015 mm and 0.046 mm, respectively. Recognizing that the pipes used repeatedly in combustion events could be corroded, a value of ε = 0.26 mm is assumed.

From Equation A.8.5c, $f_D = 0.013$:

Δ **[A.8.5d]**

$$\text{then } \frac{f_D \cdot L_{duct}}{D_h} = \frac{0.013 \cdot 12}{1.5} = 0.107, \text{ and}$$

$$K = K_{inlet} + \frac{f_D \cdot L_{duct}}{D_h} + K_{elbows} + K_{outlet}$$

$$K = 1.5 + 0.107 + 0.78 + 0.73 = 3.117$$

where:

K = 3.117

K_{inlet} = 1.5 [static pressure loss for flush duct entry, see Figure A.8.5(a)]

K_{elbows} = 0.78

K_{outlet} = 0.73

(2) Assume a P_{red} value of 1 bar-g. The solution is iterative, where the assumed value of P_{red} is replaced with the calculated value of P_{red} until the two values substantially match. A 1 percent difference between iterations is typically considered acceptable convergence.

(3) From Equation 8.2.1.1:

[A.8.5e]

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot (0.25)^{4/3}\right] \cdot 200 \cdot (25)^{3/4} \cdot \sqrt{\frac{8}{P_{red}} - 1}$$

$$A_{v0} = 0.735 \text{ m}^2$$

(4) From Equation 8.2.2.3:

[A.8.5f]

$$A_{v1} = 0.735 \cdot \left[1 + 0.6 \cdot (4-2)^{0.75} \cdot \exp\left(-0.95 \cdot P_{red}^2\right)\right]$$

$$A_{v1} = 1.02 \text{ m}^2$$

(5) From Equation 8.5.1b, and using the intended vent area of 1.77 m^2:

[A.8.5g]

$$E_1 = \frac{1.77 \cdot 12}{25}$$

$$E_1 = 0.85$$

(6) From Equation 8.5.1c, and using the installed vent area of 1.77 m^2:

[A.8.5h]

$$E_2 = \frac{10^4 \cdot 1.77}{\left[1 + 1.54 \cdot (0.25)^{4/3}\right] \cdot 200 \cdot (25)^{3/4}}$$

$$E_2 = 6.37$$

(7) From Equation 8.5.1a, with A_{v4} equal to A_{v1}, assuming no increase for turbulence, inertia, or partial volume:

[A.8.5i]

$$A_{vf} = (1.02) \cdot \left[1 + 1.18 \cdot (0.85)^{0.8} \cdot (6.37)^{0.4}\right] \cdot \sqrt{\frac{3.117}{1.5}}$$

$$A_{vf} = 4.67 \text{ m}^2$$

(8) Because the calculated value of A_{vf} is not equal to the installed vent area, go back to Step 2, and change P_{red} until the A_{vf} calculated in Step 7 is equal to the specified vent area of 1.77 m^2. A trial-and-error process (or the goal seek button in Excel) satisfies the requirement in Step 8 when P_{red} = 2.72 bar-g.

(9) From 8.5.9, Equation A.8.5j and Equation A.8.5k show that there is no deflagration-to-detonation-transition (DDT) propensity for this particular application:

[A.8.5j]

$$L_{eff} \le \min\left[\frac{10{,}000 \cdot 1.5}{200}, \frac{11{,}000}{200}\right]$$

$$L_{eff} \le \min\ [75, 55]$$

$$\le 55$$

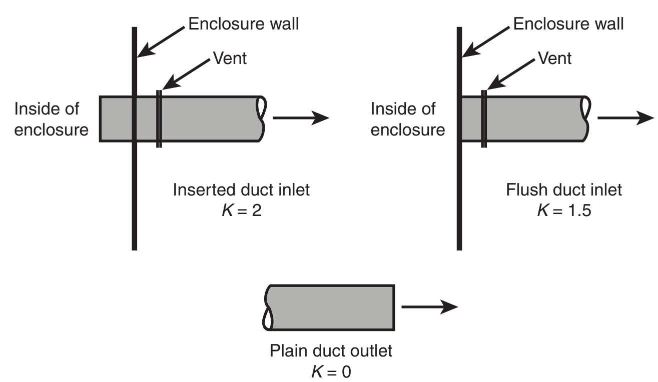
[A.8.5k]

$$L_{dusty} = (8 - 2.723) \cdot \frac{25}{1.77}$$

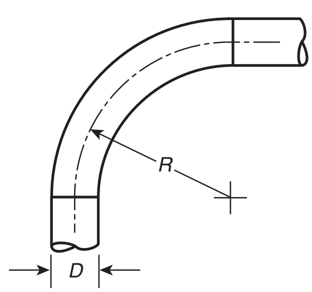
$$= 74.5 \text{ m}$$

Because L_{duct} = 12 m, L_{eff} = min [12, 75] = 12 m ≤ 55 m. Therefore, DDT is not expected.

A.8.5.1 This solution of Equation 8.5.1a is iterative, because E_1 and E_2 are both functions of A_{vf}.

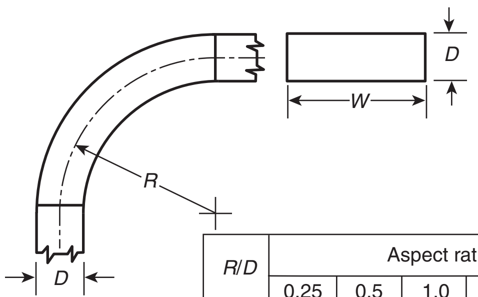


Δ **FIGURE A.8.5(a) Loss Coefficients for Inlets and Plain Duct Outlet.**



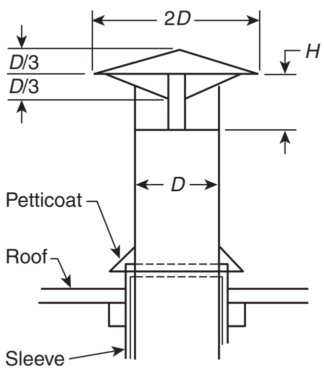
R/D	K
2.75	0.26
2.50	0.22
2.25	0.26
2.00	0.27
1.75	0.32
1.50	0.39

FIGURE A.8.5(b) Loss Coefficients for Round Elbows.



R/D	Aspect ratio, W/D					
	0.25	0.5	1.0	2.0	3.0	4.0
1.5	0.28	0.18	0.13	0.13	0.12	0.12
2.0	0.24	0.15	0.11	0.11	0.10	0.10
3.0	0.24	0.15	0.11	0.11	0.10	0.10

FIGURE A.8.5(c) Loss Coefficients for Square and Rectangular Elbows.



H No. of Diameters	K
1.0 D	0.10
0.75 D	0.18
0.70 D	0.22
0.65 D	0.30
0.60 D	0.41
0.55 D	0.56
0.50 D	0.73
0.45 D	1.0

FIGURE A.8.5(d) Loss Coefficients for Rain Hats.

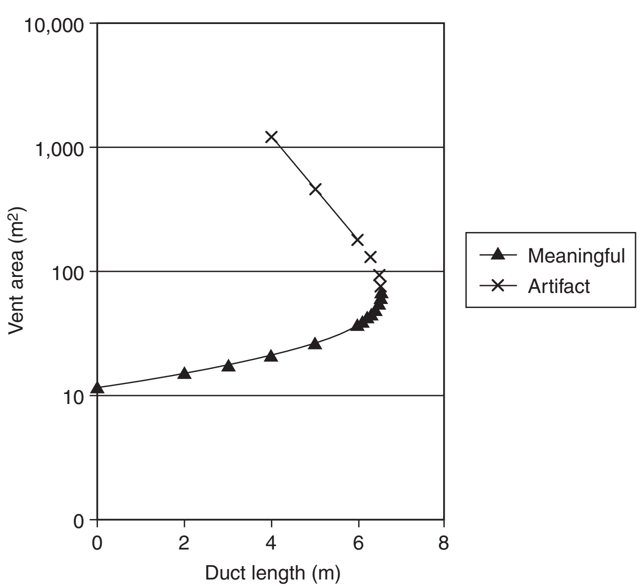
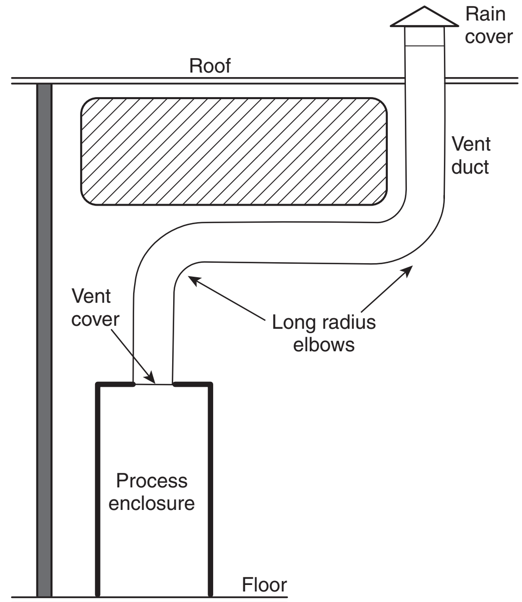


FIGURE A.8.5(e) A_v **vs. Duct Length.**



Δ **FIGURE A.8.5(f) Example Vent Duct Installation.**

A.8.6.1.1 For deflagration venting accomplished by means of vent closures located in the sidewall of the enclosure, the closures should be distributed around the wall near the top.

A.8.6.3 In such cases, design and operating conditions (internal and external pressure, wind loads, and snow loads) can cause the mass of the roof to exceed that prescribed for deflagration vent closure.

A.8.7.1 A key assumption made for the three alternatives in 8.7.1 is that the clean air plenum above the tube sheet is essentially free of dust accumulations.

The prescription for determining the maximum flame length is not the same as in Chapter 6 for general enclosures. Private dust collector test data provided to the committee does not support the general approach for determining maximum flame path length based on vent location in these devices. Flame extension along the entire major axis, beyond the location of the vent, is presumed due to the filter elements providing a gas expansion path to the clean side of the collector.

A.8.7.1.1 Where a dust collection system is constructed of multiple modules, each independently vented, the flame path length should be determined in each module.

A.8.7.1.2 Many flexible and rigid filter elements extend upstream from the tube sheet and retain dust on the outer surface. This section does not subtract the volume of such elements from the effective volume. Pocket filter elements extend downstream from the tube sheet and retain dust on their inner surface. This section includes the volume of such elements in the effective volume. Therefore, for dust collectors, the effective volume (V_{eff}) is equal to the total dirty side volume (V) to be used in the venting equations.

A.8.7.2 Figure A.8.7.2(a) and Figure A.8.7.2(b) show situations for flexible filters where additional vent area is not required. Figure A.8.7.2(c) through Figure A.8.7.2(g) show situations for flexible filters where restraints effectively prevent obstruction of the vent and additional vent area is not

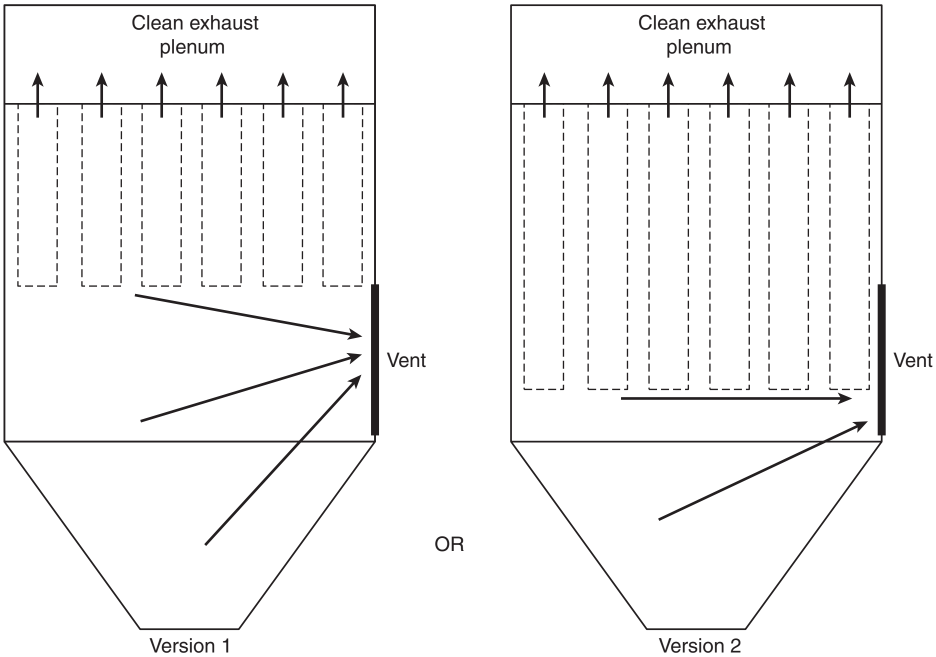
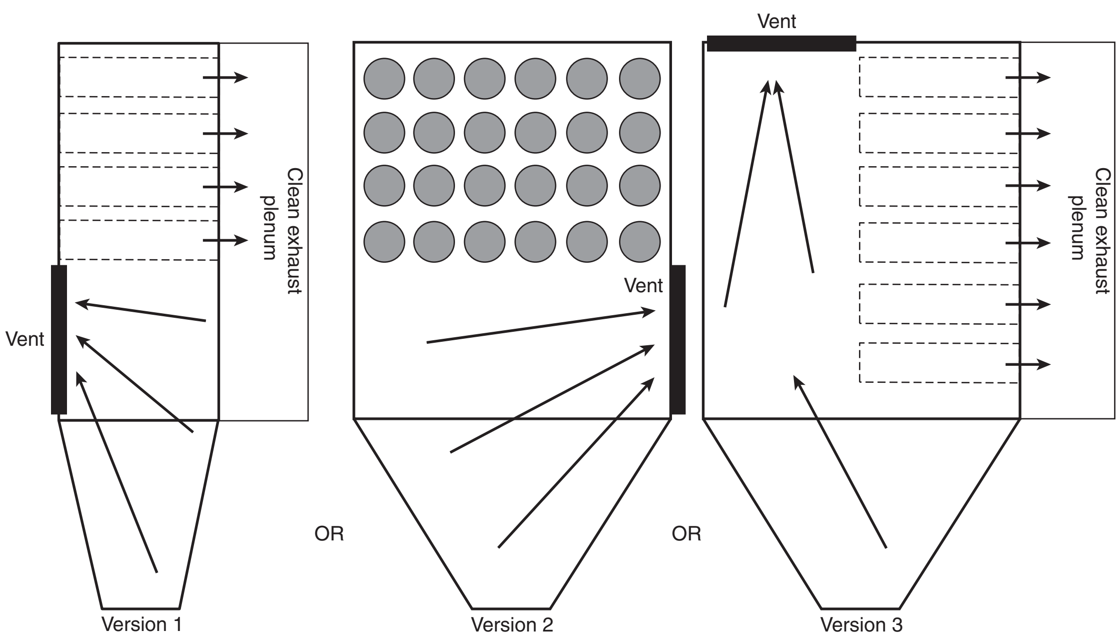


FIGURE A.8.7.2(a) Vertical Element — No Additional Vent Area.



Δ FIGURE A.8.7.2(b) Horizontal Element — No Additional Vent Area.

required. Figure A.8.7.2(h) shows a situation for flexible filters in which the vent is located totally above the free end of the filter, restraints are not provided, and additional vent area is required.

A.8.8.1 A single-casing design has buckets moving both upward and downward within the same casing. A double casing design has one casing enclosing the buckets as they move upward and another casing enclosing the buckets as they move downward.

A.8.8.2 The boot of a bucket elevator is the inlet section at the lower elevation, while the head is the outlet section at the higher elevation.

A.8.8.3.5 Changing from metal to plastic buckets has been demonstrated to increase the explosion pressures. For example, if designing a double-casing bucket elevator with plastic buckets for a K_{St} of 100–150 bar-m/s, and intending to space vents at no more than 10 m, then the enclosure strength should be based on a P_{red} of 0.5 × 1.35 = 0.68 bar-g.

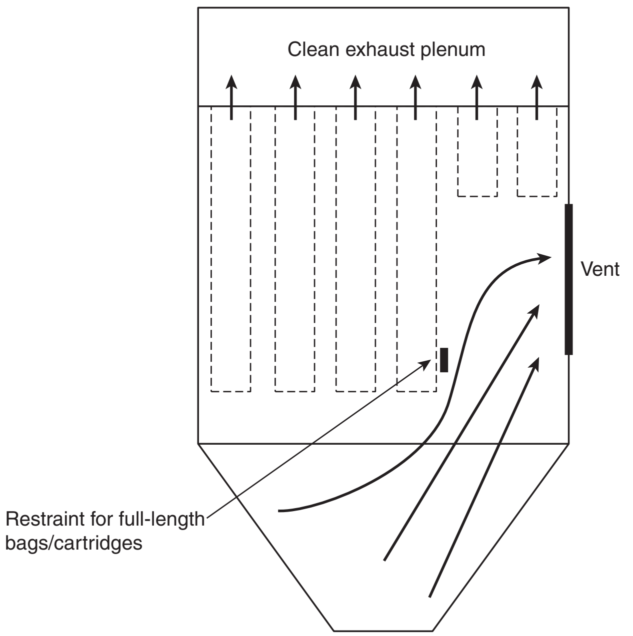


FIGURE A.8.7.2(c) Free Area Normal to Vent for Vertical Filter Elements — Side View — No Additional Vent Area.

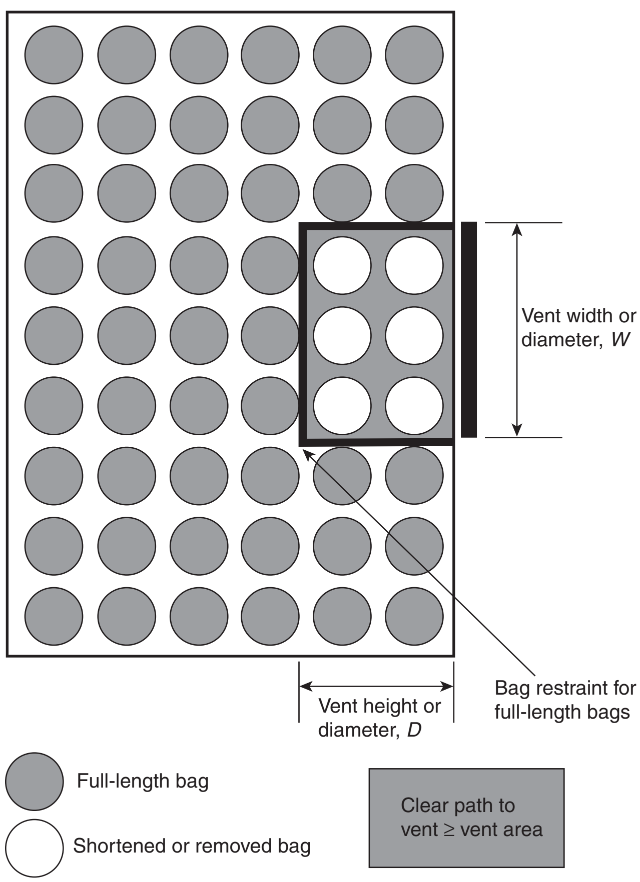


FIGURE A.8.7.2(d) Free Area Normal to Vent for Vertical Filter Elements — Plan View — No Additional Vent Area.

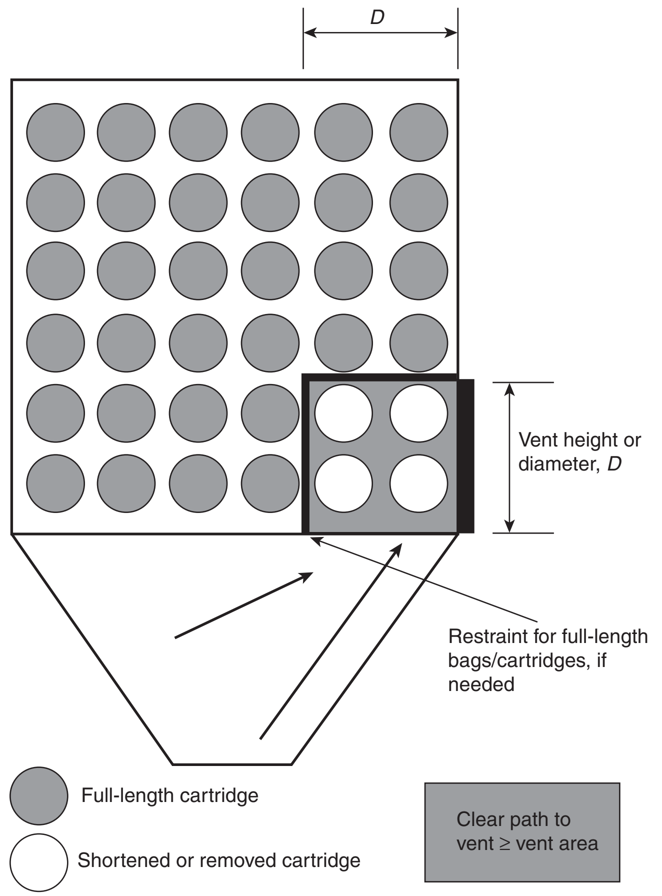


FIGURE A.8.7.2(e) Free Area Normal to Vent for Horizontal Filter Elements — Version 1, End View — No Additional Vent Area.

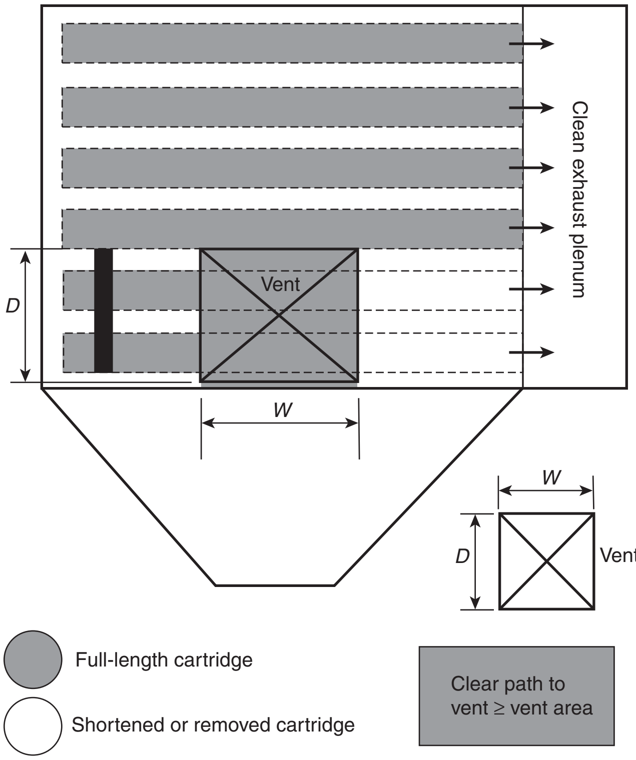
A.8.8.3.6 The vent area can be located on the bucket face, the sides, or both as suitable for the installation.

A.8.8.4 P_{stat} should be as low as possible.

• **A.8.9** Even with complete extinguishment of flame, the immediate area surrounding the vent can experience overpressure and radiant energy. Venting indoors has an effect on the building that houses the protected equipment due to increased pressurization of the surrounding volume [110].

A.8.10 A bin vent is an air material separator attached to a larger storage vessel but not provided with a physical separation between the two. The collected dust is returned directly to the large storage vessel.

A.8.11 Interconnections between separate pieces of equipment present a special hazard. A typical case is two enclosures connected by a pipe. Ignition in one enclosure causes two effects in the second enclosure. Pressure development in the first enclosure forces gas through the connecting pipe into the second enclosure, resulting in an increase in both pressure and turbulence. The flame front is also forced through the pipe into the second enclosure, where it becomes a large ignition source. The overall effect depends on the relative sizes of the enclosures and the pipe, as well as on the length of the pipe.



Δ **FIGURE A.8.7.2(f) Free Area Normal to Vent for Horizontal Filter Elements — Version 1, Side View — No Additional Vent Area.**

This phenomenon has been investigated by Bartknecht, who discovered that the effects can be significant. Pressures that develop in the pipeline itself can also be high, especially if a deflagration changes to a detonation. Where such interconnections are necessary, deflagration isolation devices should be considered, or the interconnections should be vented. Without successful isolation or venting of the interconnection, vent areas calculated based on the design described herein can be inadequate because of the creation of high rates of pressure rise [58, 66].

Equation 8.2.1.1 and Equation 8.2.2.3 can give insufficient vent area if a dust deflagration propagates from one vessel to another through a pipeline [98]. Increased turbulence, pressure piling, and broad-flame jet ignition result in increased deflagration violence. Such increased deflagration violence results in an elevated deflagration pressure that is higher than that used to calculate vent area in Equation 8.2.1.1 and Equation 8.2.2.3.

A.8.11.1 Interconnecting pipelines with inside diameters greater than 0.3 m (1 ft) or longer than 6 m (20 ft) are not covered in this standard. Alternative protection measures can be found in Chapter 9 of this document and in NFPA 69.

A.8.11.2 The subject of enhanced explosions in interconnected enclosures is addressed in the following references:

(1) Lunn, Holbrow, Andrews, and Gummer, “Dust Explosions in Totally Closed Interconnected Vessels”
(2) Holbrow, Lunn, and Tyldesley, “Dust explosion protection in linked vessels: Guidance for containment and venting”

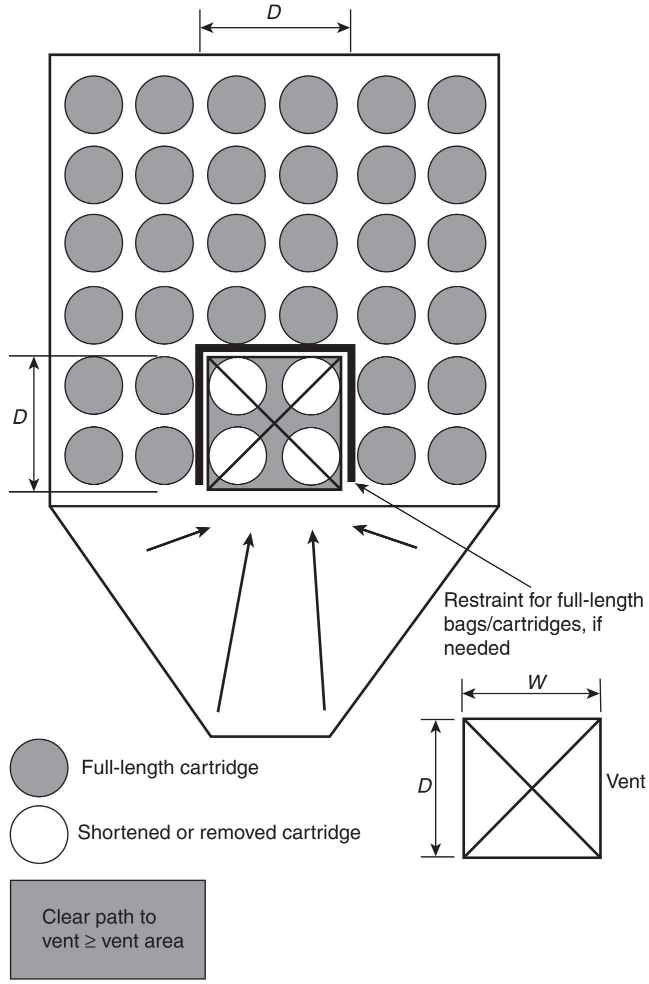


FIGURE A.8.7.2(g) Free Area Normal to Vent for Horizontal Filter Elements — Version 2, End View — No Additional Vent Area.

(3) Holbrow, Andrews, and Lunn, “Dust explosions in interconnected vented vessels”
(4) Roser, “Investigation of dust explosion phenomenon in interconnected process vessels”
(5) Roser, Vogel, Radant, Malalasekera, and Parkin, “Investigations of flame front propagation between interconnected process vessels. Development of a new flame front propagation time prediction model”
(6) Moore and Senecal, “Industrial Explosion Protection — How Safe Is Your Process?” www.nfpa.org/assets/files/PDF/Foundation%20proceedings/Industrial_Explosion_Protection.pdf

A.9.1 Relatively little systematic test work is published on the design of deflagration venting for pipes and ducts. The guidelines in this chapter are based on information contained in Bartknecht [3, 68–76, 105, 106].

The use of deflagration venting on pipes or ducts cannot be relied on to stop flame front propagation in the pipe. Venting only provides relief of the pressures generated during a deflagration.

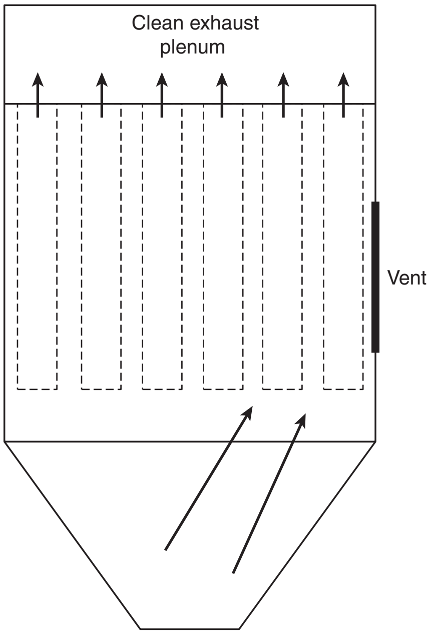


FIGURE A.8.7.2(h) Vertical Element — Additional Vent Area Required.

Several factors make the problems associated with the design of deflagration vents for pipes and ducts different from those associated with the design of deflagration vents for ordinary vessels and enclosures. Such problems include the following:

(1) Deflagrations in pipes and ducts with large length-to-diameter (*L/D*) ratios can transition to detonations. Flame speed acceleration increases, and higher pressures are generated as *L/D* increases.
(2) Pipes and ducts frequently contain devices, such as valves, elbows, and fittings, or obstacles. Such devices cause turbulence and flame stretching that promote flame acceleration and increase pressure.
(3) Deflagrations that originate in a vessel precompress the combustible material in the pipe or duct and provide a strong flame front ignition of the combustible material in the pipe or duct. Both of these factors increase the severity of the deflagration and the possibility that a detonation will occur.

Wherever it is not possible to provide vents as recommended in this chapter, two alternative approaches can be employed as follows:

(1) Explosion prevention measures should be provided as described in NFPA 69.
(2) Piping or ducts should be designed to withstand detonation pressures and provide isolation devices to protect interconnected vessels. Systems that have a design pressure of 10 bar-g are acceptable for St-1 dusts.

A.9.2 *Example.* Deflagration vents should be provided for the ducts in the system shown in Figure A.9.2. The gas flow through the system is 100 m^3/min (3500 ft^3/min), and all ducts are 0.6 m (2 ft) in diameter. The maximum allowable working pressure for the ducts and equipment is 0.2 bar-g (3 psig), and the maximum operating pressure in the system is 0.05 bar-g (0.73 psig). The system handles an St-2 dust. It is further assumed that the dryer and the dust collector are equipped with adequate deflagration vents.

As recommended by 9.2.4, *A* should be located within two vent diameters of the dryer outlet and no more than three vent diameters upstream of the first elbow. *B* and *C* should be located three diameters distance upstream and downstream of the first elbow, as recommended in 9.2.5. *F* should be located at a position approximately two diameters upstream of the dust collector inlet, based on 9.2.4.

Additional venting is needed for the 20 m (66 ft) section. The flow of 100 m^3/min corresponds to a velocity of 6 m/s (20 ft/s). Therefore, Figure 9.3.1 should be used. According to Figure 9.3.1, the vents should be placed at intervals no greater than 11 vent diameters, or approximately 6.5 m (21 ft), apart. The distance between vents *C* and *F* is 17.2 m (56 ft); therefore, two additional vents (*D* and *E*) at approximately equal spacing meet the need.

The total vent area at each vent location should be at least equal to the cross-sectional area of the duct. This results in a value of 0.2 bar-g (3 psig) for P_{red}. The vent release pressure should not exceed half P_{red} and, therefore, cannot exceed 0.1 bar-g (1.5 psig).

A.9.2.4 See Example in A.9.2.

A.9.2.9.2 The following problem illustrates the requirement in 9.2.9.2. A flare stack is 0.4 m (1.3 ft) in diameter by 40 m (130 ft) in height and is equipped with a water seal at its base. What should its design pressure be in order to protect it from the pressure developed by ignition of a fuel-air mixture that has properties similar to those of propane?

Check the maximum allowable length. From Figure 9.2.10.1, a maximum *L/D* of 28 is allowed. This stack has an *L/D* equal to 100. Therefore, it should be designed to withstand a detonation or should be protected by some other means.

The distance necessary for a deflagration to transition into a detonation is described as a length-to-diameter ratio (*L/D* for detonation). The *L/D* is dependent on ignition source strength, combustible material, piping system geometry, roughness of pipe walls, and initial conditions within the pipe.

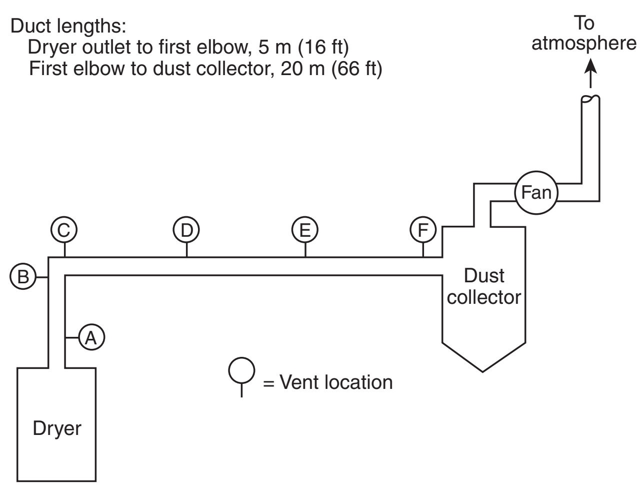


FIGURE A.9.2 Diagram for A.9.2 Example.

A.9.2.10.1 The curve identified as "Dusts with K_{St} ≤ 200" in Figure 9.2.10.1 is based on Bjorklund and Ryason [75] for gasoline vapor deflagrations. The curve identified as "Propane, dusts with K_{St} > 200" in Figure 9.2.10.1 is obtained by reducing $(L/D)_{max}$ data for gasoline vapor by 50 percent [75]. Therefore, the Committee has exercised engineering judgment in adapting the data for use with dusts as well as gases.

If the length of a pipe or duct is greater than the *L/D* indicated in Figure 9.2.10.1, a single vent cannot provide enough vent area *(see Section 9.3)*. Figure 9.2.10.1 includes safety factors for typical long-radius elbow systems. While very few conveying pipes are either straight or smooth, Figure 9.2.10.1 can be used for most applications. It does not apply where conveying pipes have sharp elbows or orifice plates along their lengths.

A.9.2.10.2.2.1 The following problem illustrates the requirement in 9.2.10.2.2.1. A dryer that handles a dust whose K_{St} is 190 is 2 m (6.6 ft) in diameter and 20 m (65.6 ft) long and is designed with a single vent. What is the pressure that can occur during a vented explosion?

(1) *Maximum Allowable Length.* According to Figure 9.2.10.1, an *L/D* of approximately 25 is allowable. The dryer has an *L/D* of 10, so this is acceptable.
(2) *Maximum Pressure.* According to Figure 9.2.10.2.2.1, a pressure of approximately 0.5 bar-g (7.3 psig) develops in such dryer equipment by means of the deflagration of the specified dust. Therefore, the equipment should have a design pressure of at least this value.

A.9.3.1 The following problem illustrates the requirement in 9.3.1. A straight duct that is 1 m (3.3 ft) in diameter and 100 m (330 ft) long is to be protected by deflagration vents. It contains a hydrocarbon-air mixture that has properties similar to those of propane. The vent spacing needed to limit the deflagration pressure to 0.17 bar-g (2.5 psig), where the vents are designed to open at 0.05 bar-g (0.73 psig), must be determined. Figure 9.3.1 specifies that the vents should be placed no more than 7.6 m (25 ft) apart. To meet this requirement, a vent should be placed at each end, and 13 additional vents should be evenly spaced along the duct.

A.10.1 Openings fitted with fixed louvers can be considered as open vents. However, the construction of the louvers partially obstructs the opening, thus reducing the net free vent area. The obstruction presented by the louvers decreases the flow rate of gases that pass through the vent and increases the pressure drop across the vent.

N **A.10.2.1.2** A test method for evaluating maximum P_{red} is presented in EN 14797, *Explosion venting devices*. Other dynamic loading test methods can be used to validate application limits including maximum K_{St}, fuel types (organic dust only, gas only, hybrid mixtures, or metal dusts), P_{red}, and *dP/dt* fragmentation limits.

A.10.3.2 Specially designed fasteners that fail, under low mechanical stress, to release a vent closure are commercially available, and some have been tested by listing or approval agencies.

A.10.3.2.2 Large panel closures that are installed on buildings or other large low-strength enclosures cannot be tested as a complete assembly.

A.10.4 Where the vent closure panel is a double-wall type (such as an insulated sandwich panel), single-wall metal vent panel restraint systems should not be used. The restraint system shown in Figure A.10.4(a) should be used for double-wall panels. The panel area should be limited to 3.1 m^2 (33 ft^2), and its mass should be limited to 12.2 kg/m^2 (2.5 lb/ft^2). Forged eyebolts should be used. Alternatively, a "U" bolt can be substituted for the forged eyebolt. A shock absorber device with a fail-safe tether should be provided.

The bar washer on the exterior of the panel should be oriented horizontally, should span the panel width (less 2 in. and any panel overlap), and should be attached to the panel with as many bolts as practical (i.e., at every panel flat for a corrugated panel). High-quality wire rope clips should be used to ensure the restraint system functions properly. It is noted that this panel restraint system was developed based on tests in which the peak enclosure pressure achieved was approximately 1 psig or less; hence, its performance at higher explosion pressures might not be reliable.

Where large, lightweight panels are used as vent closures, it is usually necessary to restrain the vent closures so that they do not become projectile hazards. The restraining method shown in Figure A.10.4(b) illustrates one method that is particularly suited for conventional single-wall metal panels. The key feature of the system includes a 50 mm (2 in.) wide, 10 gauge bar washer. The length of the bar is equal to the panel width, less 50 mm (2 in.) and less any overlap between panels. The bar washer–vent panel assembly is secured to the building structural frame using at least three 10 mm (⅜ in.) diameter through-bolts.

The restraining techniques shown are specific to their application and are intended only as examples. Each situation necessitates individual design. Any vent restraint design should be documented by the designer. No restraint for any vent closure should result in restricting the vent area. It is possible for a closure tether to become twisted and to then bind the vent to less than the full opening area of the vent.

The stiffness of the double-wall panel is much greater than that of a single-wall panel. The formation of the plastic hinge occurs more slowly, and the rotation of the panel can be incomplete. Both factors tend to delay or impede venting during a deflagration.

The component sizes indicated in Figure A.10.4(a) have been successfully tested for areas up to 3.1 m^2 (33 ft^2) and for mass of up to 12.2 kg/m^2 (2.5 lb/ft^2). Tests employing fewer than three rope clips have, in some instances, resulted in slippage of the tether through the rope clips, thus allowing the panel to become a free projectile.

The shock absorber is a thick, L-shaped piece of steel plate to which the tether is attached. During venting, the shock absorber forms a plastic hinge at the juncture in the "L," as the outstanding leg of the "L" rotates in an effort to follow the movement of the panel away from the structure. The rotation of the leg provides additional distance and time, over which the panel is decelerated while simultaneously dissipating some of the panel's kinetic energy.

The L-shaped shock absorber should be ductile annealed steel and designed for each venting application, such that it does not break. Stronger is not always better. The shock absorber is a one-time use item and should be replaced when the panel is replaced. The wire rope and other attachment items might also need replacement after use.

The panel should be replaced soon after an opening event. Wind will eventually fatigue the tether system and the dangling panel might fall to the ground.

A.10.5.1 Closures that are held shut with spring-loaded, magnetic, or friction latches are most frequently used for this form of protection.

A.10.5.1.1 It is important that hinges on hinged vent closures be capable of resisting the expected forces. If hinges are weak, if they are attached weakly, or if the door frame is weak, the vent closures can tear away in the course of venting a deflagration and become projectile hazards.

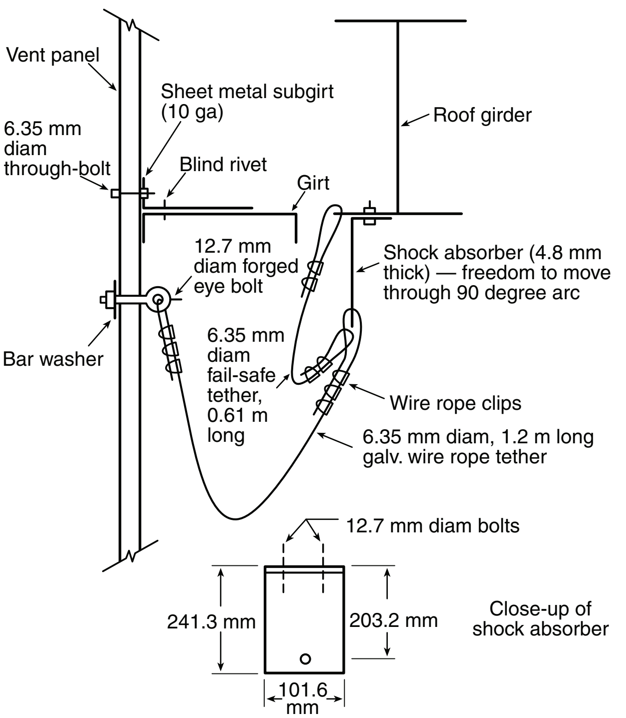


FIGURE A.10.4(a) An Example of a Restraint System for Double-Wall Insulated Metal Vent Panels.

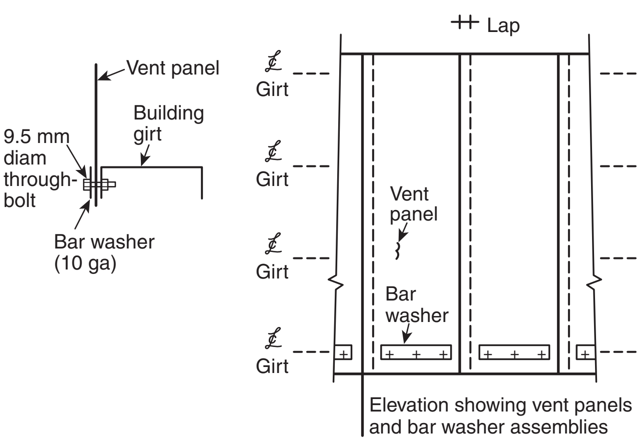


FIGURE A.10.4(b) An Example of a Restraint System for Single-Wall Metal Vent Panels.

A.10.5.1.2 It is difficult to vent equipment of this type if the shell, drum, or enclosure revolves, turns, or vibrates.

A.10.5.1.6 If construction is strong, the vent closure can close rapidly after venting. This can result in a partial vacuum in the enclosure, which in turn can result in inward deformation of the enclosure.

Figure 10.5.1.6 shows the vacuum relief vent area, as a function of enclosure size, that is used to prevent the vacuum from exceeding the vacuum resistance of the enclosure, in millibars.

A.10.5.2 Rupture diaphragms can be designed in round, square, rectangular, or other shapes to effectively provide vent relief area to fit the available mounting space. *(See Figure A.10.5.2.)*

Some materials that are used as rupture diaphragms can balloon, tear away from the mounting frame, or otherwise open randomly, leaving the vent opening partially blocked on initial rupture. Although such restrictions can be momentary, delays of only a few milliseconds in relieving deflagrations of dusts or gases that have high rates of pressure rise can cause extensive damage to equipment.

A.11.2 A sample vent closure information form is shown in Figure A.11.2.

A.11.3.4 For symbols, placement, and layout, refer to ANSI Z535.4, *Product Safety Signs and Labels.*

A.11.4 A sample annual inspection form is shown in Figure A.11.4.

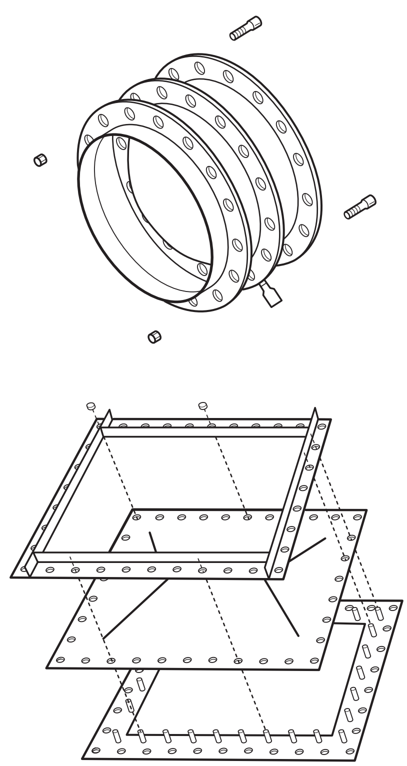


FIGURE A.10.5.2 Typical Rupture Diaphragm.

VENT CLOSURE INFORMATION FORM

Date: ____________

CONTACT INFORMATION

Company name: ____________

Address: ____________

City: ________ State: ____ Zip code: ______

Telephone: ____________

Responsible person: ____________

Title: ____________

Telephone: ____________

Report writer: ____________

Equipment/process protected: ____________

Vent ID number: ____________

Vent size: ____________

Vent type: ____________

Vent opening pressure: ____________

Vent location: ____________

Vent manufacturer: ____________

Vent model number: ____________

Vent construction material: ____________

Vent panel ID: ____________

HAZARD DETAILS

Name of material: ____________

Hazard category: ❑ Dust ❑ Gas ❑ Mist ❑ Vapor ❑ Hybrid

K_{St} or K_G value of material: ____________ bar-m/sec

P_{max} value of material: ____________ ❑ bar-g ❑ or psig

VENT DEVICE DETAILS

Mounting frame: ❑ Yes ❑ No

Frame type: ❑ Welded ❑ Bolted

Thermal insulation: ❑ Yes ❑ No

Gasket material: ____________

Sanitary sealing: ❑ Yes ❑ No

Vent restraints: ❑ Yes ❑ No

PROTECTED ENCLOSURE DETAILS *Rectangular Bag House (for example)*

Enclosure location: ____________

Normal operating pressure: ❑ ________ bar-g ❑ ________ psig @ ________

Normal operating temperature: ❑ ________ °C ❑ ________ °F

Maximum operating pressure: ❑ ________ bar-g ❑ ________ psig @ ________

Maximum operating temperature: ❑ ________ °C ❑ ________ °F

Maximum vacuum conditions: ❑ ________ bar-g ❑ ________ psig ❑ ________ in. W.C.

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Δ **FIGURE A.11.2 Sample Vent Closure Information Form.**

VENT CLOSURE INFORMATION FORM *(continued)*

Frequency and magnitude of pressure cycles: ____________________

Vessel volume and dimensions: ____________________

Vessel aspect ratio: ____________________

Vessel strength: ____________________

Design calculations: NFPA 68 Chapter ________

Other information (to be collected and attached):

- ❏ Data sheets
- ❏ Manufacturer's instruction, installation, and maintenance manuals
- ❏ Vent closure details
- ❏ Vent frame
- ❏ MSDS (of process material)
- ❏ Material K_{St}/K_G test report (the value used for the vent design)
- ❏ Copy of vent identification label
- ❏ Process risk assessment report
- ❏ Process plan view showing vent relief path
- ❏ Process elevation view showing vent relief path
- ❏ Proximity of personnel to vent relief path
- ❏ Management of change requirements
- ❏ Mechanical installation details
- ❏ Manufacturer's service and maintenance forms
- ❏ Verification of conformity documentation
- ❏ Vent restraint documentation
- ❏ Process interlocks (details)

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Δ **FIGURE A.11.2** ***Continued***

ANNUAL INSPECTION FORM

USER CONTACT INFORMATION

Company name: ______________________ Date inspected: __________

Address: ______________________ Time: __________

City: __________ State: __________ Zip code: __________

Telephone: ______________________

Inspector's name: ______________________

Inspection company: ______________________

Address: ______________________

City: __________ State: __________ Zip code: __________

Telephone: ______________________

Vent ID#: ______________________

Vent location: ______________________

Vent manufacturer: ______________________

INSPECTION

Follow the manufacturer's recommendations and the following:

Is the vent:

1. Clear of obstructions? ❑ Yes ❑ No
2. Corroded? ❑ Yes ❑ No
3. Mechanically or physically damaged? ❑ Yes ❑ No
4. Clearly labeled: Warning. Explosion relief device? ❑ Yes ❑ No
5. Clearly tagged/labeled with manufacturer's information? ❑ Yes ❑ No
6. Protected from ice and snow? ❑ Yes ❑ No
7. Painted or coated? (Other than by the manufacturer) ❑ Yes ❑ No
8. Showing buildup or deposits? ❑ Yes ❑ No
9. Bulging, damaged, or deformed (from original shape)? ❑ Yes ❑ No
10. Changed, altered, or tampered with? ❑ Yes ❑ No
11. Showing signs of fatigue? ❑ Yes ❑ No
12. Provided with fasteners and mounting hardware in place? ❑ Yes ❑ No
13. Frame damaged or deformed? ❑ Yes ❑ No
14. Released? ❑ Yes ❑ No
15. Opening sensor operable and wiring up to current codes? ❑ Yes ❑ No
16. Provided with seals, tamper, or other opening indicators intact? ❑ Yes ❑ No
17. Provided with restraints in place and attached? ❑ Yes ❑ No
18. Provided with hinges lubricated and operating freely? ❑ Yes ❑ No
19. Clean and free of contamination? ❑ Yes ❑ No

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Δ FIGURE A.11.4 Sample Annual Inspection Form.

ANNUAL INSPECTION FORM *(continued)*

Looking from the vent outward, can you see personnel working or hazardous material being stored in your direct line of sight? ❑ Yes ❑ No

If yes, describe:

____

____

____

Abnormal conditions found:

____

____

____

Abnormal conditions corrected at time of inspection:

____

____

____

Abnormal conditions that still need attention/addressed:

____

____

____

Action required by management:

____

____

____

Process engineer/supervisor notified? ❑ Yes ❑ No

Date addressed: ______________________________

Action required? ❑ Yes ❑ No

Signature: ______________________________

Have you observed changes to the process and/or its surroundings that should invoke the company's management of change procedure? ❑ Yes ❑ No

Inspector's signature: ______________________________

Manager's signature: ________________________ Date: ____________

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Δ **FIGURE A.11.4** ***Continued***

A.11.4.2 The frequency depends on the environmental and service conditions to which the devices are to be exposed. Process or occupancy changes that can introduce significant changes in condition, such as changes in the severity of corrosive conditions or increases in the accumulation of deposits or debris, can necessitate more frequent inspection. It is recommended that an inspection be conducted after a process maintenance turnaround. Inspections should also be conducted following any natural event that can adversely affect the operation and the relief path of a vent closure (e.g., hurricanes or snow and ice accumulations).

A.11.6 The vent closure design parameters can include the following items, among others:

(1) Manufacturer
(2) Model number
(3) Identification number
(4) Location
(5) Size
(6) Type
(7) Opening pressure
(8) Panel weight
(9) Material(s)

A.11.9.2 It is recommended that changes be reviewed with life safety system and equipment suppliers.

Annex B Fundamentals of Deflagration

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

B.1 General.

B.1.1 Deflagration Requirements. The following are necessary to initiate a deflagration:

(1) Fuel concentration within flammable limits
(2) Oxidant concentration sufficient to support combustion
(3) Presence of an ignition source

B.1.2 Deflagration Pressure.

B.1.2.1 The deflagration pressure, *P*, in a closed volume, *V*, is related to the temperature, *T*, and molar quantity, *n*, by the following ideal gas law equation:

[B.1.2.1]

$$P = \frac{n \cdot R \cdot T}{V}$$

where:
R = universal gas constant.

B.1.2.2 The maximum deflagration pressure, P_{max}, and rate of pressure rise, *dP/dt*, are determined by test over a range of fuel concentrations. *(See Annex C.)* The value of P_{max} for most ordinary fuels is 6 to 10 times the absolute pressure at the time of ignition.

B.1.2.3 The value of $(dP/dt)_{max}$ is the maximum for a particular fuel concentration, referred to as the *optimum concentration. (See examples in Figure B.1.2.3.)*

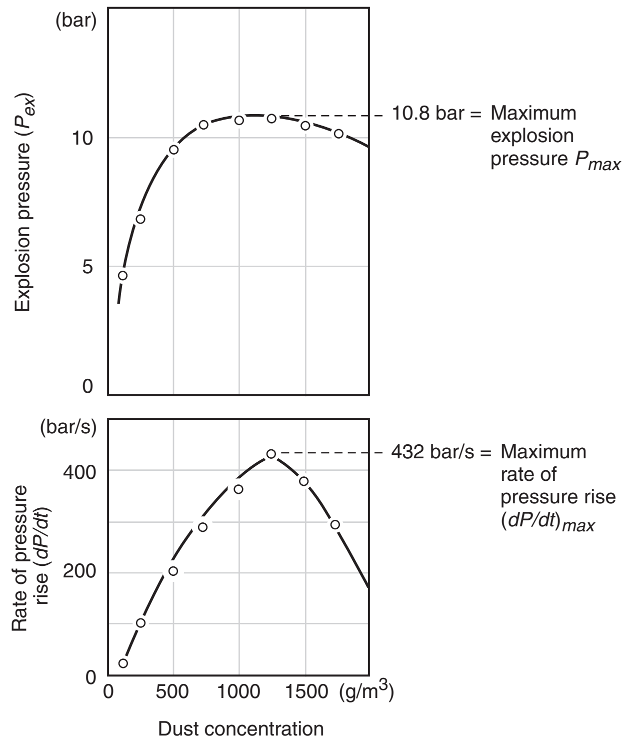


FIGURE B.1.2.3 Variation of Deflagration Pressure and Deflagration Index with Concentration for Several Dusts. (Adapted from Bartknecht [51])

B.1.2.4 Based on the K_{St} values, dusts have been categorized into three hazard classes: St-1, St-2, and St-3. These classes indicate the relative explosibility hazard and deflagration vent sizing requirements, as shown in Table B.1.2.4.

B.1.2.5 Burning Velocity and Flame Speed.

B.1.2.5.1 The burning velocity is the rate of flame propagation relative to the velocity of the unburned gas that is ahead of it. The fundamental burning velocity, S_u, is the burning velocity of a laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas. The values of S_u for many gases have been measured and published. *(See Annex D.)*

B.1.2.5.2 Flame speed, S_f, is the speed of a flame front relative to a fixed reference point. Its minimum value is equal to the fundamental burning velocity times an expansion factor equal

Table B.1.2.4 Hazard Classes of Dust Deflagrations

Hazard Class	K_{St} (bar-m/s)*	P_{max} (bar-g)*
St-1	≤200	10
St-2	201–300	10
St-3	>300	12

Note: See Annex F for examples of K_{st} values.
*K_{St} and P_{max} are determined in approximately spherical calibrated test vessels of at least 20 L capacity per ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds.*

to the ratio of the density of the unburned gas to the density of the burned gas.

B.1.2.6 Beginning with the 2013 edition of NFPA 68, the fundamental burning velocity, S_u, is used to characterize the burning rate of gases. Earlier editions used a normalized maximum rate of pressure rise, K_G, analogous to K_{St} for dusts. Venting correlations were based on K_G tested in an initially quiescent mixture. Differences in test conditions could result in significant change in measured K_G. In particular, increasing the volume of the test enclosure and increasing the ignition energy could result in increased K_G values, as described in Annex E of the 2007 edition.

B.2 Fuel.

B.2.1 General. Any material capable of reacting rapidly and exothermically with an oxidizing medium can be classified as a fuel. A fuel can exist in a gas, liquid, or solid state. Liquid fuels that are dispersed in air as fine mists, solid fuels that are dispersed in air as dusts, and hybrid mixtures pose similar deflagration risks as gaseous fuels.

B.2.2 Concentration. The concentration of a gaseous fuel in air is usually expressed as a volume percentage (vol %) or mole percentage (mol %). The concentrations of dispersed dusts and mists are usually expressed in units of mass per unit volume, such as grams per cubic meter (g/m^3).

B.2.3 Flammable Gas.

B.2.3.1 Flammable gases are present in air in concentrations below and above which they cannot burn. Such concentrations represent the flammable limits, which consist of the lower flammable limit, *LFL*, and the upper flammable limit, *UFL*. It is possible for ignition and flame propagation to occur between the concentration limits. Ignition of mixtures outside these concentration limits fails because insufficient energy is given off to heat the adjacent unburned gases to their ignition temperatures. Lower and upper flammable limits are determined by test and are test-method dependent. Published flammable limits for numerous fuels are available.

For further information, see NFPA 325. (Note: Although NFPA 325 has been officially withdrawn from the *National Fire Codes*®, the information is still available in NFPA's *Fire Protection Guide to Hazardous Materials.*)

B.2.3.2 The mixture compositions that are observed to support the maximum pressure, P_{max}, and the maximum rate of pressure rise, $(dP/dt)_{max}$, for a deflagration are commonly on the fuel-rich side of the stoichiometric mixture. It should be noted that the concentration for the maximum rate of pressure rise and the concentration for P_{max} can differ.

B.2.4 Combustible Dust.

B.2.4.1 Solid particulates smaller than 420 μm (0.017 in.) (capable of passing through a U.S. No. 40 standard sieve) are classified as dusts. The fineness of a particular dust is characterized by particle size distribution. The maximum pressure and K_{St} increase with a decrease in the dust particle size, as shown in Figure B.2.4.1.

B.2.4.2 Particle Size.

B.2.4.2.1 Dust particle size can be reduced as a result of attrition or size segregation during material handling and processing. Such handling and processing can lead to the gradual reduction of the average particle size of the material being handled and can increase the deflagration hazard of the dust. Minimum ignition energy is strongly dependent on particle size [1]. Figure B.2.4.2.1 illustrates this effect.

B.2.4.2.2 A combustible dust that is dispersed in a gaseous oxidizer and subjected to an ignition source does not always deflagrate. The ability of a mixture to propagate a deflagration depends on factors such as particle size, volatile content of solid particles, and moisture content.

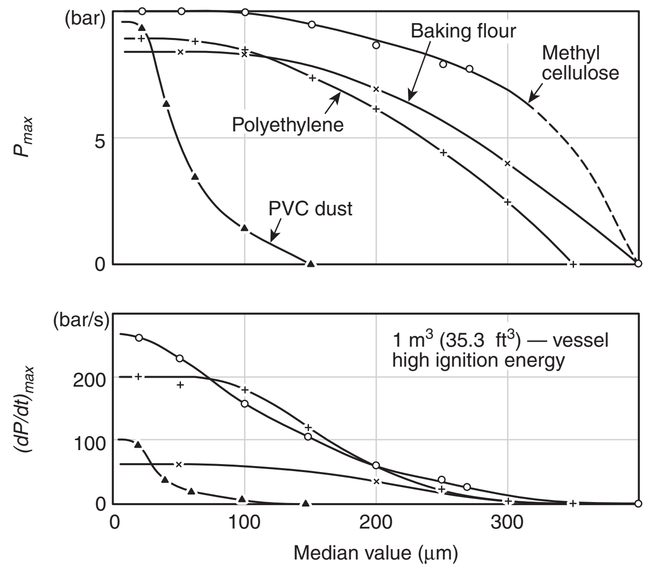


FIGURE B.2.4.1 Effect of Particle Size of Dusts on the Maximum Pressure and Maximum Rate of Pressure Rise [3].

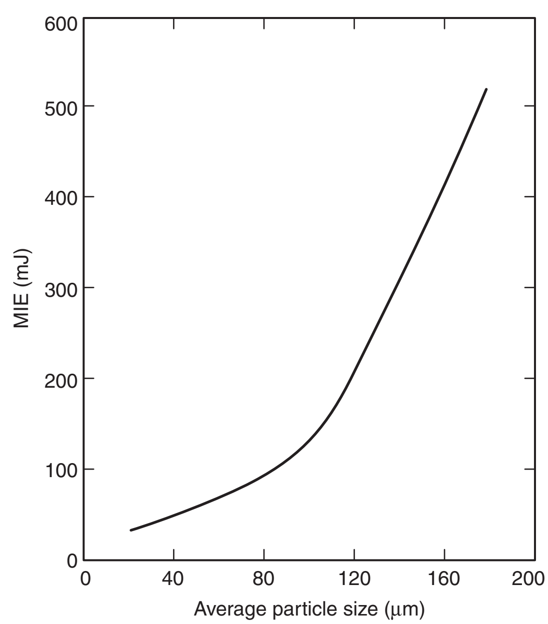


FIGURE B.2.4.2.1 Effect of Average Particle Diameter of a Typical Agricultural Dust on the Minimum Ignition Energy. (Unpublished data courtesy of U.S. Mine Safety and Health Administration.)

B.2.4.3 The predominant mechanism of flame propagation in clouds of most combustible dusts is through the combustion of flammable gases emitted by particles heated to the point of vaporization or pyrolysis. Some dusts can propagate a flame through direct oxidation at the particle surface. Thus, the chemical and physical makeup of a dust has a direct bearing on its means of propagating a flame when dispersed in air.

B.2.4.4 A minimum dust cloud concentration, commonly known as the lower flammable limit (LFL) or the minimum explosible concentration (MEC), can support flame propagation. The LFL of a dust is dependent on its composition and particle size distribution. Large particles participate inefficiently in the deflagration process.

B.2.4.5 Combustible dusts that accumulate on surfaces in process areas can become airborne by sudden air movement or mechanical disturbance. Dusts can pass through ruptured filter elements. In such instances, a combustible concentration of dispersed dust can become established where it normally would not be present.

B.2.4.6 Combustible dusts do not, for most practical purposes, exhibit upper flammable limits in air. This fact is a consequence of the flame propagation mechanism in dust clouds. Thus, deflagrations usually cannot be prevented by maintaining high dust cloud concentrations.

B.2.4.7 The combustion properties of a dust depend on its chemical and physical characteristics. The use of published dust flammability data can result in an inadequate vent design if the dust being processed has a smaller mean particle size than the dust for which data are available, or if other combustion properties of the dust differ. Particle shape is also a consideration in the deflagration properties of a dust. The flammability characteristics of a particular dust should be verified by test. *(See Section C.5.)*

The shape and particle size distribution of the dust is affected by the mechanical abuse that the material has undergone by the process that has created the dust in the first place. An example of this is a polymeric dust created by the suspension polymerization of styrene (in water) that results in a particle shape that are spherical (resembling small spheres).

A polymeric dust created by sending a bulk polymerized polystyrene block through a hammermill results in a dust that has been fractured and has many sharp edges and points. Even if the particle size distribution of the two types of particles are similar (suspension polymerization particles versus hammermill-generated dusts), the K_{St} values for these two samples will be different. The rate of pressure rise for the spherical particles will be slower than the dust sample created by the hammermill operation.

It will be permissible, for design purposes, to accept the K_{St} values subjected to a process similar to the final process design, but radical changes in the process involving differences in the type of particle shape require verification of the K_{St} values.

B.2.5 Hybrid Mixture.

B.2.5.1 The presence of a flammable gas in a dust-air mixture reduces the apparent lower flammable limit and ignition energy. The effect can be considerable and can occur even though both the gas and the dust are below their lower flammable limit. Careful evaluation of the ignition and deflagration characteristics of the specific mixtures is necessary. *(See Figure B.2.5.1.)*

B.2.5.2 It has been shown that the introduction of a flammable gas into a cloud of dust that is normally a minimal deflagration hazard can result in a hybrid mixture with increased maximum pressure, P_{max}, and maximum rate of pressure rise, $(dP/dt)_{max}$. An example of this phenomenon is the combustion of polyvinyl chloride dust in a gas mixture. *(See Figure B.2.5.2.)*

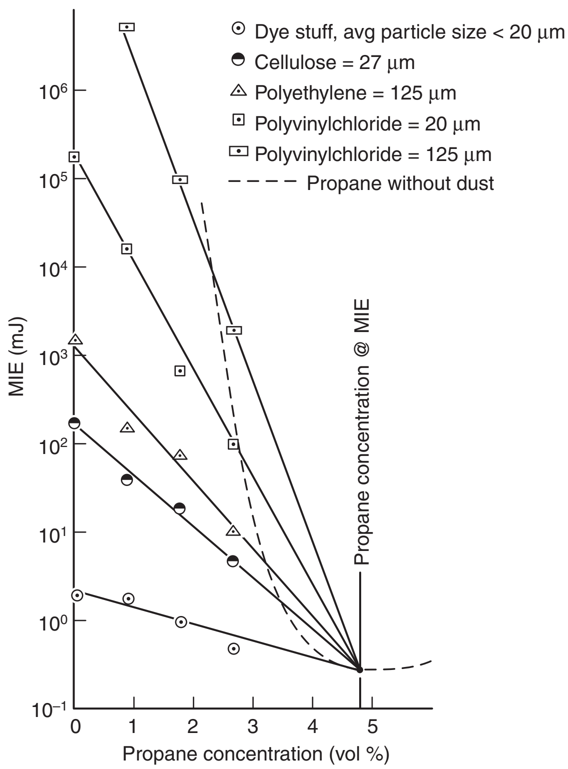


FIGURE B.2.5.1 Lowest MIE of Hybrid Mixtures Versus Propane Content.

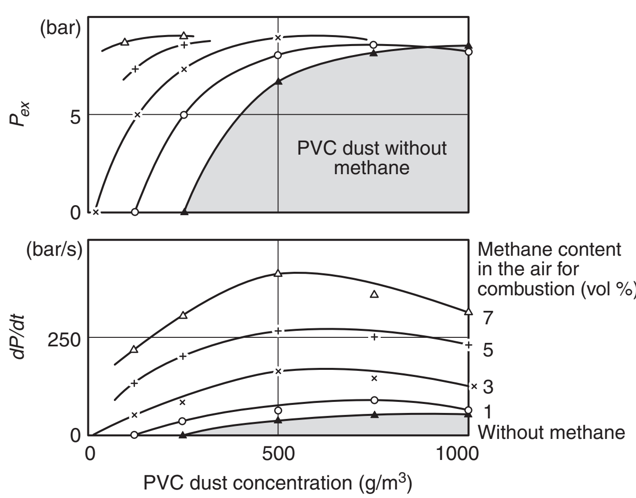


FIGURE B.2.5.2 Deflagration Data for Hybrid Mixtures of Polyvinyl Chloride Dust and Methane Gas in Air [4].

B.2.5.3 Situations where hybrid mixtures can occur in industrial processes include fluidized bed dryers drying solvent–wet combustible dusts, desorption of combustible solvent and monomer vapors from polymers, and coal-processing operations.

B.2.6 Mist. A mist of flammable or combustible liquids has deflagration characteristics that are analogous to dusts. The lower flammable limit for dispersed liquid mists varies with droplet size in a manner that is analogous to particle size for dusts. The determination of these deflagration characteristics is complicated by droplet dispersion, coalescence, and settling. A typical LFL for a fine hydrocarbon mist is 40 g/m^3 to 50 g/m^3, which is approximately equal to the LFL for combustible hydrocarbon gases in air at room temperature. Mists of combustible liquids can be ignited at initial temperatures well below the flash point of the liquid [62–65].

B.3 Oxidant.

B.3.1 The oxidant for a deflagration is normally the oxygen in the air. Oxygen concentrations greater than 21 percent tend to increase the fundamental burning velocity and increase the probability of transition to detonation. Conversely, oxygen concentrations less than 21 percent tend to decrease the rate of combustion. Most fuels have an oxygen concentration limit below which combustion cannot occur.

B.3.2 Substances other than oxygen can act as oxidants. While it is recognized that deflagrations involving the reaction of a wide variety of fuels and oxidizing agents (e.g., oxygen, chlorine, fluorine, oxides of nitrogen, and others) are possible, discussion of deflagration in this standard is confined to those cases where the oxidizing medium is normal atmospheric air consisting of 21 volume percent oxygen unless specifically noted otherwise.

B.4 Inert Material.

B.4.1 Inert Gases. Inert gases can be used to reduce the oxidant concentration.

B.4.2 Inert Powder.

B.4.2.1 Inert powder can reduce the combustibility of a dust by absorbing heat. The addition of inert powder to a combustible dust–oxidant mixture reduces the maximum rate of pressure rise and increases the minimum concentration of combustible dust necessary for ignition. See Figure B.4.2.1 for an example of the effect of admixed inert powder. A large amount of inert powder is necessary to prevent a deflagration; concentrations of 40 percent to 90 percent are needed.

B.4.2.2 Some inert powders in small concentrations, such as silica, can be counterproductive because they can increase the dispersibility of the combustible dust.

B.5 Ignition Sources. Some types of ignition sources include electric (e.g., arcs, sparks, and electrostatic discharges), mechanical (e.g., friction, grinding, and impact), hot surfaces (e.g., overheated bearings), and flames (welding torches and so forth).

B.5.1 One measure of the ease of ignition of a gas, dust, or hybrid mixture is its MIE. The MIE is typically less than 1 mJ for gases and often less than 100 mJ for dusts. Minimum ignition energies are reported for some gases and dust clouds [7, 17, 90, 92].

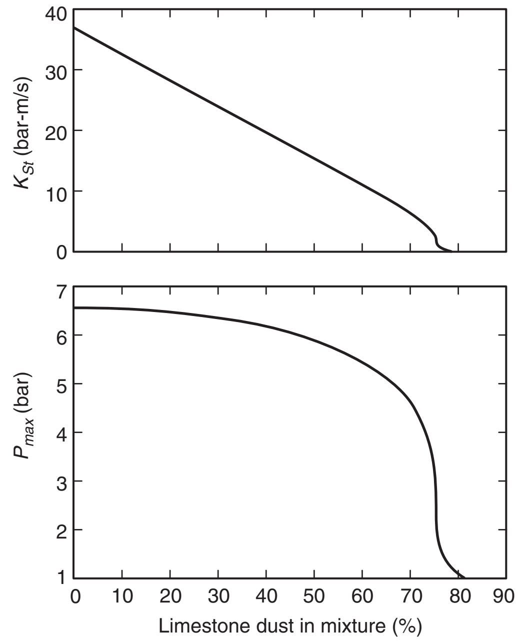


FIGURE B.4.2.1 Effect of Added Inert Dust on Deflagration Data for Coal Dust in Air [109].

B.5.2 An ignition source such as a spark or a flame can travel from one enclosure to another. A hot, glowing particle such as a grinding spark can travel a considerable distance and can ignite a flammable mixture along the way. Similarly, stronger ignition sources, such as flame jet ignitions, deserve special consideration. A flame produced by an ignition source in one enclosure can become a much larger ignition source if it enters another enclosure. The increase in the energy of the ignition source can increase the maximum rate of pressure rise developed during a deflagration.

B.5.3 The location of the ignition source within an enclosure can affect the rate of pressure rise. In the case of unvented spherical enclosures, ignition at the center of the enclosure results in the highest rate of pressure rise. In the case of elongated enclosures, ignition near the unvented end of an elongated enclosure could result in higher overall pressure.

B.5.4 Simultaneous multiple ignition sources intensify the deflagration that results in an increased dP/dt.

B.6 Effect of Initial Temperature and Pressure. Any change in the initial absolute pressure of the fuel-oxidant mixture at a given initial temperature produces a proportionate change in the maximum pressure developed by a deflagration of the mixture in a closed vessel. Conversely, any change in the initial absolute temperature at a given initial pressure produces an inverse change in the maximum pressure attained. *(See Figure B.6.)* This effect can be substantial in cases of vapor explosions at cryogenic temperatures.

B.7 Effect of Turbulence.

B.7.1 Turbulence causes flames to stretch, which increases the net flame surface area that is exposed to unburned materials, which in turn leads to increased flame speed.

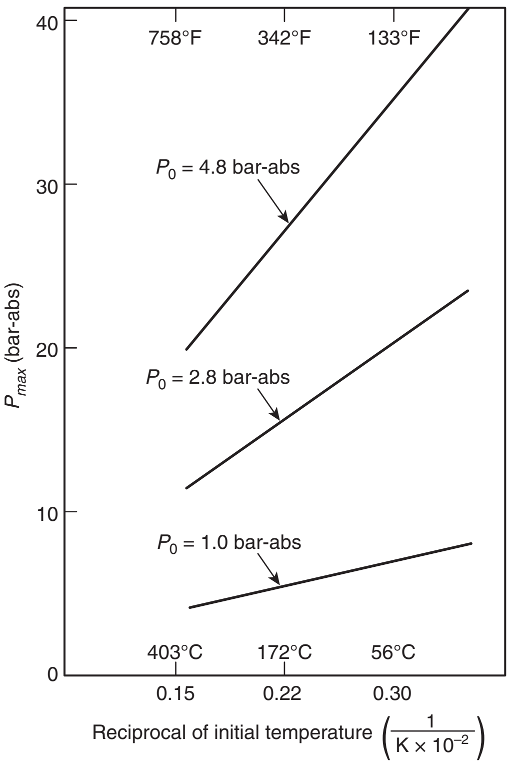


FIGURE B.6 Effect of Initial Temperature on the Maximum Deflagration Pressure of Near-Stoichiometric Mixtures of Methane-Air at Three Initial Pressures, P_0 [19].

B.7.2 Initial turbulence in closed vessels results in higher rates of pressure rise and in somewhat higher maximum pressure than would occur if the fuel-oxidant mixture were initially subject to quiescent conditions. Turbulence results in an increase in the vent area needed. Figure B.7.2 illustrates the effects of turbulence and of fuel concentration.

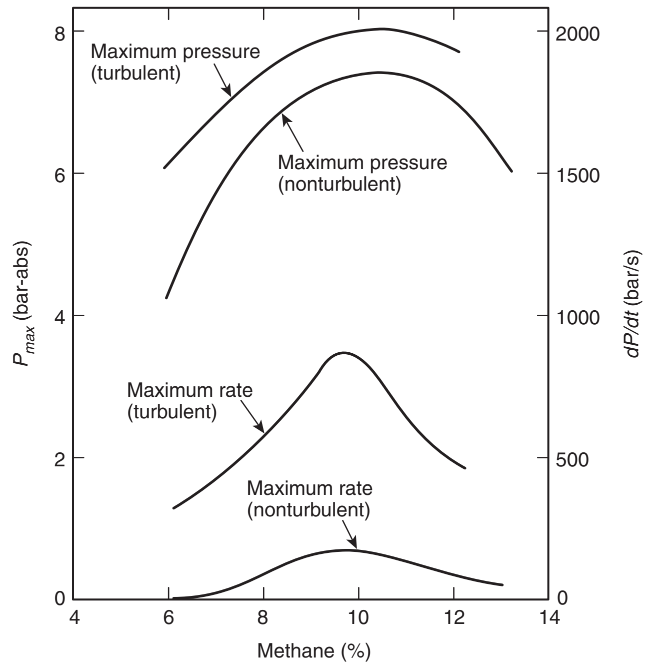


FIGURE B.7.2 Effect of Turbulence on the Maximum Pressure and Rate of Pressure Rise for Methane–Air Mixtures. (Adapted from [20] and [21])

B.7.3 Turbulence is also created during deflagration as gases and dusts move past obstacles within the enclosure. In elongated enclosures, such as ducts, turbulence generation is enhanced and flame speeds can increase to high values, causing transition from deflagration to detonation. Venting, because of the flow of unburned gases through the vent opening, can cause turbulence both inside and outside the enclosure.

Annex C Guidelines for Measuring Deflagration Parameters of Dusts

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

C.1 General Comments. ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, sets forth a method for determining the maximum pressure and the rate of pressure rise of combustible dusts [96]. This annex discusses how that test procedure relates to the venting of large enclosures, but it does not describe the test procedure in detail. Since gases are not addressed in ASTM E1226, test procedures are discussed in this annex.

ASTM E2019, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*, and ASTM E582, *Standard Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures*, provide additional information on test methods for dusts and gases. Britton [92] reviewed ignition energy test methods that have been developed for dusts and gases.

C.2 Purpose. The purpose of deflagration index measurements is to predict the effect of the deflagration of a particular material (dust or gas) in a large enclosure without carrying out full-scale tests.

C.3 Basic Principles. Information presented in this standard and other international standards are based on large-scale tests carried out in vented vessels using a variety of test materials and vessel sizes [3, 47]. For each test material and vessel volume, the maximum reduced deflagration pressure, P_{red}, was found for a series of vents with various areas, A_v, and opening pressures, P_{stat}. Only a single material classification (the S_u or K_{St} index) related to burning rate needs to be experimentally obtained. A maximum closed volume deflagration pressure, P_{max}, also must be obtained. If the volume and the mechanical constraints of the enclosure to be protected are known, the user can determine from the equations the necessary venting.

C.3.1 The K_{St} Indices. The test dusts used during the large-scale tests were classified according to the maximum rate of pressure rise recorded when each was deflagrated in a 1 m^3 (35 ft^3) closed test vessel. The maximum rate of pressure rise found in the 1 m^3 (35 ft^3) vessel was designated K_{St}. K_{St} is not a fundamental material property but depends on the conditions of the test. The classification work carried out in the 1 m^3 (35 ft^3) vessel provides the only direct link between small-scale closed vessel tests and the large-scale vented tests.

C.3.2 Standardization of a Test Facility. The objective of standardization is to validly compare the deflagration behavior of a particular material with others for which full-scale test data are available. Without access to the 1 m^3 (35 ft^3) vessel in which the original K_{St} classifications were made, it is essential to standardize the test conditions that are employed using samples tested either in the 1 m^3 (35 ft^3) vessel or in a vessel that has been standardized to it. ASTM defines the standardization requirements for dusts. To calibrate for dusts, which cannot be identified by composition alone, it is necessary to obtain samples that have established K_{St} values. *(See Section C.5.)*

C.3.3 Determination of the K_{St} Index. If the maximum rate of pressure rise is measured in a vessel with a volume of other than 1 m^3 (35 ft^3), Equation C.3.3 is used to normalize the value obtained to that of a 1 m^3 (35 ft^3) vessel:

[C.3.3]

$$\left(\frac{dP}{dt}\right)_{max} \cdot \left(V^{1/3}\right) = K$$

where:
P = pressure (bar-g)
t = time (s)
V = volume (m^3)
K = normalized K_{St} index (bar-m/s)

The measured maximum deflagration pressure, P_{max}, is not scaled for volume, and the experimental value can be used for design purposes. The maximum rate of pressure rise is normalized to a volume of 1 m^3 (35 ft^3) using Equation C.3.3. If the maximum rate of pressure rise is given in bar per second, and the test volume is given in cubic meters, the equation defines the K_{St} index for the test material.

Example: The volume of a spherical test vessel is 26 L (0.026 m^3), and the maximum rate of pressure rise, determined from the slope of the pressure-time curve, is 572 bar/s (8300 psi/s). Substituting these values for the variables in Equation C.3.3, the normalized index equals 572 $(0.026)^{1/3}$, or 169 bar-m/s.

C.3.4 Effect of Volume on K_{St}. The effect of vessel volume alone on K_{St} values that are obtained for particular dusts has not been well established. Dusts cannot be suspended in a quiescent manner, and the initial turbulence introduces a nonscalable variable. However, it cannot be assumed that K_{St} in Equation C.3.3 is independent of vessel volume. It has been found [47] that K_{St} values that are obtained in the original 1 m^3 (35 ft^3) classifying vessel cannot be reproduced in spherical vessels with volumes of less than 16 L or in the cylindrical Hartmann apparatus. All existing facilities that have standardized equipment use a spherical test vessel with a volume of at least 20 L or a squat cylinder of larger volume [such as the 1 m^3 (35 ft^3) classifying vessel itself]. The principle of K_{St} standardization in such vessels is to adjust test conditions (particularly initial turbulence) until it can be demonstrated that all dusts yield K_{St} values that are in agreement with the values that have been established in the 1 m^3 (35 ft^3) vessel [96]. If vessels of volumes other than 1 m^3 (35 ft^3) are used, Equation C.3.3 must be used. Use of vessels with different volumes can lead to errors that are dependent on K_{St}. The possibility of such errors should be considered where test data are applied to vent design [77].

C.3.5 Effect of Initial Pressure. The initial pressure for deflagration testing is 1 standard atm (absolute pressure of 14.7 psi, 760 mm Hg, or 1.01 bar). Alternatively, a standard pressure of 1 bar can be used with negligible error. If initial pressures are not of standard value, they should be reported, and correction methods should be applied. P_{max} is proportional to initial test pressure, and any difference between initial test pressure and 1 standard atm is multiplied by the deflagration pressure ratio (usually between 7 and 12) in the measured P_{max} value. Measured values are affected to a smaller degree. The effect of initial pressure is most important where tests are conducted at ambient pressure. Ambient pressure can vary from extremes of absolute pressure of 0.89 bar to 1.08 bar (12.9 psi to 15.6 psi), even at sea level, and it decreases with elevation. For example, at an elevation of 2 km (1.25 mi), the average absolute pressure at a latitude of 50°N is 0.79 bar-abs (11.5 psi). It is readily seen that a P_{max} value measured at such an elevation is approximately 20 percent lower than that measured at 1 standard atm, assuming a 10:1 deflagration pressure ratio. Conducting tests under standard conditions, rather than correcting the measured values, is always recommended.

C.4 Gas Testing.

C.4.1 Fundamental Burning Velocity. (Reserved)

C.4.2 Maximum Explosion Pressure, P_{max}. The test vessel used for gas testing should be spherical, with a volume of at least 5 L and a recommended volume of 20 L or greater. Because the only source of initial turbulence is the ignition source employed, it is important that the flame front is not unduly distorted by the ignition process. The ignition source should be centrally located and should approximate a point source. A discrete capacitor discharge carrying no great excess of energy above that needed to ignite the mixture is recommended. Fused-wire igniters and chemical igniters can cause multipoint ignition and should not be used for routine P_{max} measurements in small vessels.

Verification should be made that each gas mixture is well mixed and quiescent immediately prior to ignition. The maximum pressure is measured systematically for several compositions close to the stoichiometric mixture until the maximum value *(P_{max})* has been determined. A table of P_{max} values is then established for the standardized gases as measured in the test vessel.

The P_{max} value for the test gas first has to be determined under conditions identical to those used for standardization.

A database in which P_{max} values are given for a wide variety of gases that have been tested under the standardized conditions should be established for the test equipment. P_{max} values should not be reported unless the database or, at a minimum, the P_{max} values for the standardized gases are also reported.

Most flammable gas mixtures at the optimum concentration can be ignited conveniently in small vessels by using a capacitor spark of 100 mJ or less, which can serve as a normal ignition source for standardization. However, the ignition recommendations for certain exceptional gas mixtures can exceed this figure substantially. Before a gas mixture is designated as noncombustible, it should be subjected to a strong ignition source. *(See Section C.6.)*

C.5 Dust Testing. Dust samples that have the same chemical composition do not necessarily display similar K_{St} values or even similar deflagration pressures *(P_{max})*. The burning rate of a dust depends markedly on the particle size distribution and shape and on other factors such as surface oxidation (aging) and moisture content. The form in which a given dust is tested should bear a direct relation to the form of that dust in the enclosure to be protected. Although Annex F provides both K_{St} and dust identities for samples that are tested in a 1 m^3 (35 ft^3) vessel, it should not be assumed that other samples of the same dusts yield the same K_{St} values. Such data cannot be used for vessel standardization but are useful in determining trends. The test vessel that is to be used for routine work should be standardized using dust samples whose K_{St} and P_{max} characteristics have been established in the standard 1 m^3 (35 ft^3) vessel [96].

C.5.1 Obtaining Samples for Standardization. Samples should be obtained that have established K_{St} values in St-1, St-2, and St-3 dusts. At the time this standard was published, suitable standard samples (with the exception of lycopodium dust) were not generally available. ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, defines the required agreement with values that are generated in the standard 1 m^3 (35 ft^3) vessel.

C.5.2 Effect of Dust-Testing Variables. The following factors affect the measured K_{St} for a particular spherical test vessel (20 L or greater) and a particular prepared dust sample:

(1) Mass of sample dispersed or concentration
(2) Uniformity of dispersion
(3) Turbulence at ignition
(4) Ignition strength

The concentration is not subject to standardization, because it should be varied for each sample that is tested until the maximum K_{St} has been determined. The maximum K_{St} usually corresponds to a concentration that is several times greater than stoichiometric. ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, recommends testing a series of concentrations. Measured K_{St} is plotted against concentration, and tests continue until the maximum is determined. By testing progressively leaner mixtures, the minimum explosive concentration (lean limit or LFL) can similarly be determined. The limit can be affected by ignition energy.

C.5.2.1 Obtaining a Uniform Dust Dispersion. The uniformity of dust dispersion is implied by the ability to achieve consistent and reproducible K_{St} values in agreement with the established values for the samples that are tested. Poor dispersion leads to low values of K_{St} and P_{max}.

A number of dust dispersion methods exist. For small vessels, the most common methods used are the perforated ring and the whipping hose. The perforated ring *(see [96] and Section G.2)* fits around the inside surface of the test vessel and is designed to disperse the dust in many directions. A ring of this type is described in Donat [47] in relation to the dust classification work in the 1 m^3 (35 ft^3) vessel. However, the device can clog in the presence of waxy materials, low-density materials, and materials that become highly electrically charged during dispersion. To minimize these problems, the whipping hose has been used [77]. This is a short length of heavy-duty rubber tubing that "whips" during dust injection and disperses the dust. Comparison of these two methods under otherwise identical conditions [77] indicates that they are not necessarily interchangeable and that the dispersion method should be subject to standardization.

C.5.2.2 Standardizing Turbulence at Ignition. During dust injection, the partially evacuated test vessel receives a pulse of air from the air bomb that brings the pressure to 1 atm (absolute) and disperses dust placed below the dispersion system. Some time after the end of injection, the igniter is fired. The following test condition variables affect turbulence at ignition in the test vessel:

(1) Air bomb volume
(2) Air bomb pressure
(3) Initial vessel pressure
(4) Injection time
(5) Ignition delay time

References [77] and [80] describe combinations of the variables in C.5.2.2(1) through C.5.2.2(5) that have yielded satisfactory results. For example, a 26 L test vessel [77] employs a 1 L air bomb at absolute pressure of 300 psi (20.7 bar). Having established the air bomb volume and pressure, the initial test vessel reduced pressure and injection time are set so that, after dust injection, the test vessel is at 1 atm (absolute). It should be noted that the air bomb and test vessel pressures do not need to equalize during dust dispersion. Injection time and ignition delay time are set using solenoid valves that are operated by a timing circuit. For standardization, reproducibility of timing is essential, and it is possible that the optimum ignition delay time is approximately 10 milliseconds. Fast-acting valves and accurate timing devices should be employed.

Standardization that uses well-characterized samples *(see C.5.1)* is considered complete when samples in St-1, St-2, and St-3 dusts have been shown to yield the expected K_{St} (to within acceptable error) with no adjustment of the variables specified in C.5.2.2. In addition, the mode of ignition *(see C.5.2.3)* should not be changed for standardized testing.

C.5.2.3 Ignition Source. The ignition source can affect determined K_{St} values even if all other variables determined remain constant. It has been found that, in a 1 m^3 (35 ft^3) vessel, capacitor discharge sources of 40 mJ to 16 J provide K_{St} and P_{max} data comparable to those obtained using a 10 kJ chemical igniter [47]. In the same vessel, a permanent spark gap underrated both K_{St} and P_{max} for a range of samples. References [77] and [81] provide a description of how comparable K_{St} and P_{max} values were obtained in vessels of approximately 20 L, using between one and six centrally located electric match igniters rated at 138 J each.

Various types of electrically initiated chemical ignition source devices have proven satisfactory during routine tests. The most popular are two 138 J electric match igniters and two 5 kJ pyrotechnic devices. These ignition sources are not interchangeable, and standardization should be based on a fixed type of igniter. The matches have insufficient power to ignite all combustible dust suspensions. Therefore, any dust that appears to be classified as St-0 should be retested using two 5 kJ pyrotechnic igniters *(see Section C.6)*. The routine use of the pyrotechnic igniter as a standardized source necessitates a method of correction for its inherent pressure effects in small vessels [77]. Therefore, neither source is ideal for all applications.

C.5.3 Dust Preparation for K_{St} Testing. It is necessary for a given dust to be tested in a form that bears a direct relation to the form of that dust in any enclosure to be protected *(see Section C.5)*. Only standardized dusts and samples taken from such enclosures are normally tested in the as-received state. The following factors affect the K_{St}:

(1) Size distribution
(2) Particle shape
(3) Contaminants (gas or solid)

Although dusts can be produced in a coarse state, attrition can generate fines. Fines can accumulate in cyclones and baghouses, on surfaces, and in the void space when large enclosures are filled. For routine testing, it is assumed that such fines can be represented by a sample screened to sub-200 mesh (75 μm). For comprehensive testing, cascade screening into narrow-size fractions of constant weight allows K_{St} to be determined for a series of average diameters. Samples taken from the enclosure help in determining representative and worst-case size fractions that are to be tested. If a sufficient sample cannot be obtained as sub-200 mesh (75 μm), it might be necessary to grind the coarse material. Grinding can introduce an error by affecting the shape of the fines produced. The specific surface of a sample, which affects burning rate, depends on both size distribution and particle shape.

Where fines accumulation is considered, the accumulation of additives also has to be considered. Many dust-handling processes can accumulate additives such as antioxidants that are included as only a small fraction of the bulk. Such accumulation can affect K_{St} and, by reducing the ignition energy necessary to ignite the mixture, can increase the probability of a deflagration [77].

Flammable gases can be present in admixtures with dusts (hybrid mixtures), and many accumulate with time as a result of gas desorption from the solid phase. Where this possibility exists, both K_{St} and ignition energy can be affected. The effect of hybrid mixtures can be synergistic to the deflagration, and a gas that is present at only a fraction of its lower flammable limit needs to be considered [3]. Testing of hybrid mixtures can be carried out by injecting the gas-dust mixture into an identical gas mixture that is already present in the test vessel. The gas concentration (determined based on partial pressure at the time of ignition) should be systematically varied to determine the range of hybrid K_{St} values that can apply to the practical system.

The use of a whipping hose *(see C.5.2.1)* or rebound nozzle should avoid the necessity of using inert flow-enhancing additives to help dust dispersion in most cases. Such additives should not be used in testing.

C.6 Classification as Noncombustible. A gas or dust mixture cannot be classed as noncombustible (for example, St-0 dust) unless it has been subjected repeatedly to a strong chemical ignition source of 10 kJ. If a material fails to ignite over the range of concentrations tested using the standard ignition source, then, after the equipment is checked using a material of known behavior, the test sequence is repeated using a 10 kJ chemical igniter. It is necessary to establish that the strong ignition source cannot yield a pressure history in the vessel that can be confused with any deflagration it produces.

It can be impossible to unequivocally determine whether a dust is noncombustible in the case of small vessels (e.g., the 20 L vessel). Such determination is difficult because strong igniters such as 10 kJ pyrotechnics tend to overdrive the flame system, in addition to producing marked pressure effects of their own. Cashdollar and Chatrathi [97] have demonstrated the overdriving effect when determining minimum explosible dust concentrations. Mixtures that are considered to be explosible in a 20 L (0.02 m^3) vessel do not propagate flame in a 1 m^3 (35 ft^3) vessel at the same concentration. Cashdollar and Chatrathi [97] recommend the use of a 2.5 kJ igniter for lower flammable limit measurements, which produced results similar to those of the 10 kJ igniter in a 1 m^3(35 ft^3) vessel. In contrast, ASTM E1515, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*, specifies the use of a 5 kJ ignition source for MEC (lower flammable limit) testing. The ideal solution is to use large (10 kJ) igniters in larger [1 m^3 (35 ft^3)] vessels. The authors further recommend an ignition criterion of an absolute pressure ratio greater than 2 plus a K_{St} greater than 1.5 bar-m/s.

An alternative to the use of the strong ignition source and its associated pressure effects in small vessels is to test fractions of a finer size than the routine sub-200 mesh (75 μm). Dust ignition energy varies with the approximate cube of particle diameter [77]; therefore, the use of electric matches can be extended to identification of St-0 dusts. Similarly, the dust lean limit concentration can be subject to ignition energy effects, which decrease with the sample's decreasing particle size. Such effects largely disappear where sub-400 mesh samples are tested. In the case of gases, a strong ignition source that consists of capacitance discharges in excess of 10 J, or fused-wire sources of similar energy, can be used. Such sources are routinely used for flammable limit determination.

C.7 Instrumentation Notes. Data can be gathered by analog or digital methods, but the rate of data collection should be capable of resolving a signal of 1 kHz or higher frequency (for digital methods, more than one data point per millisecond). For fast-burning dusts and gases, particularly in small vessels, faster rates of data logging can be necessary to achieve resolution. Data-logging systems include oscilloscopes, oscillographs, microcomputers, and other digital recorders. An advantage of digital methods is that both the system operation and subsequent data reduction can be readily automated using computer methods [77]. A further advantage of digital methods is that expansion of the time axis enables a more accurate measurement of the slope of the pressure-time curve than can be obtained from an analog oscilloscope record. Where using automated data reduction, it is essential to incorporate appropriate logic to mitigate the effect of spurious electrical signals. Such signals can be reduced by judicious cable placement, grounding, and screening, but they are difficult to avoid altogether. It is advantageous to confirm automated values manually using the pressure-time curve generated.

Where gas mixtures are created by the method of partial pressures, it is important to incorporate a gas-temperature measuring device (for example, a thermocouple) to ensure that the mixture is created at a constant temperature. Gas analysis should be used where possible.

It has been found that piezoelectric pressure transducers are satisfactory for deflagration pressure measurements in dust-testing systems as a result of good calibration stability. The transducer should be flush-mounted to the inside wall of the vessel and coated with silicone rubber, thereby minimizing acoustic and thermal effects.

The entire test system should be routinely maintained and subjected to periodic tests using standard materials of known behavior. Soon after initial standardization, large quantities of well-characterized dust samples (St-1, St-2, and St-3) of a type not subject to aging or other effects should be prepared. Where stored, these dusts can be used for periodic system performance tests.

Annex D Deflagration Characteristics of Select Flammable Gases

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

Δ **D.1 General.** The fundamental burning velocity values given in Table D.1 are based on NACA Report 1300 [82]. For the purpose of scaling the NACA burning velocity values in this standard, a reference value of 39 cm/s for the fundamental burning velocity of propane has been used. The 2018 version of this standard used a reference value of 46 cm/s for the fundamental burning velocity of propane for this purpose, but the current value (39 cm/s) reflects a consensus of the best available data. The compilation given in Perry's *Chemical Engineers' Handbook* [83] is based on the same data (NACA Report 1300) and also uses a reference value of 39 cm/s for the fundamental burning velocity of propane. Where newer and more reliable data than the NACA data set are available, those data are used, as noted in Table D.1.

D.2 P_{max} Values. Table D.2 provides P_{max} values for several gases. The values were determined by tests in a 5 L (0.005 m^3) sphere with ignition by an electric spark of approximately 10 J energy. Where the fuels had sufficient vapor pressure, the tests were done at room temperature. Where the fuels did not have sufficiently high vapor pressure, the tests were done at elevated temperature, and the test results were then extrapolated to room temperature. The source of the test data is the laboratory of Dr. W. Bartknecht, Ciba Geigy Co., Basel, Switzerland (private communication).

N **Table D.1 Fundamental Burning Velocities of Selected Gases and Vapors**

Fuel	CAS Registry Number®	Legacy Values (NFPA 68 2018 Ed.) Fundamental Burning Velocity (cm/s)	Revised Fundamental Burning Velocity (cm/s)
Acetone	67-64-1	54	46
Acetylene	74-86-2	167	141
Acrolein	107-02-8	66	56
Acrylonitrile	107-13-1	50	43
Allene (propadiene)	463-49-0	87	74
Benzene	71-43-2	48	41[a]
n-butyl-	104-51-8	37	33[a]
tert-butyl-	98-06-6	39	33[a]
1,2-dimethyl-	95-47-6	37	31[a]
1,2,4-trimethyl-	95-63-6	39	33[a]
1,2 Butadiene (methylallene)	590-19-2	68	58
1,3-Butadiene	106-99-0	64	55
2,3-dimethyl-	513-81-5	52	44
2-methyl-	78-79-5	55	46
n-Butane	106-97-8	45	42[ab]
2-cycloproyl-	5750-02-7	47	40
2,2-dimethyl-	75-83-2	42	36
2,3-dimethyl-	79-29-8	43	36
2-methyl-	78-78-4	43	37
2,2,3-trimethyl-	464-06-2	42	36
Butanone	78-93-3	42	36
1-Butene	106-98-9	51	43
2-cyclopropyl-	5809-54-1	50	43
2,3-dimethyl-	563-78-0	46	39
2-ethyl-	760-21-4	46	39
2-methyl-	563-46-2	46	39
3-methyl-	563-45-1	49	41
2,3-dimethyl-2-butene	563-79-1	44	37
3-Butene-1-yne (vinylacetylene)	689-97-4	89	75
1-Butyne	107-00-6	68	58
3,3-dimethyl-	917-92-0	56	48
2-Butyne	503-17-3	61	51
Carbon disulfide	75-15-0	58	50
Carbon monoxide	630-08-0	46	39

(continues)

N **Table D.1** ***Continued***

Fuel	CAS Registry Number®	Legacy Values (NFPA 68 2018 Ed.) Fundamental Burning Velocity (cm/s)	Revised Fundamental Burning Velocity (cm/s)
Cyclobutane	287-23-0	67	57
ethyl-	4806-61-5	53	45
isopropyl-	872-56-0	46	39
methyl-	598-61-8	52	44
methylene-	1120-56-5	61	51
Cyclohexane	110-82-7	46	39
methyl-	108-87-2	44	37
Cyclohexene	110-83-8		40
Cyclopentadiene	542-92-7	46	39
Cyclopentane	287-92-3	44	37
methyl-	96-37-7	42	36
Cyclopentene	142-29-0		41
Cyclopropane	75-19-4	56	48
cis-1,2-dimethyl-	930-18-7	55	46
trans-1,2-dimethyl-	2402-06-4	55	46
ethyl-	1191-96-4	56	48
methyl-	594-11-6	58	49
1,1,2-trimethyl-	4127-45-1	52	44
trans-Decalin (decahydronaphthalene)	493-02-7	36	31[a]
n-Decane	124-18-5	43	37[a]
1-Decene	872-05-9	44	37[a]
Diethyl ether	60-29-7	47	40
Dimethyl ether	115-10-6	54	46[c]
Ethane	74-84-0	47	41[d]
Ethene (ethylene)	74-85-1	80	68
Ethyl acetate	141-78-6	38	32
Ethylene oxide	75-21-8	108	91
Ethylenimine	151-56-4	46	39
Gasoline (100-octane)		40	34
n-Heptane	142-82-5	46	39[ae]
Hexadecane	544-76-3	44	37[a]
1,5-Hexadiene	592-42-7	52	44
n-Hexane	110-54-3	46	39[ae]
1-Hexene	592-41-6	50	42
1-Hexyne	693-02-7	57	48

(continues)

N **Table D.1** ***Continued***

Fuel	CAS Registry Number®	Legacy Values (NFPA 68 2018 Ed.) Fundamental Burning Velocity (cm/s)	Revised Fundamental Burning Velocity (cm/s)
3-Hexyne	928-49-4	53	45
HFC-32 (Difluoromethane)	75-10-5	6.7	6.7[f]
HFC-143 (1,1,2-Trifluoroethane)	430-66-0	13.1	13[f]
HFC-143a (1,1,1-Trifluoroethane)	420-46-2	7.1	7.1[f]
HFC-152a (1,1-Difluoroethane)	75-37-6	23.6	24[f]
Hydrogen	1333-74-0	312	286[g]
Isopropyl alcohol	67-63-0	41	35
Isopropylamine	75-31-0	31	27
Jet fuel JP-1 (average)		40	34
Jet fuel JP-4 (average)		41	35
Methane	74-82-8	40	37[h]
diphenyl-	101-81-5	35	30
Methyl alcohol	67-56-1	56	48
n-octane	111-65-9		39[ac]
1,2-Pentadiene (ethylallene)	591-95-7	61	52
cis-1,3-Pentadiene	1574-41-0	55	46
trans-1,3-Pentadiene (piperylene)	2004-70-8	54	46
2-methyl-(cis or trans)-	926-54-5	46	39
1,4-Pentadiene	591-93-5	55	46
2,3-Pentadiene	591-96-8	60	51
n-Pentane	109-66-0	46	40[ae]
2,2-dimethyl-	590-35-2	41	35
2,3-dimethyl-	565-59-3	43	37
2,4-dimethyl-	108-08-7	42	36
2-methyl-	107-83-5	43	37
3-methyl-	96-14-0	43	37
2,2,4-trimethyl-(isooctane)	540-84-1	41	35
1-Pentene	109-67-1	50	43
2-methyl-	763-29-1	47	40
4-methyl-	691-37-2	48	41
cis-2 Pentene	627-20-3	51	43
1-Pentyne	627-19-0	63	53

(continues)

N **Table D.1** ***Continued***

Fuel	CAS Registry Number®	Legacy Values (NFPA 68 2018 Ed.) Fundamental Burning Velocity (cm/s)	Revised Fundamental Burning Velocity (cm/s)
4-methyl-	7154-75-8	53	45
2-Pentyne	627-21-4	61	51
4-methyl-	21020-27-9	54	46
Propane	74-98-6	46	39[i]
2-cyclopropyl-	3638-35-5	50	43
1-deutero-	20717-73-1	40	34
1-deutero-2-methyl-	50463-25-7	40	34
2-deutero-2-methyl-	13183-68-1	40	34
2,2-dimethyl-	463-82-1	39	33
2-methyl- (isobutane)	75-28-5	41	35
Propene (propylene)	115-07-1		44
2-cyclopropyl-	4663-22-3	53	45
2-methyl-	115-11-7	44	43[i]
Propionaldehyde	123-38-6	58	49
Propylene oxide (1,2-epoxypropane)	75-56-9	82	70
1-Propyne	74-99-7	82	70
Spiropentane	157-40-4	71	60
Tetrahydropyran	142-68-7	48	41
Tetralin (tetrahydronaphthalene)	119-64-2	39	33[a]
Toluene (methylbenzene)	108-88-3	41	35[a]

For U.S. customary units, 2.54 cm/s = 1 in./s.
[a] Extrapolated from experiments performed at higher temperatures.
[b] Veloo, P.S., Y.L. Wang, F.N. Egolfopoulos, and C.K. Westbrook, "A Comparative Experimental and Computational Study of Methanol, Ethanol, and n-Butanol Flames," Combustion and Flame, Vol. 157, pp. 1989-2004 (2010).
[c] Wang, Y.L., A.T. Holley, Chungsheng Ji, F.N. Egolfopoulos, T.T. Tsotsis, and H.J. Curran, "Propagation and extinction of premixed dimethyl-ether/air flames," Proceedings of the Combustion Institute 32, No. 1, pp. 1035-1042 (2009).
[d] Park, Okjoo, P.S. Veloo, and F. N. Egolfopoulos, "Flame studies of C2 hydrocarbons," Proceedings of the Combustion Institute 34, No. 1, pp. 711-718 (2013).
[e] Ji, Chunsheng, E. Dames, Y.L. Wang, Hai Wang, and F.N. Egolfopoulos, "Propagation and extinction of premixed C5–C12 n-alkane flames," Combustion and Flame, 157, No. 2, pp. 277-287 (2010).
[f] Takizawa, Kenji, Akifumi Takahashi, Kazuaki Tokuhashi, Shigeo Kondo, and Akira Sekiya, "Burning velocity measurement of fluorinated compounds by the spherical-vessel method," Combustion and Flame, 141, No. 3, pp. 298-307 (2005).
[g] Kwon, O. C., and G.M. Faeth, "Flame/stretch interactions of premixed hydrogen-fueled flames: measurements and predictions," Combustion and Flame, 124, No. 4, pp. 590-610 (2001).
[h] Park, Okjoo, P.S. Veloo, Ning Liu, and F.N. Egolfopoulos, "Combustion characteristics of alternative gaseous fuel," Proceedings of the Combustion Institute 33, No. 1, pp. 887-894 (2011).
[i] Unpublished data from Prof. Egolfopoulos.

Table D.2 Flammability Properties of Gases 5 L (0.005 m^3) Sphere; E = 10 J, normal conditions [101]

Flammable Material	P_{max} (bar-g)
Acetophenone[a]	7.6
Acetylene	10.6
Ammonia[b]	5.4
β-Naphthol[c]	4.4
Butane	8.0
Carbon disulfide	6.4
Diethyl ether	8.1
Dimethyl formamide[a]	8.4
Dimethyl sulfoxide[a]	7.3
Ethane[a]	7.8
Ethyl alcohol	7.0
Ethyl benzene[a]	7.4
Hydrogen	6.8
Hydrogen sulfide	7.4
Isopropanol[a]	7.8
Methane	7.1
Methanol[a]	7.5
Methylene chloride	5.0
Methyl nitrite	11.4
Neopentane	7.8
Octanol[a]	6.7
Octyl chloride[a]	8.0
Pentane[a]	7.8
Propane	7.9
South African crude oil	6.8–7.6
Toluene[a]	7.8

[a]Measured at elevated temperatures and extrapolated to 25°C (77°F) at normal conditions.
[b]E = 100 J–200 J.
[c]200°C (392°F).

Annex E Estimating Fundamental Burning Velocity

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

Δ **E.1 Estimating Method.** Fundamental burning velocity, S_u, is taken as the largest value of laminar burning velocity, S, obtained by any mixture of a flammable gas in air. S_u is determined experimentally and is a characteristic of any particular fuel whether as a single component or as a mixture of flammable components.

The value of S_u can be estimated using the method given here if an experimental value of S_u is not available.

Britton proposed the following correlation for estimating S_u values of fuels burning exclusively to carbon dioxide plus water [122]:

Δ **[E.1a]**

$$S_u = 1482.8 - 30.281(-\Delta H_c / \chi_{OF}) + 0.1586(-\Delta H_c / \chi_{OF})^2$$

where:
S_u = fundamental burning velocity (cm/s)
ΔH_c = heat of combustion of the fuel (kcal/mole)
χ_{OF} = ratio of oxygen to fuel in stoichiometric mixture

The quantity $(-\Delta H_c/\chi_{OF})$ is known as the "heat of oxidation." For the fuels identified in Figure E.1, the correlation coefficient for Equation E.1(a) is 97 percent.

For fuel species consisting of carbon, hydrogen, oxygen, nitrogen, or halogens ($C_cH_hO_mN_nX_x$) with stoichiometric coefficients c, h, m, n, x, the stoichiometric ratio of oxygen to fuel is calculated as follows:

[E.1b]

$$\chi_{OF} = c + (h\text{-}x\text{-}2m)/4$$

χ_{OF} can be used to calculate the stoichiometric ratio of the fuel in air as follows:

[E.1c]

$$C_{st} = 100/(1 + 4.773\chi_{OF})$$

Example:

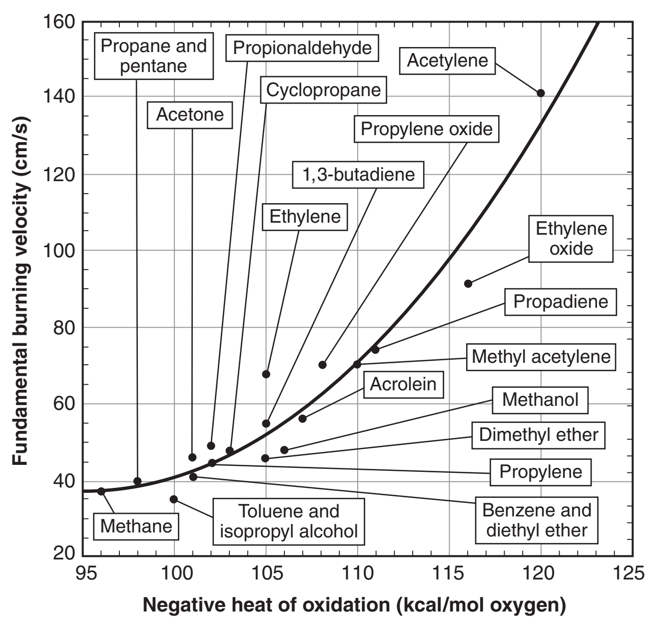
Methane (CH_4)

ΔH_c = −192 kcal/mole fuel

χ_{OF} = c + (h-x-2m) / 4 = 1 + (4-0-0) / 4 = 2

$-\Delta H_c/\chi_{OF}$ = (192 kcal/mole fuel) / (2 moles oxygen per mole of fuel) = 96 kcal/mole oxygen

Figure E.1, from Britton [122], compares the predictions made with the expression given in Equation E.1(a) with laminar burning velocity (LBV) data. The LBV data were all taken from NACA 1300 (referenced to burning velocity of 39 cm/s for propane) apart from methane, where a value of 37 cm/s was considered more reliable, as discussed in Britton [122].



Δ **FIGURE E.1 Comparison of Predicted and Measured Burning Velocities.**

E.2 Using Estimated or New S_u Data. Whether values for unlisted materials are estimated or determined by test, they must be adjusted using the burning velocity of a reference fuel (37 cm/s for methane or 39 cm/s for propane). Equation E.2 shows how the correction should be made in the case of propane reference fuel. The test for the reference gas and the test for the new material should be performed using the same method and conditions.

Δ **[E.2]**

$$LBV_{68,new} = LBV_{test,new} \frac{39 \text{ cm/s}}{LBV_{test,propane}}$$

Annex F Deflagration Characteristics of Select Combustible Dusts

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

F.1 Introduction. Table F.1(a) through Table F.1(e) are based on information obtained from Forschungsbericht Staubexplosionen [86].

For each dust, the tables show the mass median diameter of the material tested as well as the following test results obtained in a 1 m^3 (35 ft^3) vessel:

(1) Minimum explosive concentration
(2) Maximum pressure developed by the explosion, P_{max}
(3) Maximum rate of pressure rise $(dP/dt)_{max}$
(4) K_{St} value, which is equivalent to $(dP/dt)_{max}$ because of the size of the test vessel
(5) Dust hazard class as St-1, St-2, or St-3, as defined in Table B.1.2.4

F.2 Explanation of Test Data. The user is cautioned that test data on the flammability characteristics of dusts are sample specific. Dusts that have the same chemical identities — for example, as a chemical — or that are nominally derived from the same sources, such as grain dusts, can vary widely in K_{St} values. For example, various calcium stearate dusts have been found to have ranges of K_{St} values that designate the respective dusts as in St-1 through St-3. Therefore, care should be taken in the use of data from these tables.

Table F.1(a) Agricultural Products

Material	Mass Median Diameter (μm)	Minimum Flammable Concentration (g/m^3)	P_{max} (bar-g)	K_{St} (bar-m/s)	Dust Hazard Class
Cellulose	33	60	9.7	229	2
Cellulose pulp	42	30	9.9	62	1
Cork	42	30	9.6	202	2
Corn	28	60	9.4	75	1
Egg white	17	125	8.3	38	1
Milk, powdered	83	60	5.8	28	1
Milk, nonfat, dry	60	—	8.8	125	1
Soy flour	20	200	9.2	110	1
Starch, corn	7	—	10.3	202	2
Starch, rice	18	60	9.2	101	1
Starch, wheat	22	30	9.9	115	1
Sugar	30	200	8.5	138	1
Sugar, milk	27	60	8.3	82	1
Sugar, beet	29	60	8.2	59	1
Tapioca	22	125	9.4	62	1
Whey	41	125	9.8	140	1
Wood flour	29	—	10.5	205	2