# NFPA 68

# Standard on Explosion Protection by Deflagration Venting

## 2007 Edition

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**NFPA 68**

**Standard on**

# Explosion Protection by Deflagration Venting

**2007 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 December 1, 2006, with an effective date of December 20, 2006, and supersedes all previous editions.

This edition of NFPA 68 was approved as an American National Standard on December 20, 2006.

## Origin and Development of NFPA 68

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

Since 1954, extensive experimentation has been done in Great Britain and Germany and has 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 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 effectively communicate the principles of venting deflagrations to users. 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. These changes were made 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 providing 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 underwent *Manual of Style* revision as well.

The 2007 edition represents a complete revision, including a change from guide to standard. The new “Standard on Explosion Protection by Deflagration Venting” now provides mandatory requirements for the design, location, installation, maintenance, and use of devices and systems that vent combustion gases and pressures from deflagrations. The Committee incorporated a new chapter on performance-based design that enables 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. This 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.

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**Samuel A. Rodgers,** *Chair*
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Professional Loss Control Incorporated, Canada [SE]

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**Erdem A. Ural,** Loss Prevention Science & Technologies, Incorporated, MA [SE]
**Bert von Rosen,** Natural Resources Canada, Canada [E]
**Robert G. Zalosh,** Worcester Polytechnic Institute, MA [SE]

### Alternates

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**Gary A. Chubb,** Chubb Engineering, LLC, KS [M]
(Alt. to Columbian TecTank)
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(Alt. to S. M. Stuart)
**Ettore Contestabile,** Natural Resources Canada, Canada [E]
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**Randal R. Davis,** Kidde-Fenwal, Incorporated, MA [M]
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(Alt. to R. W. Nelson)
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# Explosion Protection by Deflagration Venting

**2007 Edition**

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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. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex L. Editorial changes to extracted material consist of revising references to an appropriate division in this document or the inclusion of the document number with the division number when the reference is to the original document. 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 I, K, and L.

## 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 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.

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

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

**1.5 Retroactivity.**

**1.5.1** 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.

**1.5.1.1** 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.

**1.5.1.2** 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.

**1.5.1.3** 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.

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

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

**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 | $1.00 \times 10^{-6}$ 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 $ft^3$ |

**Table 1.6** ***Continued***

| Parameter | Unit | Equivalent |
|---|---|---|
| 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-sec |
| | 1 Btu | 1055 J |
| | 1 J | 0.738 ft-lb |
| $K_G$ and $K_{St}$ conversion | 1 bar-m/sec | 47.6 psi-ft/sec |
| | 1 psi-ft/sec | 0.021 bar-m/sec |
| Concentration | 1 oz avoirdupois/$ft^3$ | 1000 $g/m^3$ |

Key to abbreviations in Table 1.6:

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
sec = 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/sec or psi/sec)
$F_r$ = reaction force constant (lb)
$K_G$ = deflagration index for gases (bar-m/sec)
$K_{St}$ = deflagration index for dusts (bar-m/sec)
$L_n$ = 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 or psi)
$P_{es}$ = enclosure strength (bar or psi)
$P_{ex}$ = explosion pressure (bar or psi)
$P_{max}$ = maximum pressure developed in an unvented vessel (bar or psi)
$P_0$ = initial pressure (bar or psi)
$P_{red}$ = reduced pressure [i.e., maximum pressure actually developed during a vented deflagration (bar or psi)]
$P_{stat}$ = static activation pressure (bar or psi)
$dP$ = pressure differential (bar or psi)
$S_u$ = fundamental burning velocity (cm/sec)
$S_f$ = flame speed (cm/sec)
$t_f$ = duration of pressure pulse (sec)
*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,* 2002 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2006 edition.

**2.3 Other Publications.**

**2.3.1 API Publications.** American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070.

API 650, *Welded Steel Tanks for Oil Storage*, 1998.

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

ASME *Boiler and Pressure Vessel Code*, 1998.

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

ASTM E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts,* 2005.

**2.3.4 ISO Publications.** International Organization for Standardization, 1, rue de Varembè, Case postale 56, CH-1211 Geneve 20, 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.

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

NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres,* 2004 edition.

NFPA 484, *Standard for Combustible Metals,* 2006 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2006 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.** A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

**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.

**3.3.2 Combustible Dust.** A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentration, regardless of particle size or shape. [**654**, 2006]

**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 variable, *K. (See 3.3.19,* $K_G$*, and 3.3.20,* $K_{St}$*.)*

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

**3.3.7 Dust.** Any finely divided solid, 420 μm or 0.017 in. or less in diameter (that is, material capable of passing through a U.S. No. 40 Standard Sieve).

**3.3.8* Enclosure.** A confined or partially confined volume.

**3.3.9 Equivalent Diameter.** See 3.3.18, Hydraulic Diameter.

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

**3.3.16 Fundamental Burning Velocity.** See 3.3.1.1.

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

**3.3.18* 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.

**3.3.19*** $K_G$**.** The deflagration index of a gas cloud.

**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.*** A mixture of a flammable gas at greater than 10 percent of its lower flammable limit with either a combustible dust or a combustible mist.

**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**, 2004]

**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. [**484**, 2006]

**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 3.3.17, Gas.

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

**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.

**4.2.2 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:

$$K = \left(\frac{dP}{dt}\right)_{max} \cdot V^{1/3} \qquad \textbf{(6.1.1)}$$

**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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*.

**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.

**6.1.3*** The most accurate value of $K_G$ shall be determined directly by test, as outlined in Annex C.

**6.1.3.1** If testing cannot be done to determine $K_G$ for a particular gas, $K_G$ shall be permitted to be approximated by ratioing from the $K_G$ of propane (100 bar-m/sec) on the basis of the corresponding fundamental burning velocity *(see Annex D)* of propane (46 cm/sec) and the fundamental burning velocity of the gas in question. *(See Table E.1 for $K_G$ values.)*

**6.1.3.2** 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 (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 $K_G$ or 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 $K_G$ or 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 and $K_{St}$ = 500 bar-m/sec.

**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.

$$P_{red} \le \left(\tfrac{2}{3}\right) \cdot F_u \cdot P_{mawp} \qquad \textbf{(6.3.1.3.2a)}$$

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

$$P_{red} \le \left(\tfrac{2}{3}\right) \cdot F_y \cdot P_{mawp} \qquad \textbf{(6.3.1.3.2b)}$$

where:

$P_{red}$ = maximum pressure developed in a vented enclosure [bar (psi)]
$F_u$ = 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 (psi)] 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*):

$$P_{red} \le \frac{P_{es}}{DLF} \qquad \textbf{(6.3.2)}$$

where:

$P_{red}$ = maximum pressure developed during venting [bar (psi)]
$P_{es}$ = enclosure strength evaluated based on static pressure calculations for either deformation or burst [bar (psi)]
$DLF$ = $X_m/X_s$
$X_m$ = 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 equivalently provide venting sufficient to prevent $P_{red}$ from exceeding two-thirds of $P_{es}$, evaluated based on static pressure calculations.

**6.3.2.3** 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*** Care shall be taken to ensure that the weakest structural element, as well as any equipment or other devices that can be supported by structural elements, is 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:

$$F_r = a \cdot DLF \cdot A_v \cdot P_{red} \qquad \textbf{(6.3.5.2)}$$

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 (psi)]

**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.
(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 [114].

$$t_f = b \cdot \left(\frac{P_{max}}{P_{red}}\right)^{0.5} \cdot \left(\frac{V}{A_v}\right) \qquad \textbf{(6.3.5.5)}$$

where:

$t_f$ = duration of pressure pulse after vent opening (sec)
$b$ = $4.3 \cdot 10^{-3}(1.3 \cdot 10^{-3})$
$P_{max}$ = maximum pressure developed in an unvented explosion [bar (psi)]
$P_{red}$ = maximum pressure developed during venting [bar (psi)]
$V$ = 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:

$$I = 0.52 \cdot F_r \cdot t_f \qquad \textbf{(6.3.5.6)}$$

where:

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

**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** Internal volume of dust collector bags, filters, or cartridges shall be permitted to be eliminated when determining the effective volume of an elongated enclosure, when the vent is positioned as required by 8.7.1(1) or 8.7.1(2).

**6.4.3.3.2** Partial volume *(see Section 8.3)* shall not be considered in the determination of effective volume per this section.

**6.4.3.3.3** 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.

**6.4.3.3.4** 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.

**6.4.3.3.5** 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.

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

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:

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

**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:

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

**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, 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*** 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.

**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 7.6.4 and Section 8.8 for gases and dusts, respectively.)*

**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 7.6.4 and Section 8.8)*.

**6.6.2.2** Deflagration vents shall be permitted to be located closer to buildings and normally occupied areas than the distances determined by 7.6.4 or Section 8.8, 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 7.6.4 or 8.8.2. This method shall not be used to reduce the radial hazard distance as defined in 7.6.4.2 and 8.8.2.2 [116].

**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 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 1.5*D*, where *D* is the equivalent diameter of the vent.
(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.

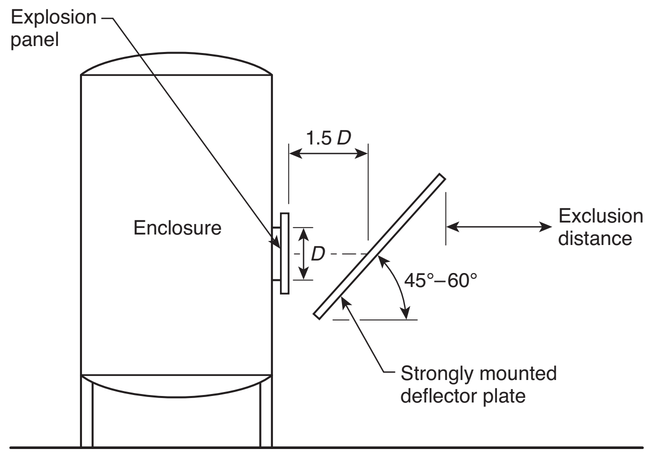



**FIGURE 6.6.2.4 Design for an Installation of a Blast Deflector Plate.**

**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.

**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 7.2.2.5.2 and Equation 8.2.7.2 (for gas and dust, respectively), all vent area correlations presented in this standard shall be permitted to be used without correction [112].

**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.

**6.8 Effects of Vent Discharge Ducts.**

**6.8.1** 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.

**6.8.2** A vent duct shall have a cross section at least as great as that of the vent itself.

**6.8.3*** Vent area calculations shall include the effects of vent ducts. *(See Sections 7.4 and 8.5 for gases and dusts, respectively.)*

**6.8.4** Vent ducts and nozzles with total lengths of less than one hydraulic diameter shall not require a correction to increase the vent area.

**6.8.5** 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 $P_{red}$.

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

**6.9 Venting with Flame Arresting and Particulate Retention.**

**6.9.1*** Where external venting is not feasible, 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. *(See Section 10.6.)*

**6.9.2** Particulate retention devices shall be listed and shall be considered only for use within the tested range of $K_{St}$, dust loading, dust type, enclosure volume, and $P_{red}$.

**6.9.3*** The vent area calculated in Chapters 7 and 8 shall be adjusted using experimentally determined efficiency values. *(See 10.6.2.)*

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

## 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 with an *L/D* of ≤5 and that contain a gas or mist.

**7.1.1.1** This chapter shall be used with the requirements contained in the rest of this standard.

**7.1.1.2** In particular, Chapters 6, 9, and 10 shall be reviewed before applying the information in this chapter.

**7.1.2** The vent area shall be distributed symmetrically and evenly on the enclosure external surfaces.

**7.1.3*** The design of deflagration venting for combustible mists shall be based on the $K_G$ for propane of 100 bar-m/sec or the equivalent $S_u$ for propane of 46 cm/sec unless specific test data are available.

**7.2 Venting of Gas or Mist Deflagration in Low-Strength Enclosures.**

**7.2.1** This section shall apply to the design of deflagration vents for low-strength enclosures that are capable of withstanding reduced pressures, $P_{red}$, of not more than 0.1 bar (1.5 psi).

**7.2.2*** The minimum required vent area for low-strength enclosures shall be determined by the following equation:

$$A_v = \frac{C \cdot (A_S)}{P_{red}^{1/2}} \qquad \textbf{(7.2.2)}$$

where:
$A_v$ = vent area [m$^2$ (ft$^2$)]
$C$ = venting parameter
$A_S$ = internal surface area of enclosure [m$^2$ (ft$^2$)]
$P_{red}$ = maximum pressure developed in a vented enclosure during a vented deflagration [bar (psi)]

**7.2.2.1** The venting parameter, *C*, shall be defined by the following equations for fundamental burning velocity, $S_u$, less than 60 cm/sec.

For $C$(bar$^{1/2}$):

$$C = 1.57 \cdot 10^{-5} \cdot (S_u)^2 + 1.57 \cdot 10^{-4} \cdot (S_u) + 0.0109 \qquad \textbf{(7.2.2.1a)}$$

For $C$(psi$^{1/2}$):

$$C = 6.1 \cdot 10^{-5} \cdot (S_u)^2 + 6.1 \cdot 10^{-4} \cdot (S_u) + 0.0416 \qquad \textbf{(7.2.2.1b)}$$

**7.2.2.2*** Figure 7.2.2.2 shall be used to determine values of venting parameters, *C*. A relationship between the venting parameter, *C*, and burning velocity of the fuel, as shown in Figure 7.2.2.2, shall be considered valid for applications with flammable vapor and mists with burning velocities up to and including 60 cm/sec.

**7.2.2.3** The design of deflagration venting for mists shall be based on the venting parameter for propane.

**7.2.2.4** In this application, $P_{red}$ shall not exceed $P_{es}$ (in bar or psi, not to exceed 0.1 bar or 1.5 psi).

**7.2.2.5 Effects of Panel Inertia.**

**7.2.2.5.1** When the mass of the vent panel is less than or equal to 40 kg/m$^2$ and $K_G$ is less than or equal to 130 bar-m/sec, Equation 7.2.2.5.2 shall be used to determine whether an incremental increase in vent area is needed and the requirements of 7.2.2.6 shall be used to determine the value of that increase.

**7.2.2.5.2*** The vent area determined by Equation 7.2.2 shall be adjusted for vent mass when the vent mass exceeds $M_T$ as calculated in Equation 7.2.2.5.2:

$$M_T = \left[6.67 \cdot (P_{red}^{0.2}) \cdot (n^{0.3}) \cdot \left(\frac{V}{K_G^{0.5}}\right)\right]^{1.67} \qquad \textbf{(7.2.2.5.2)}$$

where:
$M_T$ = threshold mass (kg/m$^2$)
$P_{red}$ = bar
$n$ = number of panels
$V$ > 1 m$^3$
$K_G$ ≤ 130

**7.2.2.6** If $M > M_T$, the vent area shall be increased by adding the calculated area, $\Delta A_i$, from Equation 7.2.2.6:

$$\Delta A_i = A_v \cdot (0.0075) \cdot M^{0.6} \cdot \frac{K_G^{0.5}}{n^{0.3}} \cdot V \cdot P_{red}^{0.2} \qquad \textbf{(7.2.2.6)}$$

where:
$A_v$ = vent area calculated by Equation 7.2.2
$M$ = mass of vent panel (kg/m$^2$)

**7.2.2.7** If $K_G$ is less than 75 bar-m/sec, $K_G$ = 75 shall be used in Equation 7.2.2.6.

**7.2.3* Elongated Enclosures.** For elongated enclosures, the vent area shall be applied as evenly as possible with respect to the longest dimension.

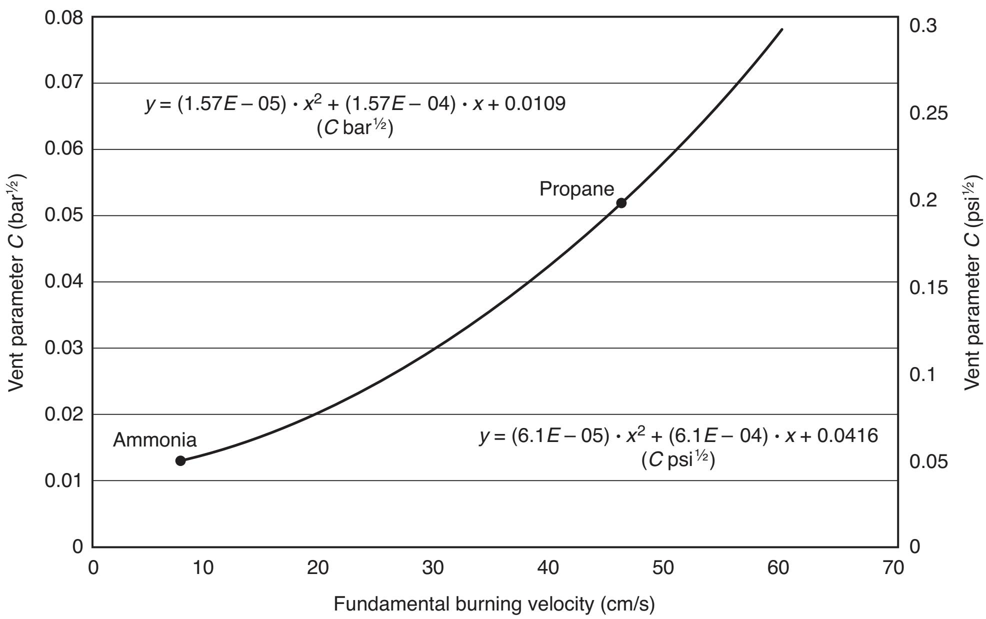



**FIGURE 7.2.2.2 Venting Parameter as a Function of Fundamental Burning Velocity.**

**7.2.3.1** If the available vent area is restricted to one end of an elongated enclosure, the ratio of length to diameter shall not exceed 3.

**7.2.3.2** For cross sections other than those that are circular or square, the effective diameter shall be permitted to be taken as the hydraulic diameter, 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.

**7.2.3.3** Therefore, for enclosures with venting restricted to one end, the venting equation constraints shall apply as follows:

$$L_3 < 12 \cdot \left(\frac{A}{p}\right) \quad \textbf{(7.2.3.3)}$$

where:

$L_3$ = longest dimension of the enclosure [m (ft)] measured to the center of the vent

$A$ = cross-sectional area [$m^2$ ($ft^2$)] normal to the longest dimension

$p$ = perimeter of cross section [m (ft)]

**7.2.3.4** If an enclosure can contain a highly turbulent gas mixture and the vent area is restricted to one end, or if the enclosure has many internal obstructions and the vent area is restricted to one end, the $L/D$ of the enclosure shall not exceed 2, or the following equation shall be used:

$$L_3 < 8 \cdot \left(\frac{A}{p}\right) \quad \textbf{(7.2.3.4)}$$

**7.2.3.5** Where the dimensional constraints on the enclosure are not met, the alternative methods described in Chapters 7 through 9 shall be considered for solutions.

**7.2.3.6** An alternative value of $C$ shall be permitted to be used where large-scale tests are conducted for a specific application.

**7.2.4* Calculation of Internal Surface Area.**

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

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

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

**7.2.4.1.3** Surface corrugations shall be neglected, as well as minor deviations from the simplest shapes.

**7.2.4.1.4** 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.

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

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

**7.2.5* Methods to Reduce Vent Areas.**

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

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

**7.2.6 Vent Design.** *(See also Sections 6.5 through 6.7.)*

**7.2.6.1*** For low-strength enclosures, $P_{red}$ shall exceed $P_{stat}$ by at least 0.024 bar (0.35 psi).

**7.2.6.2** If an enclosure is subdivided into compartments by walls, partitions, floors, or ceilings, each compartment that contains a deflagration hazard shall be provided with its own vent.

**7.2.6.3*** Each closure shall be designed and installed to move freely without interference by obstructions such as ductwork or piping.

**7.2.6.4*** Guarding shall be provided to prevent personnel from falling against vent closures.

**7.2.6.5** The minimum pressure needed for the weakest structural member shall be obtained by substituting the values for the available area, the internal surface area, and the applicable *C* value for the variables in Equation 7.2.2 and then calculating $P_{red}$, the maximum allowable pressure

**7.2.6.6*** The vent area shall be distributed as evenly as possible over the building's skin.

### 7.3 Venting of Gas or Mist Deflagration in High-Strength Enclosures.

**7.3.1*** This section shall apply to enclosures that are capable of withstanding a $P_{red}$ of more than 0.1 bar (1.5 psi).

**7.3.2* Basic Principles.**

**7.3.2.1** The user shall refer to 3.3.32.1 and Chapter 6 for specific comments relating to enclosure strength.

**7.3.2.2** The vent shall be designed to prevent the deflagration pressure inside the vented enclosure from exceeding two-thirds of the enclosure strength.

**7.3.2.3** Vent closures shall open dependably.

**7.3.2.3.1** The proper operation of vent closures shall not be hindered by deposits of snow, ice, paint, sticky materials, or polymers.

**7.3.2.3.2** Operation of vent closures shall not be prevented by corrosion or by objects that obstruct the opening of the vent closure, such as piping, air-conditioning ducts, or structural steel.

**7.3.2.4** Vent closures shall withstand exposure to the materials and process conditions within the enclosure that is being protected.

**7.3.2.5** Vent closures shall withstand ambient conditions on the nonprocess side.

**7.3.2.6** Vent closures shall reliably withstand fluctuating pressure differentials that are below the design release pressure and shall also withstand any vibration or other mechanical forces to which they can be subjected.

**7.3.3 Vent Area Calculations.**

**7.3.3.1** The length-to-diameter ratio, *L/D*, of the enclosure determines the equation(s) that shall be used for calculating the necessary vent area. *(See Chapter 6.)*

**7.3.3.1.1** For noncircular enclosures, the value that shall be used for diameter is the hydraulic diameter.

**7.3.3.1.2** When the enclosure includes changes in diameter, such as in a cone or hopper, the hydraulic diameter shall be modified accordingly, and becomes the effective hydraulic diameter *(see 6.4.3.6)*.

**7.3.3.2*** For *L/D* values of 2 or less, Equation 7.3.3.2, from [101], shall be used for calculating the necessary vent area, $A_v$, in m$^2$:

$$A_v = \left\{\left[(0.127)\cdot \log_{10}(K_G) - (0.0567)\right]\cdot P_{red}^{-0.582}\right\}\cdot V^{2/3} + \left[(0.175)\cdot P_{red}^{-0.572}(P_{stat}-1)\right]\cdot V^{2/3} \quad \textbf{(7.3.3.2)}$$

where:
$K_G \leq$ 550 bar-m/sec
$P_{red} \leq$ 2 bar and at least 0.05 bar > $P_{stat}$
$P_{stat} \leq$ 0.5 bar
$V \leq$ 1000 m$^3$

Initial pressure before ignition ≤ 0.2 bar

**7.3.3.3*** ***L/D*** **Values from 2 to 5.**

**7.3.3.3.1** For *L/D* values from 2 to 5, and for $P_{red}$ no higher than 2 bar, the required vent area, $A_v$, calculated from Equation 7.3.3.2, shall be increased by adding more vent area, $\Delta A$, calculated from Equation 7.3.3.3.1 as follows:

$$\Delta A = \frac{A_v \cdot K_G \cdot \left(\frac{L}{D} - 2\right)^2}{750} \quad \textbf{(7.3.3.3.1)}$$

**7.3.3.3.2** Equation 7.3.3.3.1 shall be subject to the limitations stated in 7.3.3.2.

**7.3.3.3.3** For long pipes or process ducts where *L/D* is greater than 5, the guidelines in Chapter 9 shall be used.

**7.3.3.4** In addition to calculating the vent area using Equations 7.3.3.2 and 7.3.3.3.1, the vent area shall be permitted to be determined by the use of the graphs in Section H.1 for gases.

**7.3.3.5** The restrictions given for Equation 7.3.3.2 shall also apply to the graphs in Section H.1. *(See Section H.1 for an example.)*

**7.3.3.6 Effects of Panel Inertia.**

**7.3.3.6.1** When the mass of the vent panel is less than or equal to 40 kg/m$^2$ and $K_G$ is less than or equal to 130 bar-m/sec, Equation 7.3.3.6.2 shall be used to determine whether an incremental increase in vent area is needed, and the requirements of 7.3.3.7 shall be used to determine the value of that increase.

**7.3.3.6.2*** The vent area determined by Equation 7.3.3.2 shall be adjusted for vent mass when the vent mass exceeds $M_T$ as calculated in Equation 7.3.3.6.2.

$$M_T = \left[6.67 \cdot \left(P_{red}^{0.2}\right)\cdot\left(n^{0.3}\right)\cdot\left(\frac{V}{K_G^{0.5}}\right)\right]^{1.67} \quad \textbf{(7.3.3.6.2)}$$

where:
$M_T$ = threshold mass (kg/m$^2$)
$P_{red}$ = bar
$n$ = number of panels
$V$ > 1 m$^3$
$K_G \leq$ 130

**7.3.3.7** If $M > M_T$, the vent area shall be increased by adding the calculated area, $\Delta A_i$, from Equation 7.3.3.7:

$$\Delta A_i = A_v \cdot (0.0075)\cdot M^{0.6}\cdot\left(\frac{K_G^{0.5}}{n^{0.3}}\right)\cdot V \cdot P_{red}^{0.2} \quad \textbf{(7.3.3.7)}$$

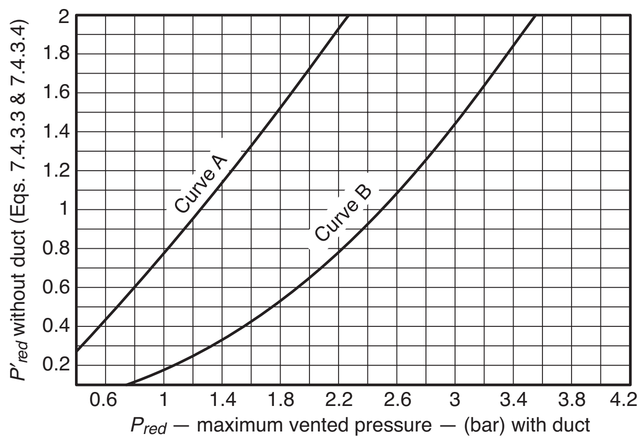
where:
$M$ = mass of vent panel (kg/m$^2$)
$A_v$ = vent area calculated by Equation 7.3.3.2

**7.3.3.7.1** If $K_G$ is less than 75 bar-m/sec, $K_G$ = 75 shall be used in the equation.

**7.4* Effects of Vent Ducts.**

**7.4.1*** Where using Equations 7.3.3.2 and 7.3.3.3.1 with vent ducting, a lower value shall be used in place of $P_{red}$.

**7.4.2** Duct lengths shorter than 3 m (10 ft) and 4 duct hydraulic diameters in length shall be treated using Curve A in Figure 7.4.2. For ducts exceeding either of these limitations, Curve B shall be used.




Notes:
1. Curve A to be used for duct length < 3 m (10 ft) and < 4 duct hydraulic diameters.
2. Curve B to be used for duct length of 3 m to 6 m (10 ft to 20 ft) or ≥4 duct hydraulic diameters. Curve B is not valid for duct lengths > 6 m (20 ft).
3. Note 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.

**FIGURE 7.4.2 Maximum Pressure Developed During Venting of Gas, With and Without Vent Ducts.**

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

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

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

**7.4.3.3** For vent ducts with lengths < 3 m (10 ft) and < 4 duct hydraulic diameters, the following equation, representing Curve A in Figure 7.4.2, shall be used to determine $P'_{red}$:

$$P'_{red} = 0.779 \cdot (P_{red})^{1.161} \qquad \textbf{(7.4.3.3)}$$

where $P'_{red}$ = a pseudo-value for $P_{red}$ for use in Equation 7.3.3.2 for calculating vent areas for gases when a vent duct is used [bar (psi)].

**7.4.3.4** For vent ducts with lengths of 3 m to 6 m (10 ft to 20 ft) or ≥ 4 duct hydraulic diameters, the following equation, representing Curve B in Figure 7.4.2, shall be used:

$$P'_{red} = 0.172 \cdot (P_{red})^{1.936} \qquad \textbf{(7.4.3.4)}$$

**7.4.4** The vented material discharged from an enclosure during a deflagration shall be directed to a safe outside location to avoid injury to personnel and to minimize property damage. *(See Section 6.8.)*

**7.4.5*** If it is necessary to locate enclosures that need deflagration venting inside buildings, vents shall not discharge within the building.

**7.4.5.1*** Vent ducts shall be used to direct vented material from the enclosure to the outdoors.

**7.4.6*** A vent duct shall have a cross section at least as great as that of the vent itself.

**7.4.7*** Vent ducts shall be as straight as possible.

**7.4.7.1** If bends are unavoidable, they shall be as shallow-angled as practical (that is, they shall have as long a radius as practical).

**7.4.8** Where vent ducts vent through the roof of an enclosure, consideration shall be given to climatic conditions. *(See Section 6.5.)*

**7.5* Effects of Initial Turbulence and Internal Appurtenances for Enclosures with Initial Pressures Near Atmospheric.** Hydrogen $K_G$ (550 bar-m/sec) shall be used for venting initially turbulent gases that have values, in the quiescent state, that are close to or less than that of propane.

**7.6 Effects of Initial Elevated Pressure.**

**7.6.1** The maximum pressure developed during venting from the initially elevated pressure shall be calculated using the following equation:

$$P_{red,2} = (P_{red,1}) \cdot \left(\frac{P_2}{P_1}\right)^{\gamma} \qquad \textbf{(7.6.1)}$$

where:

$P_{red,\,2}$ = actual maximum pressure (bar abs) developed by the deflagration in a vented enclosure when the initial elevated pressure before ignition is $P_2$ (bar abs)

$P_{red,\,1}$ = $P_{red}$ as determined in Equations 7.3.3.2 and 7.3.3.3.1 (converted to bar abs)

$P_2$ = elevated initial pressure before ignition (bar abs)

$P_1$ = atmospheric pressure (1.0 bar abs)

**7.6.2** Figure 7.6.2 shall not be extrapolated beyond $A_v/V^{2/3}$ = 0.35.

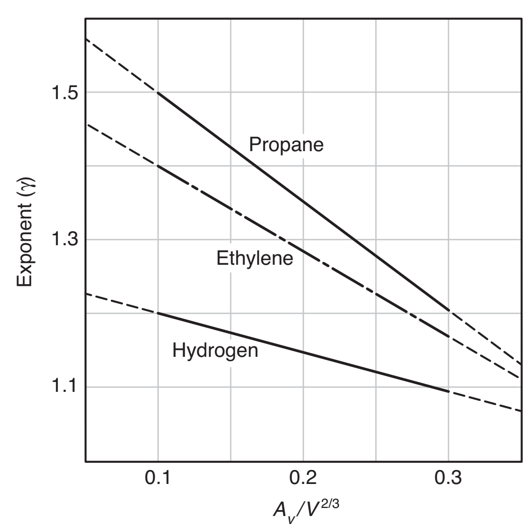



**FIGURE 7.6.2 Value of Exponent, γ, as a Function of $A_v/V^{2/3}$. [59]**

**7.6.3** For calculations that involve elevated pressure, the procedure required in 7.6.3.1 and 7.6.3.2 shall be used.

**7.6.3.1*** The value that is used for $P_2$ shall be chosen to represent the likely maximum pressure at which a flammable gas mixture can exist at the time of ignition. It shall be permitted to be as low as the normal operating pressure.

**7.6.3.2*** The enclosure shall be located to accommodate the blast wave.

**7.6.4* Fireball Dimensions.**

**7.6.4.1*** The hazard zone from a vented gas deflagration shall be calculated by the following equation:

$$D = 3.1 \cdot \left(\frac{V}{n}\right)^{0.402} \qquad \textbf{(7.6.4.1)}$$

where:
$D$ = axial distance (front-centerline) from vent (m)
$V$ = volume of vented enclosure ($m^3$)
$n$ = number of evenly distributed vents

**7.6.4.2** The hazard zone measured radially (to the sides, measured from the centerline of the vent) shall be calculated as one-half $D$.

## 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* less than or equal to 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 applying the information in this chapter.

**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 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, either ASTM E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts,* or ISO 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** The *L/D* of the enclosure shall be determined according to Section 6.4.

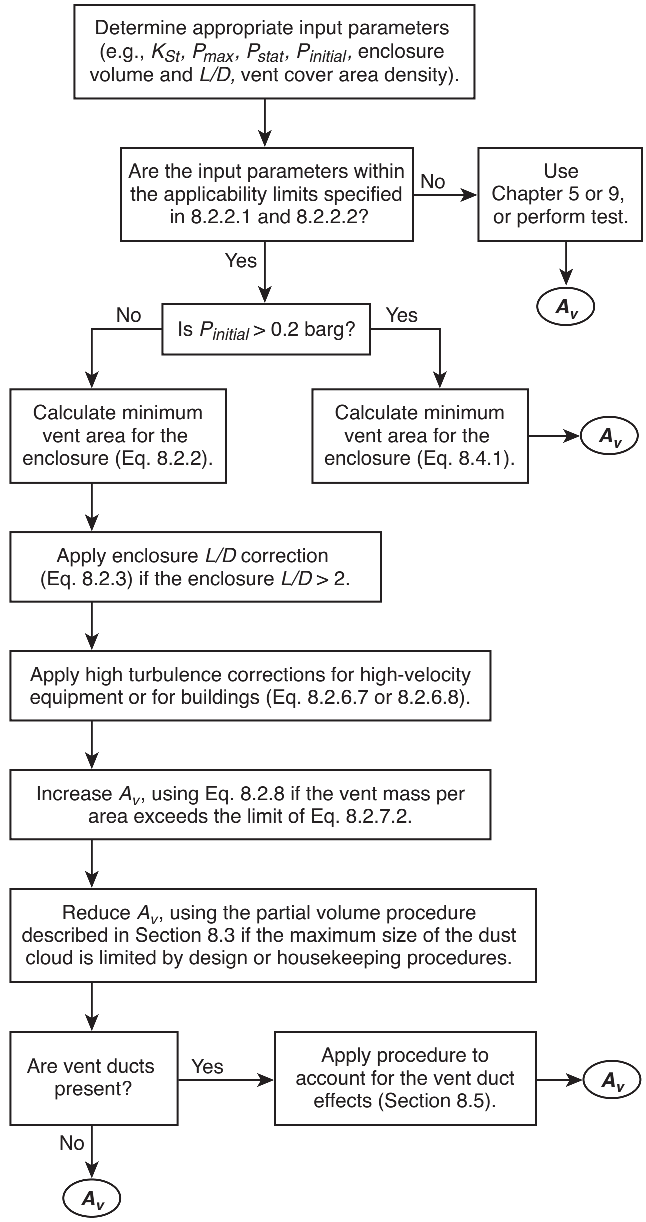



**FIGURE 8.1.1.4 Dust Explosion Vent Sizing Calculation Flowchart for Chapter 8.**

**8.2.2** Equation 8.2.2 shall be used to calculate the minimum necessary vent area, $A_{v0}$, in $m^2$:

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1} \qquad \textbf{(8.2.2)}$$

where:
$A_{v0}$ = vent area calculated from Equation 8.2.2 ($m^2$)
$P_{stat}$ = nominal static burst pressure of the vent (bar)
$K_{St}$ = deflagration index (bar-m/sec)
$V$ = enclosure volume ($m^3$)
$P_{max}$ = maximum pressure of a deflagration (bar)
$P_{red}$ = reduced pressure after deflagration venting (bar) [115]

**8.2.2.1** Equation 8.2.2 shall apply to initial pressures before ignition of 1 bar absolute ± 0.2 bar.

**8.2.2.2** The following limitations shall be applicable to Equation 8.2.2:

(1) 5 bar $\leq P_{max} \leq$ 12 bar
(2) 10 bar-m/sec $\leq K_{St} \leq$ 800 bar-m/sec
(3) 0.1 m$^3$ $\leq V \leq$ 10,000 m$^3$
(4) $P_{stat} \leq$ 0.75 bar

**8.2.2.3** When *L/D* is less than or equal to 2, $A_{v1}$ shall be set equal to $A_{v0}$.

**8.2.3** For *L/D* values greater than 2 and less than or equal to 6, the required vent area, $A_{v1}$, shall be calculated as follows:

$$A_{v1} = A_{v0} \cdot \left[1 + 0.6 \cdot \left(\frac{L}{D} - 2\right)^{0.75} \cdot \exp\left(-0.95 \cdot P_{red}^{\,2}\right)\right] \quad \textbf{(8.2.3)}$$

where $\exp(A) = e^A$, *e* is the base of the natural logarithm. [115]

**8.2.3.1*** It shall be permitted to extend Equation 8.2.3 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.

**8.2.4** For situations where vents can be distributed along the major axis of the enclosure, Equations 8.2.2 and 8.2.3 shall be permitted to be applied where *L* is the spacing between vents along the major axis.

**8.2.5** It shall be permitted to determine $A_{v0}$ and $A_{v1}$ by the use of the graphs in Section H.2 for dusts, which are based on Equations 8.2.2 and 8.2.3. *(See Section H.2 for an example.)*

**8.2.5.1** The restrictions noted for the equations shall also apply to the graphs.

**8.2.6** Three different general equations (8.2.3, 8.2.6.7, and 8.2.6.8) shall be applied to the determination of dust deflagration minimum required vent areas.

**8.2.6.1** Equation 8.2.3, which produces the smallest required vent areas, shall apply to dust handling and storage equipment within which the average air axial velocity, $v_{axial}$, and the tangential velocity, $v_{tan}$, are both less than 20 m/sec during all operating conditions.

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

$$v_{axial} = \frac{Q_{air} \cdot L}{V} \quad \textbf{(8.2.6.2)}$$

where:
$Q_{air}$ = flow rate through the equipment (m$^3$/sec)
$L$ = equipment overall length (m) in the direction of the air and product flow
$V$ = equipment volume (m$^3$)
[119,120]

**8.2.6.3*** If a circumferential (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.

**8.2.6.4** Values of $Q_{air}$, $v_{axial}$, $v_{tan\_max}$, and $v_{tan}$ shall be either measured or calculated by engineers familiar with the equipment design and operation.

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

**8.2.6.6** When the maximum value derived of $v_{axial}$ and $v_{tan}$ are less than 20 m/sec, $A_{v2}$ shall be set equal to $A_{v1}$.

**8.2.6.7*** When either $v_{axial}$ or $v_{tan}$ is larger than 20 m/sec, $A_{v2}$ shall be determined from the following equation:

$$A_{v2} = \left[1 + \frac{max\left(v_{axial}, v_{\tan}\right) - 20}{36} \cdot 0.7\right] \cdot A_{v1} \quad \textbf{(8.2.6.7)}$$

where *max(A, B)* = maximum value of either *A* or *B*. [119, 120]

**8.2.6.8*** Vent areas for buildings in which there is a dust explosion hazard shall be determined from Equation 8.2.6.8: [119,120]

$$A_{v2} = 1.7 \cdot A_{v1} \quad \textbf{(8.2.6.8)}$$

**8.2.6.9** The required vent areas for these buildings shall be permitted to be reduced through use of the partial volume Equation 8.3.1.

**8.2.7* Effects of Panel Inertia.**

**8.2.7.1** When the mass of the vent panel is less than or equal to 40 kg/m$^2$ and $K_{St}$ is less than or equal to 250 bar-m/sec, Equation 8.2.7.2 shall be used to determine whether an incremental increase in vent area is needed and the requirements of 8.2.8 shall be used to determine the value of that increase.

**8.2.7.2** The vent area shall be adjusted for vent mass when the vent mass exceeds $M_T$ as calculated in Equation 8.2.7.2:

$$M_T = \left[6.67 \cdot \left(P_{red}^{0.2}\right) \cdot \left(n^{0.3}\right) \cdot \left(\frac{V}{K_{St}^{0.5}}\right)\right]^{1.67} \quad \textbf{(8.2.7.2)}$$

where:
$M_T$ = threshold mass (kg/m$^2$)
$P_{red}$ = bar
$n$ = number of panels
$V$ = volume (m$^3$)
$K_{St}$ ≤ 250 bar-m/sec

**8.2.8** If $M > M_T$, the vent area shall be increased by adding the calculated area, $A_{v3}$, from Equation 8.2.8:

$$A_{v3} = \left[1 + (0.0075) \cdot M^{0.6} \cdot \left(\frac{K_{St}^{0.5}}{n^{0.3}}\right) \cdot V \cdot P_{red}^{0.2}\right] \cdot A_{v2} \quad \textbf{(8.2.8)}$$

where:
$A_{v2}$ = vent area calculated by Section 8.2.2.6, Equation 8.2.6.7, or Equation 8.2.6.8, as applicable
$M$ = mass of vent panel (kg/m$^2$)

**8.2.8.1** If $K_{St}$ < 75 bar-m/sec, $K_{St}$ = 75 shall be used in Equation 8.2.8.

**8.2.9** When $M \leq M_T$, $A_{v3} = A_{v2}$.

**8.3* Effects of Partial Volume.**

**8.3.1** 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:

$$A_{v4} = A_{v3} \cdot X_r^{-1/3} \cdot \sqrt{\frac{X_r - \Pi}{1 - \Pi}} \qquad \textbf{(8.3.1)}$$

where:

$A_{v4}$ = vent area for partial volume deflagration

$A_{v3}$ = vent area for full volume deflagration as determined from Equation 8.2.8 or Subsection 8.2.9

$X_r$ = fill fraction > $\Pi$

$\Pi$ = $P_{red}/P_{max}$

**8.3.2*** If $X_r \le \Pi$, deflagration venting shall not be required.

**8.3.2.1** When partial volume is not applied, $A_{v4} = A_{v3}$.

**8.3.3* Process Equipment Partial Volumes.** Process equipment involving non-solvent drying shall be permitted to use partial volume venting in accordance with Equation 8.3.1.

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

**8.3.3.2** Furthermore, if the solvent is flammable, hybrid deflagration $K_{St}$ values shall be determined.

**8.3.3.3** 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.

**8.3.3.4** In applications involving spray dryers where a partial volume venting is calculated in accordance with Equation 8.3.1, the vent shall be mounted within the chosen partial volume zone of the dryer that contains the driest fraction of material.

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

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

**8.3.4.1** 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.

**8.3.4.2** 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, $\bar{M}_s$ (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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, 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 8.2.8 and Subsection 8.2.9 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, $X_r$, from the following equation:

$$X_r = \frac{\bar{M}_f}{A_{fs} \cdot c_w \cdot H} + \frac{\bar{M}_s \cdot A_{sur}}{A_{ss} \cdot V \cdot c_w} + \frac{M_e}{V \cdot c_w} \qquad \textbf{(8.3.4.2)}$$

where:

$X_r$ = worst-case building partial fraction

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

$A_{fs}$ = measured floor areas

$c_w$ = worst-case dust concentration

$H$ = ceiling height of the building

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

$A_{sur}$ = total area of surfaces with dust deposits

$A_{ss}$ = measured sample areas of surfaces with dust deposits

$V$ = building volume

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

(a) The lowest value of $c_w$ for the various samples shall be used in the calculation. If a measured value of $c_w$ is not available, a value of 200 $g/m^3$ shall be permitted to be used in this equation.
(b) 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 cleanliness/maintenance practices in accordance with NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, an approximate value for these ratios shall be permitted to be used, based on a dust layer bulk density of 800 $kg/m^3$ and a layer thickness of 0.8 mm = 1⁄32 in. over the entire floor area and other surfaces defined in 8.3.4.2(3). The approximate value corresponding to these values is 640 $g/m^2$.

(9) If the calculated $X_r > 1$, the minimum required vent area is equal to $A_{v3}$ .
(a) If $X_r \le \Pi$, no deflagration venting is needed.
(b) If $1 > X_r > \Pi$, the minimum required vent area, $A_{v4}$ is calculated from Equation 8.3.1 as follows:

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

**8.4 Effects of Initially Elevated Pressure.**

**8.4.1** When enclosure pressure is initially greater than 0.2 bar (20 kPa), deflagration vents shall only be used when the following conditions are met:

(1) Vent duct length $L/D$ is $\le 1$
(2) Panel density is $< M_T$ and $\le 40$ $kg/m^2$
(3) $v_{axial}$ and $v_{tan} < 20$ m/sec
(4) No allowance for partial volume
(5) Equation 8.4.1 shall be used to calculate the necessary vent area:

$$A_{vep} = \frac{A_{v1}}{A_{v0}} \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot \left(\frac{P_{stat} - P_{initial}}{1 + P_{effective}}\right)^{4/3}\right] \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{1}{\Pi_{effective}} - 1} \quad \textbf{(8.4.1)}$$

where:

$A_{vep}$ = vent area ($m^2$)
$P_{stat}$ = static burst pressure of the vent (bar)
$P_{initial}$ = enclosure pressure at the moment of ignition (bar)
$P_{effective}$ = 1/3 $P_{initial}$ (bar)
$K_{St}$ = deflagration index (determined at initially atmospheric pressure) (bar-m/sec)
$V$ = enclosure volume ($m^3$)
$\Pi_{effective}$ = $(P_{red} - P_{effective}) / (P^E_{max} - P_{effective})$
$P_{red}$ = reduced pressure
$P^E_{max}$ = $[(P_{max} + 1) \cdot (P_{initial} + 1)/(1 \text{ bar-abs}) - 1]$ maximum pressure of the unvented deflagration at initially elevated pressure (bar)
$P_{max}$ = maximum pressure of an unvented deflagration initially at atmospheric pressure (bar)

**8.4.2** An enclosure shall be permitted to be protected with initially elevated pressure with deflagration vents when the vents are designed according to full-scale test data.

### 8.5* Effects of Vent Ducts.

**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 equation. This solution is iterative, as $E_1$ and $E_2$ are both functions of $A_{vf}$.

$$A_{vf} = A_{v4} \cdot \left(1 + 1.18 \cdot E_1^{0.8} \cdot E_2^{0.4}\right) \cdot \sqrt{\frac{K}{K_0}} \quad \textbf{(8.5.1a)}$$

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 8.3.1

$$E_1 = \frac{A_{vf} \cdot L_{duct}}{V} \quad \textbf{(8.5.1b)}$$

$$E_2 = \frac{10^4 \cdot A_{vf}}{\left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4}} \quad \textbf{(8.5.1c)}$$

where:

$P_{stat}$ = nominal static opening pressure of the vent cover (bar)
$V$ = enclosure volume ($m^3$)
$L_{duct}$ = vent duct overall length (m)
$K_0$ = 1.5, the resistance coefficient value assumed for the test configurations that generated the data used to validate Equations 8.2.2 and 8.2.3

$$K \equiv \frac{\Delta P}{\frac{1}{2} \cdot \rho \cdot U^2} = K_{inlet} + \frac{f_D \cdot L}{D_h} + K_{elbows} + K_{outlet} + \cdots \quad \textbf{(8.5.1d)}$$

where:

$K$ = overall resistance coefficient of the vent duct application
$K_{inlet}$, $K_{elbows}$, $K_{outlet}$ = resistance coefficients for fittings
$U$ = fluid velocity
$D_h$ = vent duct hydraulic diameter (m)
$f_D$ = D'Arcy friction factor for fully turbulent flow; see A.8.5 for typical formula [115]

**8.5.2** Under certain circumstances, there can be two solutions for vent area. In these cases, 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 or 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 plus or minus 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 permissible to use Equation 8.5.1a for vent ducts equipped with elbows, bird-screens, and rain-covers as long as these 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 when 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:

$$L_{eff} \leq \min\left[\frac{10{,}000 \cdot D}{K_{St}}, \frac{11{,}000}{K_{St}}\right] \quad \textbf{(8.5.9)}$$

where:

$\min(A, B)$ = minimum value of either *A* or *B*
$L_{eff}$ = $\min(L_{duct}, L_{dusty})$
$L_{dusty}$ = $(P_{max} - P_{red}) \cdot V/A_v$

**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 8.8)*.

**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.

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

| Model | Application |
|---|---|
| Vent ducts | $0.8 \leq P_0 \leq 1.2$ bar-abs<br>Panel density $\leq M_T$ and $\leq 40$ kg/m$^2$<br>Allow partial volume<br>$1 \leq L/D \leq 6$<br>(calculate vent duct effect last) |
| Partial volume | Allow vent duct<br>Panel density $\leq 40$ kg/m$^2$<br>$0.8 \leq P_0 \leq 1.2$ bar-abs<br>$1 \leq L/D \leq 6$<br>(calculate vent duct effect last) |
| Elevated initial pressure | No vent duct<br>Panel density $\leq M_T$ and $\leq 40$ kg/m$^2$<br>$0.2 \leq P_0 \leq 4$ bar-g<br>Full volume deflagration<br>$1 \leq L/D \leq 6$<br>(calculate elevated initial pressure effect last) |
| Panel inertia | $0.8 \leq P_0 \leq 1.2$ bar-a<br>No vent duct<br>Panel density $\leq 40$ kg/m$^2$<br>Allow partial volume<br>$1 \leq L/D \leq 6$ |

**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, as large amounts of dust can blow out into the atmosphere, ignite, and form a large fireball.

**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 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 attachments shall not be connected to the roof directly, as they could restrict the roof's operation as a vent closure.

**8.6.3.4** 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** The following three venting alternatives shall be permitted:

(1) Locate all of the venting area below the bottom of the bags, filters, or cartridges, as shown in Figure 8.7.1(a) and Figure 8.7.1(b).
   (a) When the spacing between bags is less than or equal to the radius of the bag, filter, or cartridge, the vent area shall be permitted to be calculated on the basis of the volume below the lower end of the bags.
   (b) When the spacing between bags is greater than the radius of the bag, filter, or cartridge, the vent area shall be permitted to be calculated on the basis of the dirty side only; that is, calculate the volume below the tube sheet, and subtract out the volume occupied by the bags.
(2) Locate the vents as shown in Figure 8.7.1(c) and Figure 8.7.1(d), and bags are either completely removed or shortened so that they do not extend below the top of the vent for a distance of one vent diameter from the vent. In addition, the bags immediately adjacent to the vent shall be removed and the remaining bags shall be restrained from passing through the vent. For this case, the vent area shall be permitted to be calculated on the basis of the dirty side only; that is, calculate the volume below the tube sheet, and subtract out the volume occupied by the bags.
(3) Locate the vents such that the bottom of the vent(s) is at or above the bottom of the bags, as shown in Figure 8.7.1(e), and the row of bags closest to the vent are restrained from passing through the vent. For this case, the volume used to calculate the vent area shall be the entire volume (clean and dirty) below the tube sheet.

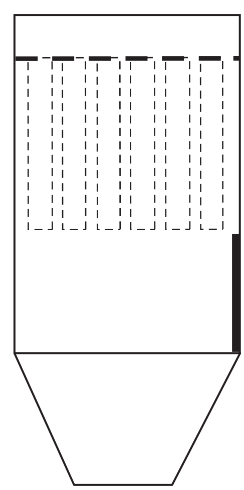


**FIGURE 8.7.1(a) Venting of Dust Collectors — Alternative Arrangement 1.**

**8.7.2** A key assumption made for the three alternatives in 8.7.1 is that the clean air plenum above the tube sheet shall be essentially free of dust accumulations.

**8.7.3** If the clean air plenum contains dust, a separate vent on the clean air side shall be calculated based on the clean air side volume.

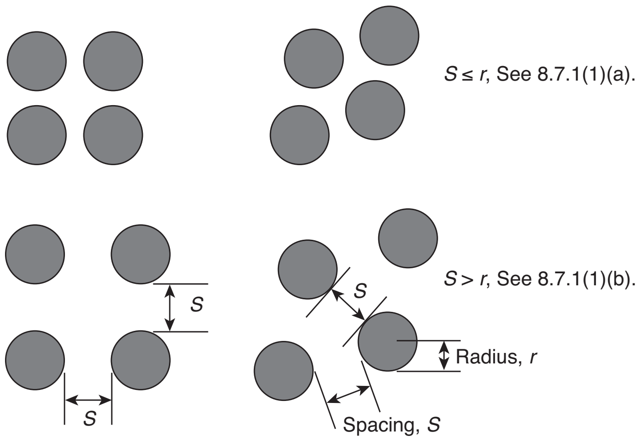



**FIGURE 8.7.1(b) Plan View of Bag Spacing for Figure 8.7.1(a).**

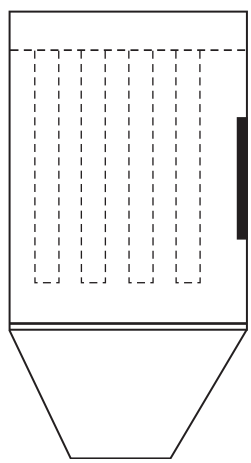


**FIGURE 8.7.1(c) Venting of Dust Collectors — Alternative Arrangement 2.**

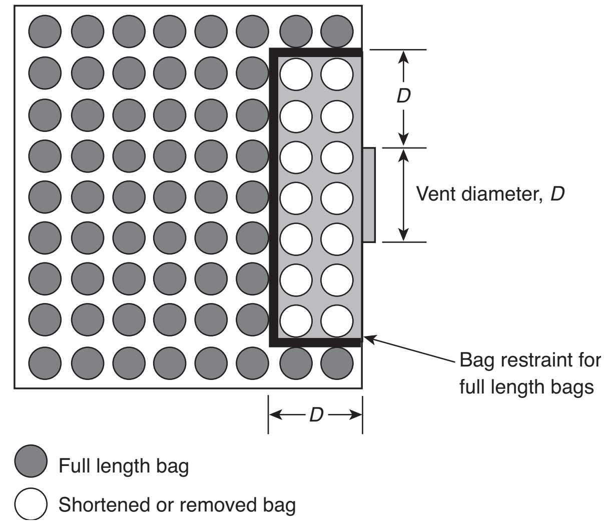



**FIGURE 8.7.1(d) Plan View of Bag Spacing for Figure 8.7.1(c).**

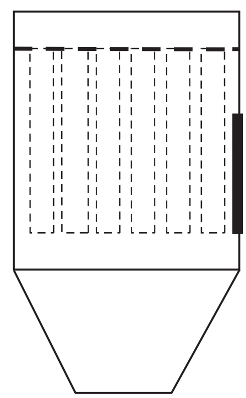


**FIGURE 8.7.1(e) Venting of Dust Collectors — Alternative Arrangement 3.**

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

**8.8.1** A documented risk assessment shall be permitted to be used to reduce the hazard distances calculated in 8.8.2 and 8.8.3.

**8.8.2*** In the case of dust deflagration venting, the distance, $D$, shall be expressed by Equation 8.8.2:

$$D = K \cdot \left(\frac{V}{n}\right)^{1/3} \quad \textbf{(8.8.2)}$$

where:
$D$ = axial distance (front) from the vent (m)
$K$ = flame length factor
$K$ = 10 for metal dusts, $K = 8$ for chemical and agricultural dusts
$V$ = volume of vented enclosure ($m^3$)
$n$ = number of evenly distributed vents

**8.8.2.1** Axial distance, calculated by Equation 8.8.2, shall be limited to 60 m. [104]

**8.8.2.2** The width of the projected flame measured from the centerline of the vent shall be calculated as one-half $D$.

**8.8.2.3** The height of the fireball shall be defined to be the same dimension $D$, with half the height located below the center of the vent and half the height located above.

**8.8.3*** Where venting is from a cubic vessel, $P_{max,a}$ value shall be indicated approximately by Equation 8.8.3 [108]:

$$P_{max,a} = 0.2 \cdot P_{red} \cdot A_v^{0.1} \cdot V^{0.18} \quad \textbf{(8.8.3)}$$

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

**8.8.4** For longer distances, $r$ (in meters), the maximum external pressure, $P_{max,r}$, shall be indicated approximately by Equation 8.8.4:

$$P_{max,r} = P_{max,a}\left(\frac{0.20 \cdot D}{r}\right) \qquad \textbf{(8.8.4)}$$

where:
$P_{max,r}$ = maximum external pressure
$P_{max,a}$ = external pressure (bar)
$D$ = maximum length of fireball (m)
$r$ = distance from vent $\geq 0.2\ D$(m)

**8.8.5** Equations 8.8.2, 8.8.3, and 8.8.4 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
(3) Static activation pressure: $P_{stat} \leq 0.1$ bar
(4) Deflagration index: $K_{St} \leq 200$ bar-m/sec
(5) $P_{max} \leq 9$ bar

**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.

**8.9.2** 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 or 1.013 bar abs)
(5) $\Delta P$ = pressure rise in the building (in same units as $P_0$)

**8.9.3** It shall be permitted to use a lower value of the coefficient shown in the equation in 8.9.2(1) where experimental data are available to substantiate the lower value.

**8.10* Deflagration Venting of Enclosures Interconnected with Pipelines.**

**8.10.1*** 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 a $P_{stat} < 0.2$ bar.
(2) Enclosures of volumes within 10 percent of each other shall be vented as determined by Equations 8.2.2 and 8.2.3.
(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 or less. The enclosure shall be designed with $P_{es}$ equal to a minimum of 2 bar.
(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, *Standard on Explosion Prevention Systems,* in order for the deflagration venting of smaller enclosures to be effective.

## 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 shall apply to systems handling gases or dusts operating at pressures up to 0.2 bar (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 (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.

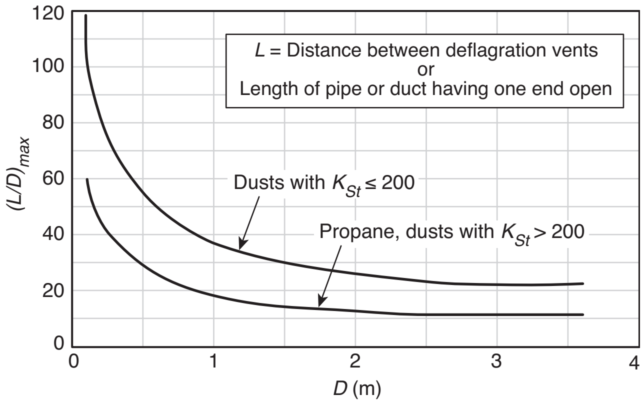



**FIGURE 9.2.10.1 Maximum Allowable Distance, Expressed as Length-to-Diameter Ratio, for a Smooth, Straight Pipe or Duct.**

**9.2.10.2.1 Flammable Gas Systems with a Flow Velocity of 2 m/sec 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/sec shall be determined from Figure 9.2.10.2.1.1.

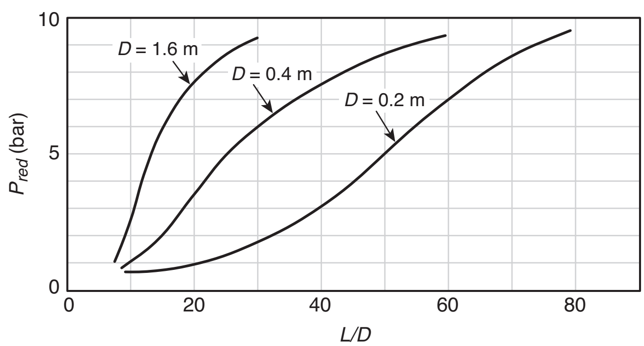



**FIGURE 9.2.10.2.1.1 Maximum Pressure Developed During Deflagration of Propane/Air Mixtures Flowing at 2 m/sec or Less in a Smooth, Straight Pipe Closed at One End.**

**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/sec 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.

**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/sec and for gases with fundamental burning velocities greater than 60 cm/sec (2 ft/sec), additional vent area shall be provided in accordance with Section 9.3.

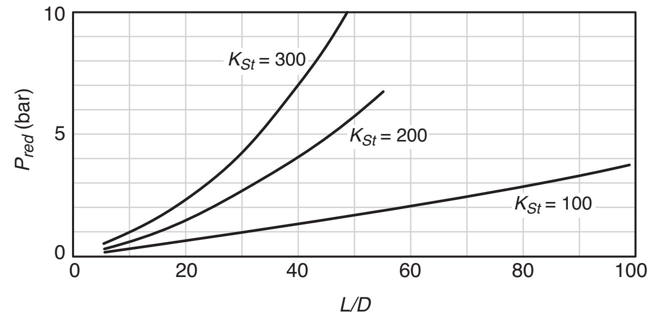



**FIGURE 9.2.10.2.2.1 Maximum Pressure Developed During Deflagration of Dust/Air Mixtures Flowing at 2 m/sec or Less in a Smooth, Straight Pipe Closed at One End.**

**9.2.12** For systems having an initial flow velocity greater than 20 m/sec, 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 (2.5 psi).

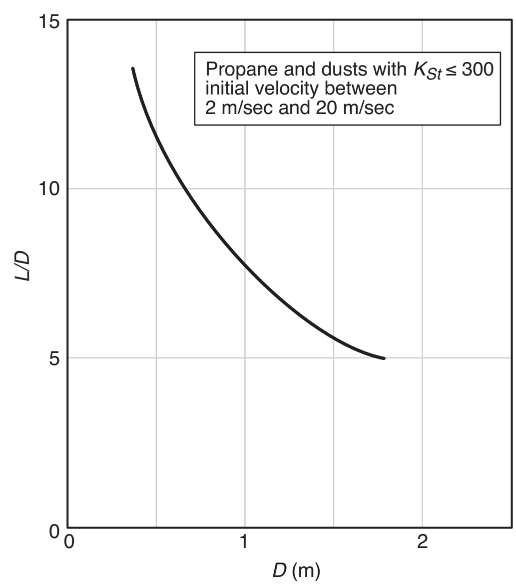



**FIGURE 9.3.1 Vent Spacing Needed to Keep $P_{red}$ from Exceeding 0.17 bar for Propane and Dusts with a $K_{St}$ Less Than 300 bar-m/sec.**

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

**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/sec 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 9.3.2b, which are limited to fundamental burning velocities below 60 cm/sec (2 ft/sec):

$$P_{red,x} = P_{red,p} \cdot \left( \frac{S_{u,x}}{S_{u,p}} \right)^2 \quad \textbf{(9.3.2a)}$$

$$L_x = L_p \cdot \left( \frac{S_{u,p}}{S_{u,x}} \right)^2 \quad \textbf{(9.3.2b)}$$

where:

$P_{red,x}$ = maximum pressure predicted for gas [bar (psi)]

$P_{red,p}$ = 0.17 bar (2.5 psi)— maximum pressure for propane

$L_x$ = distance between vents for gas [m (ft)]

$L_p$ = distance between vents for propane [m (ft)]

$S_{u,x}$ = fundamental burning velocity of gas

$S_{u,p}$ = fundamental burning velocity of propane

## 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.

**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.**

**10.2.1** The vent closure manufacturer or designer shall be responsible for documenting the value and tolerance of the $P_{stat}$ of a vent closure where installed according to the manufacturer's recommendation in the intended application.

**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.

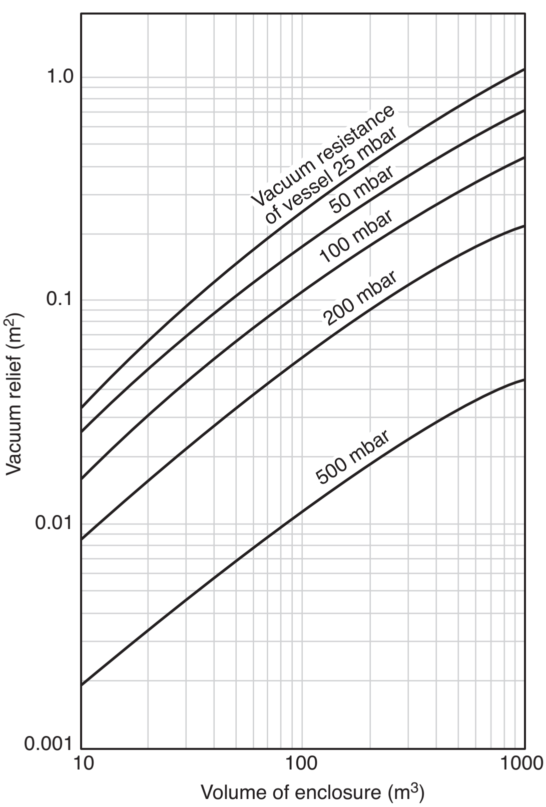



**FIGURE 10.5.1.6 Graph to Determine the Vacuum Relief Area for Vacuum Vents on Enclosures. [104]**

**10.6* Flame-Arresting and Particulate-Retention Vent Systems.**

**10.6.1** Flame-arresting and particulate-retention vent systems shall be listed for their application.

**10.6.2** 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.

**10.6.3*** The following limitations shall apply:

(1) Where a flame-arresting and particulate-retention vent system is 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 emissions
(2) A flame-arresting and particulate-retention vent system shall be sized to ensure that $P_{red}$ remains within the enclosure design limits.

## Chapter 11 Inspection and Maintenance

**11.1 General.**

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

**11.1.2** Sections 11.4 through 11.10 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

**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 per manufacturer's requirements.

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

**11.3.4*** Vent closure shall be clearly marked.

**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* 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 re-ordering purposes.

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

**11.7 Record Keeping.**

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

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

**11.8 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.

**11.8.1** 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.

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

**11.8.3** 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) The 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

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

**11.8.5** Design documentation as required by Chapter 11 shall be updated to incorporate the change.

**11.9 Maintenance.**

**11.9.1** 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.

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

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

**11.9.4** Process interlocks, if provided, shall be verified.

**11.9.5** Known potential ignition sources shall be inspected and maintained.

**11.9.6** Records shall be kept of any maintenance and repairs performed.

**11.10 Employee Training.**

**11.10.1** 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.

**11.10.2** 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, *Standard on Explosion Prevention Systems*, 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.

The following documents specify under which conditions deflagration venting (explosion protection measures) is required:

(1) NFPA 30, *Flammable and Combustible Liquids Code*
(2) NFPA 30B, *Code for the Manufacture and Storage of Aerosol Products*
(3) NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*
(4) NFPA 35, *Standard for the Manufacture of Organic Coatings*
(5) NFPA 52, *Vehicular Fuel Systems Code*
(6) NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
(7) NFPA 69, *Standard on Explosion Prevention Systems*
(8) NFPA 432, *Code for the Storage of Organic Peroxide Formulations*
(9) NFPA 484, *Standard for Combustible Metals*
(10) NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*

**A.1.3.2** For further information, see NFPA 30, *Flammable and Combustible Liquids Code.*

**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, 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 documents in a broad manner, since 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.3.3.8 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 E 681 (2004), *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases).*

**A.3.3.14 Flash Point.** See ASTM E 502 (2000), *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.3.3.15 Friction Factor, $f_D$.** D'Arcy friction factor relating pressure drop in a straight duct to velocity and wetted surface area, dimensionless:

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

where:
$D_h$ = hydraulic diameter
$\Delta P$ = pressure loss across the duct
$\rho$ = 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. The two forms differ by a factor of 4, as seen here:

$$f_F = \frac{D_h \cdot \Delta P}{2\rho \cdot U^2 \cdot L} \text{, the Fanning friction factor} \quad \textbf{(A.3.3.15a)}$$

$$f_D = \frac{2 \cdot D_h \cdot \Delta P}{\rho \cdot U^2 \cdot L} \text{, the D'Arcy friction factor} \quad \textbf{(A.3.3.15b)}$$

$$f_D = 4 f_F \quad \textbf{(A.3.3.15c)}$$

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

$$K = \frac{4 \cdot f_F \cdot L}{D_h} \text{ when using the Fanning friction factor} \quad \textbf{(A.3.3.15d)}$$

$$K = \frac{f_D \cdot L}{D_h} \text{ when using the D'Arcy friction factor} \quad \textbf{(A.3.3.15e)}$$

D'Arcy friction factors are presented in Moody diagrams and can be calculated from equations that represent the diagrams. See NFPA 750, *Standard on Water Mist Fire Protection Systems*, 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

$$\frac{1}{\sqrt{f_F}} = -4\log_{10}\left[\frac{\varepsilon}{3.7 \cdot D_h} + \frac{1.255}{\mathrm{Re}\sqrt{f_F}}\right] \quad \textbf{(A.3.3.15f)}$$

For the D'Arcy friction factor

$$\frac{1}{\sqrt{f_D}} = -2\log_{10}\left(\frac{\varepsilon}{3.7 \cdot D_h} + \frac{2.51}{\mathrm{Re}\sqrt{f_D}}\right) \quad \textbf{(A.3.3.15g)}$$

where:

ε = the absolute roughness

Re = the dimensionless Reynolds number

Note that $\varepsilon/D$ 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:

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

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

$$f_D = \left\{\frac{1}{\left[1.14 - 2\log_{10} \cdot \left(\frac{\varepsilon}{D_h}\right)\right]}\right\}^2 \quad \textbf{(A.3.3.15h)}$$

**A.3.3.18 Hydraulic Diameter.** Hydraulic diameters for circles, squares, and rectangular, triangular, and elliptical shapes are given in Darby (p. 199), 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.3.3.18a, where $A$ is the cross-sectional area normal to the longitudinal axis of the space and $p$ is the perimeter of the cross section.

$$D_h = 4 \cdot \left(\frac{A}{p}\right) \quad \textbf{(A.3.3.18a)}$$

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:

$$D_E = 2\sqrt{\frac{A}{\pi}} \quad \textbf{(A.3.3.18b)}$$

Equivalent diameters are not the same as hydraulic diameters.

**A.3.3.19 $K_G$.** See B.1.2.3.

**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.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.4.2.2.2** 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 752, *Management of Hazards Associated with Location of Process Plant 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 may 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, *Standard on Explosion Prevention Systems.*

**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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts,* 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/sec. Where the material is expected to yield $K_{St}$ values less than 50 bar-m/sec, 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 D 5680a, *Standard Practice for Sampling Unconsolidated Solids in Drums or Similar Containers,* or *Guidelines for Safe Handling of Powders and Bulk Solids,* Section 4.3.1 (CCPS).

**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.6.1.3** The maximum rate of pressure rise can be normalized to determine the $K_G$ value *(see Section B.1)*. It should be noted, however, that the $K_G$ value is not constant and varies, depending on test conditions. In particular, increasing the volume of the test enclosure and increasing the ignition energy can result in increased $K_G$ values. Although the $K_G$ value provides a means of comparing the maximum rates of pressure rise of known and unknown gases, it should be used as a basis for deflagration vent sizing only if the tests for both materials are performed in enclosures of approximately the same shape and size, and if tests are performed using igniters of the same type that provide consistent ignition energy. Annex E includes sample calculations for $K_G$ values.

Some publications have proposed the calculation of vent areas for gases based on fundamental flame and gas flow properties and experimentally determined constants [26,78,79]. These calculation procedures have not yet been fully tested and are not recommended.

**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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, 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** 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 rate of pressure development within the enclosure, vent size, and vent mass. Where deflagration vent area to enclosure volume ratio 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.

**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.

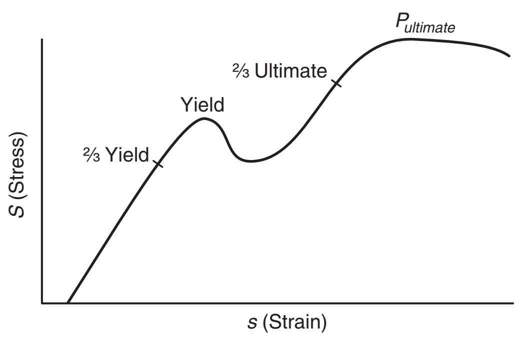



**FIGURE A.6.3.1.3 Stress–Strain Curve for Low-Carbon Steel.**

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.

**A.6.3.2** 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:

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

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

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.

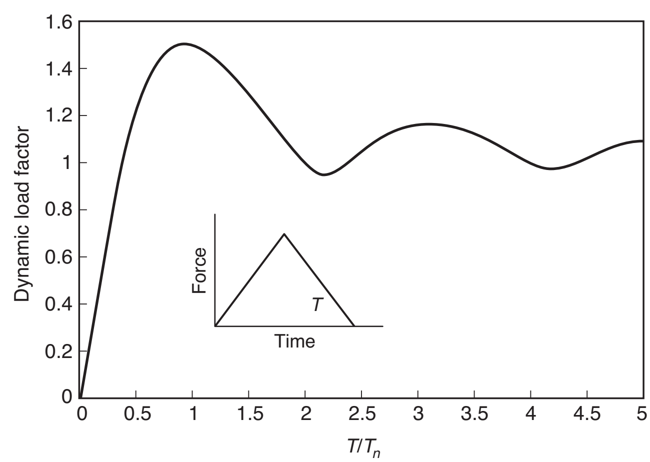



**FIGURE A.6.3.2 Maximum Response of Elastic One-Degree-of-Freedom System for Triangular Pulse Load.** ***(Courtesy of Department of Defense Explosives Safety Board, from TM5-1300, Figure 3-52)***

**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.

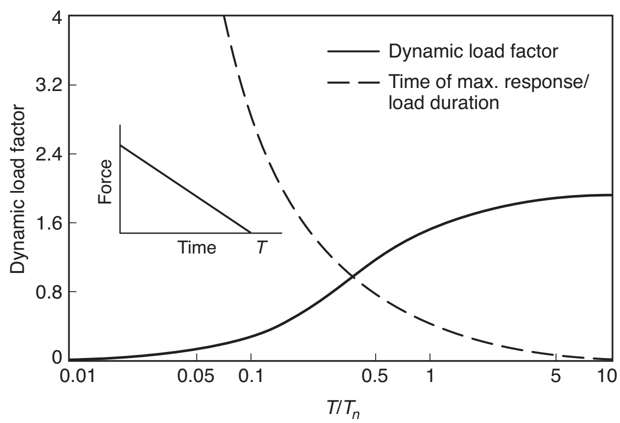



**FIGURE A.6.3.5.1 Maximum Response of Elastic One-Degree-of-Freedom System for Triangular Load.** ***(Courtesy of Department of Defense Explosives Safety Board, from TM5-1300, Figure 3-4)***

**A.6.3.5.2** An example of the calculation of reaction force, $F_r$, during venting for a vent area of 1 $m^2$ and a $P_{red}$ of 1 bar is as follows:

(1) $A_v$ = 1 $m^2$ = 1550 in.$^2$
(2) $P_{red}$ = 1 bar = 14.5 psi
(3) $F_r$ = (1) · (1.2) · (1550) · (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 to the full committee, September 15, 1999.

**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]:

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

For additional information on derivation of *DLF* and for use of the total impulse values, refer to textbooks on structural dynamics, such as J. M. 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
(3) $P_{red}$ = 0.4 bar
(4) $A_v$ = 1.4 $m^2$
(5) $t_f$ = (0.0043) · (8/0.4) $^{0.5}$ · (20/1.4)
(6) $t_f$ = 0.27 sec
The reaction force is determined as in 6.3.5.2:
(7) $F_r$ = (100) · (1.2) · (1.4) · (0.4)
(8) $F_r$ = 67 kN
(9) $I$ = (0.52) · (67) · (0.27)
(10) $I$ = 9.4 kN-sec = 9400 N-sec

**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 $D_2$ = $\pi \cdot h \cdot [(D_1)^2 + (D_1 \cdot D_2) + (D_2)^2]/12 = \pi \cdot 2 \cdot [(2)^2 + (2 \cdot 0.5) + (0.5)^2]/12$ = 2.75 $m^3$.
  (c) $V_{eff}$ = 10.18 + 2.75 = 12.93 $m^3$.
  (d) $V_{eff}$ is the shaded region in Figure A.6.4.3(a).
(3) $A_{eff} = V_{eff}/H$ = 12.93/6 = 2.155 $m^2$.
(4) $D_{he} = 4 \cdot A_{eff}/p = (4 \cdot A_{eff}/\pi)^{0.5}$, assuming a cylindrical cross section.
(5) $D_{he}$ = 1.656 m.
(6) $L/D = H/D_{he}$ = 6/1.656 = 3.62.

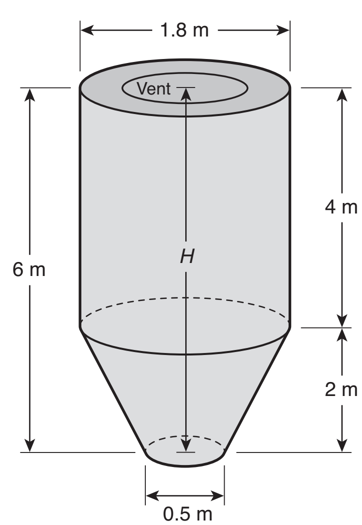



**FIGURE A.6.4.3(a) Calculating *L/D* Ratio for a Cylindrical Vessel with a Hopper and a Top Vent.**

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 $D_2$ $= \pi \cdot h \cdot [(D_1)^2 + (D_1 \cdot D_2) + (D_2{}^2)] / 12 = \pi \cdot 2 \cdot [(2)^2 + (2 \cdot 0.5) + (0.5)^2] / 12 = 2.75$ m$^3$.
  (c) $V_{eff} = 5.09 + 2.75 = 7.84$ m$^3$.
  (d) $V_{eff}$ is the shaded region in Figure A.6.4.3(b).
(3) $A_{eff} = V_{eff}/H = 7.84/4 = 1.96$ m$^2$.
(4) $D_{he} = 4 \cdot A_{eff}/p = (4 \cdot A_{eff} / \pi)^{0.5}$, assuming a cylindrical cross section.
(5) $D_{he} = 1.58$ m.
(6) $L/D = H/D_{he} = 4/1.58 = 2.53$.

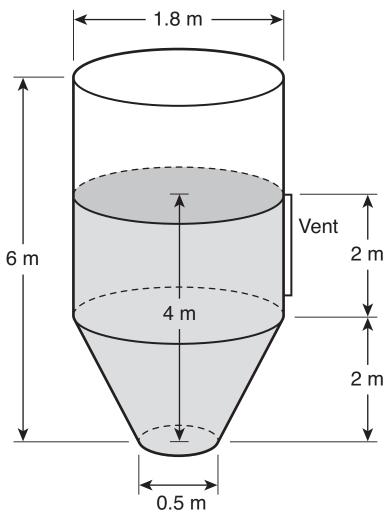



**FIGURE A.6.4.3(b) Calculating *L/D* Ratio for a Cylindrical Vessel with a Hopper and a Side Vent.**

*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(e)] = $(a_1) \cdot h \cdot (b_2 - b_1)/2 + (b_1) \cdot h \cdot (a_2 - a_1)/2 + h \cdot (a_2 - a_1) \cdot (b_2 - b_1)/3 + (a_1) \cdot (b_1) \cdot h = (0.5) \cdot 2 \cdot (1.5 - 0.3)/2 + (0.3) \cdot 2 \cdot (1.8 - 0.5)/2 + 2 \cdot (1.8 - 0.5) \cdot (1.5 - 0.3)/3 + (0.5) \cdot (0.3) \cdot 2 = 2.33$ 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(c).
(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) $L/D = H/D_{he} = 5/1.44 = 3.47$.

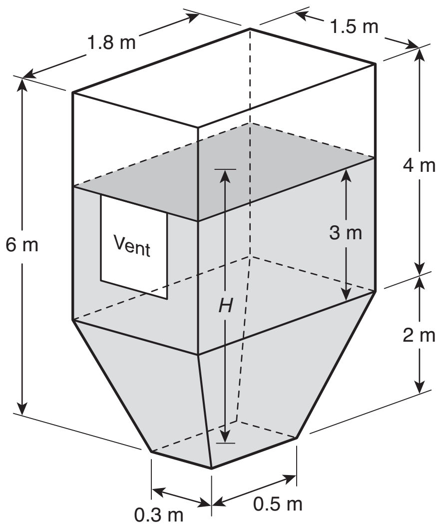



**FIGURE A.6.4.3(c) Rectangular Enclosure with a Hopper and a Side Vent.**

*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(d).
(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:

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

(2) Conical hopper:

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

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

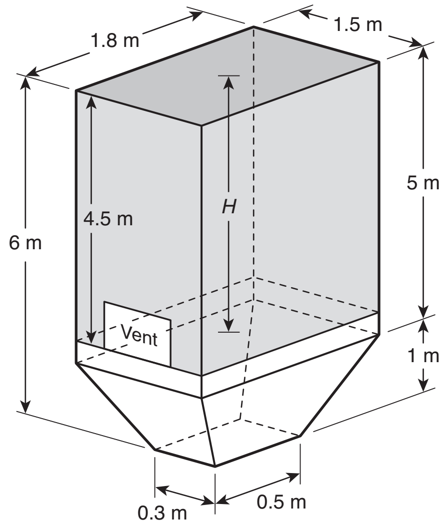



**FIGURE A.6.4.3(d) Rectangular Enclosure with a Hopper and a Side Vent Close to the Hopper.**

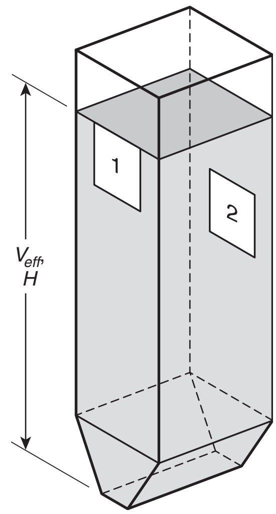



**FIGURE A.6.4.3(f) Rectangular Enclosure, with a Hopper and Two Vents on Opposite Sides of the Enclosure.**

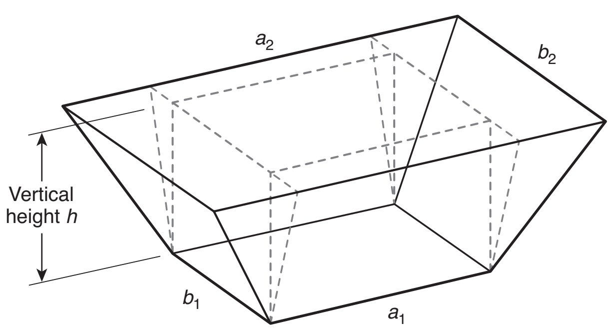



**FIGURE A.6.4.3(e) Rectangular Hopper.**

*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.

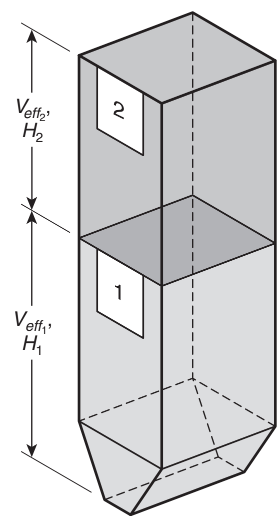



**FIGURE A.6.4.3(g) Rectangular Enclosure with a Hopper and Two Vents on the Same Vertical Line.**

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.

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.

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, *Standard on Explosion Prevention Systems.*

**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** 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 (0.5 psi).

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 1.5*D* 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, especially for initially quiescent gas mixtures where venting-induced turbulence dominates $P_{red}$.

**Table A.6.7.1 Reduced Pressure ($P_{red}$) Developed During Deflagration Venting and Influenced by Mass of Vent Closure — 5 Percent Propane in Air, Enclosure Volume = 2.6 m$^3$ [95]**

| Vent Closure Mass | | Static Opening Pressure ($P_{stat}$) (m-bar) | Vent Closure Response Time (m-sec) | Reduced $P_{red}$ (m-bar) |
|---|---|---|---|---|
| kg/m$^2$ | lb/ft$^2$ | | | |
| 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 m$^2$ (6.0 ft$^2$).

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:

$$E = \left(\frac{A_2}{A_1}\right) \cdot 100 = \text{percent efficiency} \qquad \textbf{(A.6.7.4)}$$

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.6.8.3** The addition of a vent duct can substantially increase the pressure developed in a vented enclosure.

**A.6.9.1** Even with complete retention of particulates, the immediate area surrounding the vent can experience overpressure and radiant energy. Such overpressure and radiant energy pose personnel concerns in occupied facilities.

**A.6.9.3** The retention of particulates results in a loss of venting efficiency.

**A.6.9.4** 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.7.1.1** No venting recommendations are currently available for fast-burning gases such as hydrogen with fundamental burning velocities greater than 1.3 times that of propane. Recommendations are unavailable because the recommended method allows for initial turbulence and turbulence-generating objects, and no venting data have been generated that address conditions for fast-burning gas deflagrations. The user is cautioned that fast-burning gas deflagrations can readily undergo transition to detonation. NFPA 69, *Standard on Explosion Prevention Systems*, provides alternative measures that should be used.

**A.7.1.3** By test, $K_G$ of propane is 100 bar-m/sec with a burning velocity of 46 cm/sec. For gases of unknown $K_G$, it is possible to estimate $K_G$ from burning velocity using Equation E.1.

**A.7.2.2** Equation 7.2.2 was developed from the results of tests and the analysis of industrial accidents. Deflagration vents have been effective in mitigating the consequences of many industrial building explosions. However, it should be noted that flames and pressure waves from an explosion can be hazardous, as described in A.6.6. Furthermore, test work has demonstrated that deflagrations of flammable gas mixtures in enclosures that contain turbulence-inducing objects (such as process equipment, pipework, cable trays, and so forth) can develop pressures significantly higher than predicted by Equation 7.2.2. It is therefore recommended that building vents be used in addition to taking measures to minimize the potential for flammable gas accumulations in enclosures.

Numerous methods have been proposed for calculating the vent closure area [23–27]. Some venting models use the surface area of the enclosure as a basis for determining vent area. Analysis of available data [30–45] shows that such methods overcome certain deficiencies associated with previous methods for calculating vent area.

**A.7.2.2.2** Use of Figure 7.2.2.2 provides a way to interpolate between the vent parameters previously provided to accommodate a range of fuels. Methane (previously included in the vent parameter table — Table 6.2.2 of NFPA 68, 2002 edition) has been left out of the curve deliberately because flame speeds in methane–air mixtures do not accelerate as much with turbulence as with other hydrocarbons with similar fundamental burning velocity.

The shape of the curve beyond 46 cm/sec (151 ft/sec) was developed based on limited data with fuels of higher burning velocity. The following information is offered to aid the user in determining an appropriate burning velocity (and ultimately vent parameter $C$) 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.7.2.2.2(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 for droplet size in the range of 5 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 these circumstances, they can form an aerosol consisting of very small droplets that can fall into the 5 to 35 μm range.

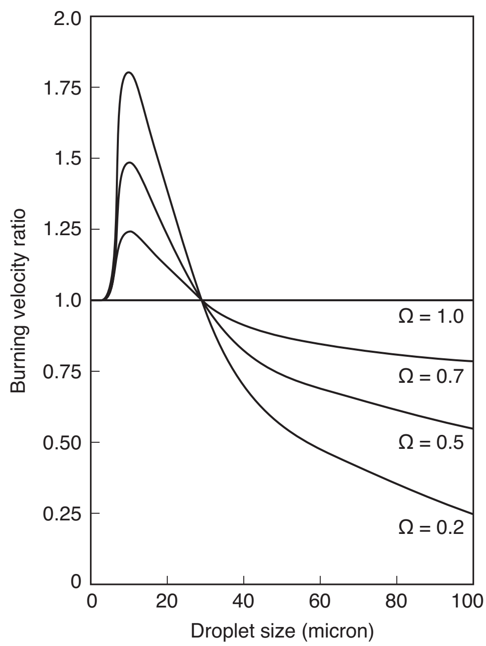



**FIGURE A.7.2.2.2(a) Burning Velocity Predictions Versus Aerosol Droplet Size at Different Values of Ω.**

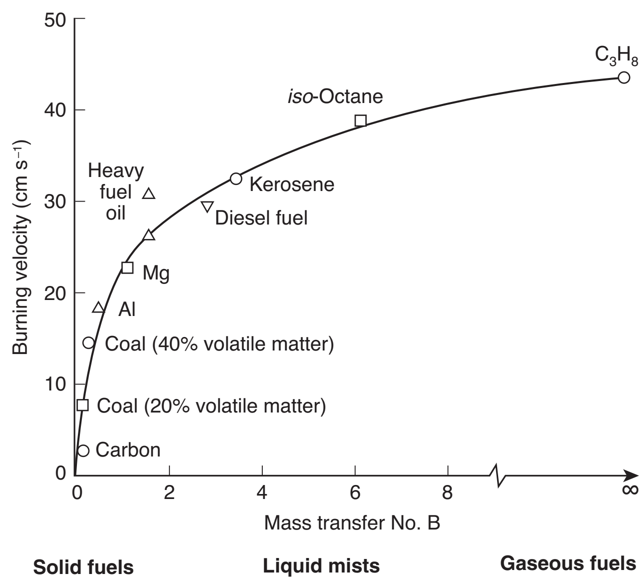



**FIGURE A.7.2.2.2(b) Burning Velocity of Mixtures of Air with Flammable Vapors, Aerosols, or Dusts. (Reprinted from F. P. Lees, *Lees Loss Prevention in the Process Industries*, 2nd ed., Butterworth–Heinemann, 1996)**

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.7.2.2.2(b) from Lees.

The dimensionless Spalding mass transfer number ($B$) is defined as:

$$B = \frac{q_{st} \cdot H + C_{pa} \cdot \left(T_g - T_b\right)}{L + C_p \cdot \left(T_b - T_s\right)}$$

where:

$q_{st}$ = mass ratio of fuel to air at stoichiometric concentration
$H$ = heat of combustion
$C_{pa}$ = specific heat of air
$C_p$ = specific heat of the fuel
$T$ = temperature of the gas ($g$), boiling point of the fuel ($b$), surface of the fuel ($s$)
$L$ = latent heat of vaporization

At the time of this writing, the Committee is unaware of any aerosol testing that has definitively correlated deflagrations of small droplet diameter (0 to 30 μm) aerosols to vent area. The information is provided as a word of warning. [118]

**A.7.2.2.5.2** Where $M$ is greater than 40 kg/m$^2$ or $K_G$ is greater than 130 bar-m/sec, it is necessary to perform testing or apply alternate explosion protection methods per NFPA 69, *Standard on Explosion Prevention Systems.*

**A.7.2.3** The form of the venting equation is such that there are no dimensional constraints on the shape of the room, provided the vent area is not applied solely to one end of an elongated enclosure *(see Sections 6.5 and 6.6 for other general vent considerations).*

**A.7.2.4 Sample Calculations of Vent Area.**

*Example A.*

**Step 1.** Calculate the internal surface area. If you consider a 20 ft × 30 ft × 20 ft (6.1 m × 9.2 m × 6.1 m) (length × width × height) dispensing room for toluene, a Class I flammable liquid, the internal surface area of the room is 3200 ft$^2$ (297 m$^2$). Next, the fundamental burning velocity of toluene is 41 cm/sec [see Table D.1(a)]. Figure 7.2.2.2 specifies a venting equation constant, $C$, of 0.17. If more than one flammable liquid could be processed in this room, the designer should consider the material with the highest burning velocity when designing the vent. The room is located against an outside wall, and, in anticipation of deflagration venting requirements, the three inside walls are designed to withstand a $P_{red}$ value of 0.69 psi (0.05 bar).

Now the vent area, $A_v$, can be determined by the following equation:

$$A_v = \frac{0.17 \cdot 3200}{0.69^{1/2}} = 655 \text{ ft}^2 \ \ (61 \text{ m}^2)$$

This area is more than is available in the outside wall, so modification is necessary.

**Step 2.** If the wall strength were increased to resist a $P_{red}$ of 1.04 psi (0.072 bar), a vent area of 533 ft$^2$ (50 m$^2$) would be needed. This wall strength can usually be achieved and is recommended over the common wall strength intended to resist a $P_{red}$ of 0.69 psi (0.048 bar).

*Example B.*

**Step 1.** Consider the building illustrated in Figure A.7.2.4(a), for which deflagration venting is needed. The building is to be protected against a deflagration of a hydrocarbon vapor that has the burning characteristics of toluene. The maximum $P_{red}$ that this building can withstand has been determined by structural analysis to be 0.5 psi (3.45 kPa).

**Step 2.** Divide the building into sensible geometric parts (Parts 1 and 2) as shown in Figure A.7.2.4(b).

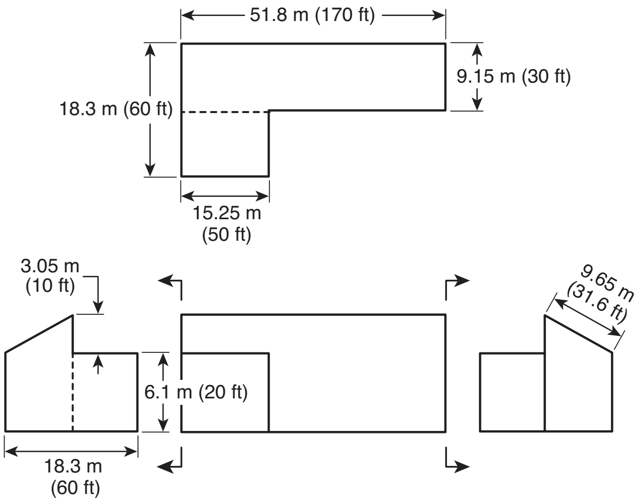



**FIGURE A.7.2.4(a) Building Used in Sample Calculation (Not to Scale) (Version I).**

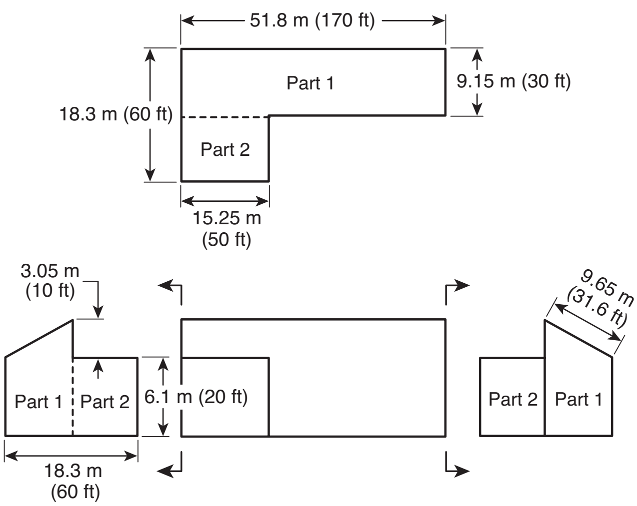



**FIGURE A.7.2.4(b) Building Used in Sample Calculation (Not to Scale) (Version II).**

**Step 3.** Calculate the total internal surface area of each part of the building.

**Part 1 Surface Area ($A_{S1}$)**

Floor = 170 ft × 30 ft = 5100 $ft^2$
(51.8 m × 9.15 m = 474 $m^2$)
Roof = 170 ft × 31.6 ft = 5372 $ft^2$
(51.8 m × 9.65 m = 499 $m^2$)
Rear wall = 170 ft × 20 ft = 3400 $ft^2$
(51.8 m × 6.1 m = 316 $m^2$)
Front wall = (120 ft × 30 ft) + (50 ft × 10 ft) = 4100 $ft^2$
[(36.6 m × 9.15 m) + (15.25 m × 3.05 m)] = 381 $m^2$
Side walls (rectangular part) = 2 × 30 ft × 20 ft = 1200 $ft^2$
(2 × 9.15 m × 6.1 m = 111 $m^2$)
Side walls (triangular part) = 30 ft × 10 ft = 300 $ft^2$
(9.15 m × 3.05 m = 28 $m^2$)
Total Part 1: $A_{S1}$ = 19,472 $ft^2$ (1809 $m^2$)

**Part 2 Surface Area ($A_{S2}$)**

Floor = 50 ft × 30 ft = 1500 $ft^2$
(15.25 m × 9.15 m = 139 $m^2$)
Roof = 50 ft × 30 ft = 1500 $ft^2$
(15.25 m × 9.15 m = 139 $m^2$)
Front wall = 50 ft × 20 ft = 1000 $ft^2$
(15.25 m × 6.1 m = 93 $m^2$)
Side walls = 2 × 30 ft × 20 ft = 1200 $ft^2$
(2 × 9.15 m × 6.1 m = 111 $m^2$)
Total Part 2: $A_{S2}$ = 5200 $ft^2$ (483 $m^2$)

**Step 4.** Thus, the total internal surface area for the whole building, $A_S$, is expressed as follows:

$A_S$ = 19,472 $ft^2$ + 5,200 $ft^2$ = 24,672 $ft^2$ (1809 $m^2$ + 483 $m^2$ = 2292 $m^2$).

**Step 5.** Calculate the total vent area, $A_v$, needed using Equation 7.2.2:

$$A_v = \frac{C \cdot A_s}{P_{red}^{\;1/2}}$$

where:
$C$ = 0.17 psi $^{1/2}$ (0.045 bar $^{1/2}$) from Figure 7.2.2.2
$A_S$ = 24,672 $ft^2$ (2292 $m^2$)
$P_{red}$ = 0.5 psi (0.0345 bar)

**Step 6.** Substituting these values,

$$A_v = \frac{0.17 \cdot 24{,}672}{0.5^{1/2}} = 5932 \text{ ft}^2 \;\; (551 \text{ m}^2)$$

**Step 7.** The total vent area needed of 5932 $ft^2$ (551 $m^2$) should be divided evenly over the outer surface of the building and should be apportioned between the parts in the same ratio as their surface area.

**Step 8.** Total vent area of Part 1:

$$A_{v1} = A_v \cdot \left(\frac{A_{s1}}{A_s}\right) = 5932 \cdot \left(\frac{19{,}472}{24{,}672}\right) = 4682 \text{ ft}^2 \;\; (435 \text{ m}^2)$$

**Step 9.** Total vent area of Part 2:

$$A_{v2} = A_v \cdot \left(\frac{A_{s2}}{A_s}\right) = 5932 \cdot \left(\frac{5200}{24{,}672}\right) = 1250 \text{ ft}^2 \;\; (116 \text{ m}^2)$$

**Step 10.** Check to determine whether sufficient external surface area on the building is available for venting.

**Step 11.** In Part 1, the vent area needed [4682 $ft^2$ (435 $m^2$)] can be obtained by using parts of the front, rear, and side walls or by using the building roof.

**Step 12.** In Part 2, the vent area needed [1250 $ft^2$ (116 $m^2$)] can be obtained by using parts of the front and side walls or by using the building roof.

Note: Only the outer "skin" of the building can be used for vent locations; a deflagration cannot be vented into other parts of the building.

**A.7.2.4.1.5** Such rooms include adjoining rooms separated by a partition incapable of withstanding the expected pressure.

**A.7.2.5** The calculated vent area, $A_v$, can be reduced by increasing the value of $P_{red}$. The value of $P_{red}$ should not be increased above 0.1 bar (1.5 psi) for the purpose of design under this chapter. If $P_{red}$ is increased above 0.1 bar (1.5 psi), the methods of Section 7.3 should be followed.

The calculated vent area, $A_v$, 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, $A_S$. The new wall should be designed in accordance with Section 7.3.

The calculated vent area, $A_v$, can be reduced if applicable large-scale tests demonstrate that the flammable material has a smaller constant, *C*, than indicated in Figure 7.2.2.2.

The need for deflagration vents can be eliminated by the application of explosion prevention techniques described in NFPA 69, *Standard on Explosion Prevention Systems*.

**A.7.2.6.1** Deflagration vent closures should release at a $P_{stat}$ value that is as low as practical, yet should remain in place when subjected to external wind forces that produce negative pressures, to prevent vents from being pulled off. In most cases, a $P_{stat}$ value of 0.01 bar (0.14 psi) is acceptable. In areas subject to severe windstorms, release pressures up to 0.015 bar (0.21 psi) are used. In any case, locating vents at building corners and eavelines should be avoided because of the higher uplift pressures in such areas. In hurricane areas, local building codes often require higher resistance to wind uplift. In such situations, the limitations of $P_{stat}$ in 7.2.6.1 should be recognized, and strengthened internal structural elements should be provided.

**A.7.2.6.3** Such a design ensures that the flow of combustion gases is not impeded by an obstructed closure.

**A.7.2.6.4** A vent closure can open if personnel fall or lean on it.

**A.7.2.6.6** Situations can arise in which the roof area or one or more of the wall areas cannot be used for vents, either because of the location of equipment or because of exposure to other buildings or to areas normally occupied by personnel.

**A.7.3.1** Enclosures include process vessels, silos, and other process equipment.

**A.7.3.2** Certain basic principles are common to the venting of deflagrations of gases, mists, and dusts. The principles include, but are not limited to, those discussed in 7.3.2.

The maximum pressure that is reached during venting, $P_{red}$, always exceeds the pressure at which the vent device releases; in some cases it is significantly higher. Maximum pressure is affected by a number of factors.

This section describes the factors and provides guidelines for determining maximum pressure.

**A.7.3.3.2** Equation 7.3.3.2 is derived from tests made under the following conditions:

(1) Volumes of test vessels: 2.4 $m^3$, 10 $m^3$, 25 $m^3$, and 250 $m^3$; *L/D* of test vessels approximately 1
(2) Initial pressure: atmospheric
(3) $P_{stat}$: 0.1 bar to 0.5 bar
(4) Ignition energy: 10 J
(5) Stationary gas mixture at time of ignition
(6) No turbulence inducers

**A.7.3.3.3** Equation 7.3.3.3.1 was developed based on the following considerations:

(1) Flame speeds and values of $P_{red}$ increase rapidly in elongated vessels with *L/D* greater than the maximum value for which Equation 7.3.3.2 is applicable.
(2) Gases with higher values of $K_G$ are more prone to flame acceleration in elongated vessels.
(3) Limited data on flame speeds and pressures are available in Chapter 5, Pipelines, Section 5.1, of W. Bartknecht [101] for propane deflagrations in an open-ended vessel with *L/D* of approximately 5.

**A.7.3.3.6.2** Where *M* is greater than 40 kg/$m^2$ or $K_G$ is greater than 130 bar-m/sec, it is necessary to perform testing or apply alternative explosion protection methods per NFPA 69, *Standard on Explosion Prevention Systems*.

**A.7.4** 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. The sizing equations and graphs in Section H.1 are based on venting deflagrations to atmosphere without vent ducts.

**A.7.4.1** The use of a vent duct with a cross section greater than that of the vent can result in a smaller increase in the pressure that develops during venting, $P_{red}$, than when using a vent duct of an equivalent cross section [93], but this effect is difficult to quantify because of limited test data.

Vent ducts should be as short and as straight as possible. Any bends can cause dramatic and unpredictable increases in the pressure that develops during venting.

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.7.4.3** 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 in this context.

**A.7.4.5** Flames and pressure waves that discharge from the enclosure during venting represent a threat to personnel and could damage other equipment.

**A.7.4.5.1** If a vented enclosure is located within buildings, it should be placed close to exterior walls so that the vent ducts are as short as possible.

**A.7.4.6** The use of a vent duct with a larger cross section than that of the vent can result in a smaller increase in the pressure that develops during venting ($P_{red}$) than if using a vent duct of an equivalent cross section [93], but this effect is difficult to quantify because of limited test data. A special requirement for vent duct cross sections in situations where the vent closure device is a hinged panel is discussed in 10.5.1.5.

**A.7.4.7** In general, any bends can cause increases in the pressure that develops during venting.

**A.7.5** 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.

If the gas system is initially turbulent, the rate of deflagration increases [3, 35]. In such a case, Equations 7.3.3.2 and 7.3.3.3.1 do not apply directly. It has been found that initially turbulent methane and propane exhibit high values.

The susceptibility of a turbulent system to detonation increases with increasing values of the quiescent. 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, alternate solutions, such as those in NFPA 69, *Standard on Explosion Prevention Systems*, should be considered.

In many industrial enclosures, the gas phase is present in a turbulent condition. Internal appurtenances within a vented enclosure can cause turbulence [55, 102]. If the gas system is initially turbulent, the rate of deflagration is increased relative to that observed in initially quiescent conditions [3, 35]. In such a case, the equations do not apply directly. It has been found that initially turbulent methane and propane exhibit $K_G$ values similar to those of initially quiescent hydrogen.

**A.7.6.3.1** On the other hand, if pressure excursions are likely during operation, it can be the maximum pressure excursion during operation or the pressure at the relief valve when in the fully open position.

**A.7.6.3.2** Venting from enclosures at initially elevated pressures results in severe discharge conditions.

**A.7.6.4** The fireball from a vented gas or dust deflagration presents a hazard to personnel who may be 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.

**A.7.6.4.1** The number of vents, *n*, should be those vents whose discharge directions are separate and evenly distributed around the circumference of a vessel or along the central axis. If multiple vent panels cover a single vent opening, they should not be treated as separate for this purpose.

**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. There are reasons why this needs to be done.

**A.8.2.3.1** 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.8.2.6.3** 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, $v_{tan\_max} = Q_{air}/A_{in}$, where $Q_{air}$ 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,

$$v_{tan\_max} = \frac{2 \cdot (3.14) \cdot N \cdot r}{60} \qquad \textbf{(A.8.2.6.3)}$$

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.8.2.6.7** The use of a velocity of 20 m/sec and 56 m/sec to separate the vent area requirements is based on a combination of the data used to derive Equation 8.2.2 (the general area correlations) and the Tamanini 1990 data [103] in Figure A.8.2.6.7 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 very 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/sec and 56 m/sec 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/sec for Equation 8.2.2, and for a higher rms velocity as determined by the correlation between $K_{St}$ and rms velocity in Figure A.8.2.6.7.

**A.8.2.6.8** 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.8.2.7** Where $M$ is greater than 40 kg/m$^2$ or $K_{St} > 250$ bar-m/sec, see Annex G for guidance.

**A.8.3** Dust concentrations in some process equipment and buildings are inherently limited to only a fraction of the enclosure volume.

**A.8.3.2** Figure A.8.3.2 illustrates the limits of partial volume corrections. At low normalized reduced pressures, $\Pi$, the vent ratio approaches the fill fraction to the 1/6th power. When fill fraction approaches $\Pi$, both the vent ratio and the necessary vent area approach zero. Subsections 8.3.3 and 8.3.4 provide guidance on the determination of the fill fraction for process vessels and for buildings, respectively.

**A.8.3.3** 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

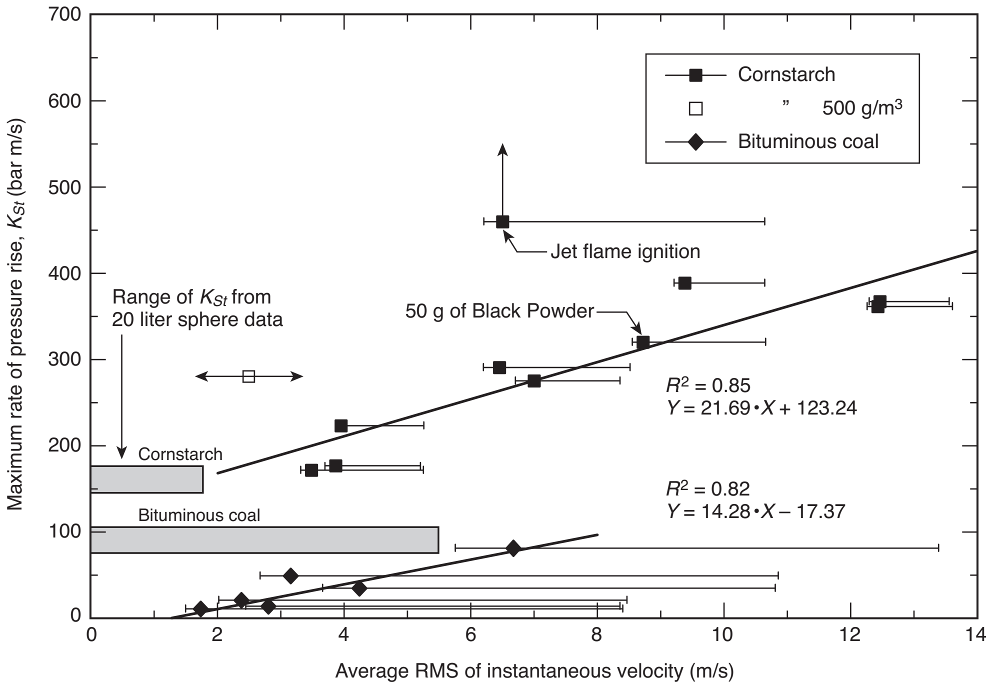



**FIGURE A.8.2.6.7 Explosion Severity for Vented Tests in the FMRC 2250 ft³ Chamber.**

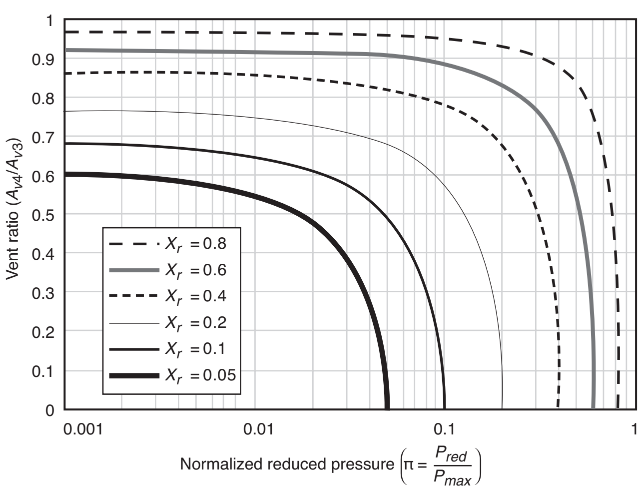



**FIGURE A.8.3.2 Partial Volume Vent Area Reduction.**

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 and a $K_{St}$ of 100 bar-m/sec at the dryer operating temperature. The deflagration vent design is to be based on a $P_{red}$ of 0.50 bar and a $P_{stat}$ = 0.10 bar. 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, $X_r$ = 0.3333, and $\prod$ = 0.50/10 = 0.050.

**Step 1.** Using Equation 8.2.2,

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot (0.10)^{4/3}\right] \cdot 100 \cdot (100)^{3/4} \cdot \sqrt{\frac{1}{0.050} - 1}$$

$$A_{v0} = 1.48 \text{ m}^2$$

**Step 2.** The partial volume vent area for this application is as follows:

$$A_{v4} = (1.48) \cdot (0.333)^{0.333} \cdot \sqrt{\frac{(0.333 - 0.050)}{1 - 0.050}} = 1.16 \text{ m}^2$$

**Step 3.** Therefore vent panels with a total vent area of at least 1.16 m² should be installed on the conical lower section of the dryer.

**A.8.5** The flow resistance coefficient *K* for this correlation is defined on the static pressure drop, Δ*P*, from the enclosure to the duct exit at a given average duct flow velocity, *U*:

$$K \equiv \frac{\Delta P}{\frac{1}{2} \cdot \rho \cdot U^2}$$

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 [115] for additional information.

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 this 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, *Standard on Explosion Prevention Systems*, can provide alternatives.

There is a minimum value for $P_{red}$ as vent area increases, beyond which solutions are not meaningful. This 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:

$$\frac{A_{vf} \cdot L}{V} \leq 1$$

For the following input values, Figure A.8.5(a) illustrates the potential solutions:

$V = 500\ m^3$
$P_{max} = 8.5$ bar
$K_{St} = 150$ bar-m/sec
$P_{stat} = 0.05$ bar
$P_{red} = 0.5$ bar
Vessel $L/D = 4$
$\varepsilon = 0.26$ mm

Straight duct, no elbows, fittings, or rain hats.

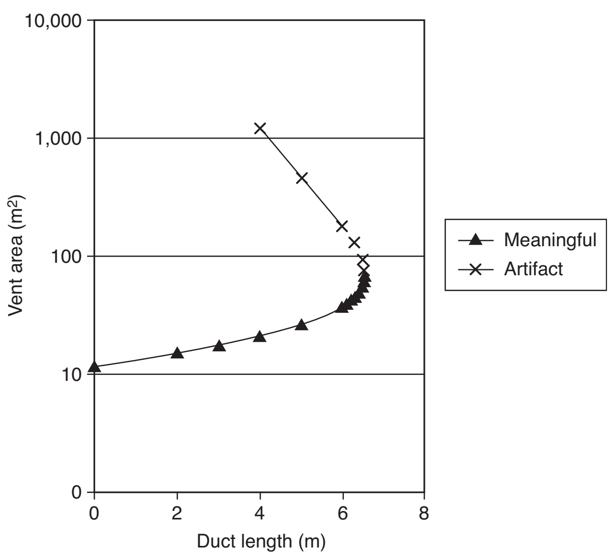



**FIGURE A.8.5(a) $A_v$ vs. Duct Length.**

*Example problem.* See Figure A.8.5(b).
*Example conditions.* Given the following:

(1) Enclosure volume, $V = 25\ (m^3)$
(2) Enclosure $L/D = 4$
(3) Vent diameter, $D_v = 1.5$ (m)
(4) Duct diameter, $D_h = 1.5$ (m)
(5) $A_v = 1.77\ (m^2)$
(6) $P_{stat} = 0.25$ (bar-g)
(7) $K_{St} = 200$ (bar-m/s)
(8) $P_{max} = 8$ (bar)
(9) Duct length = 12 (m)
(10) Duct effective roughness, $\varepsilon = 0.26$ (mm)
(11) Elbows = 2 × 90°
(12) Elbow flow resistance = 2 × 1.2 = 2.4
(13) Rain hat flow resistance = 0.75

Calculate $P_{red}$.

While Section 8.5 provides the equations in a form to calculate the vent area based on an allowable $P_{red}$, this example shows

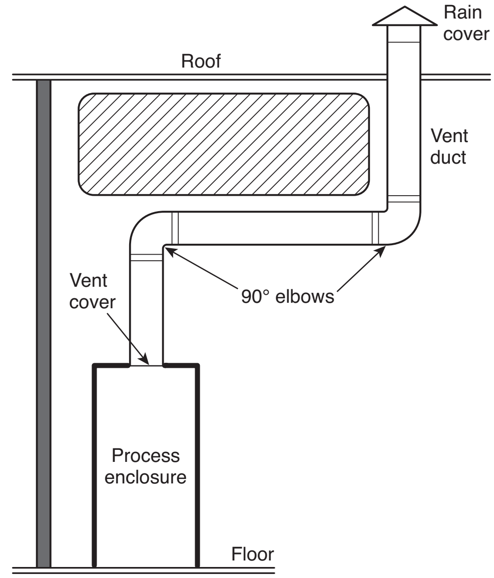



**FIGURE A.8.5(b) Example Vent Duct Installation.**

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 [115] 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:

$$f_D = \left\{ \frac{1}{\left[ 1.14 - 2\log_{10}\left( \frac{\varepsilon}{D_h} \right) \right]} \right\}^2 \quad \textbf{(A.8.5a)}$$

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 $\varepsilon$ = 0.26 mm is assumed.

From Equation A.8.5a, $f_D = 0.013$:

$$\text{then } \frac{f_D \cdot L}{D_h} = \frac{0.013 \cdot 12}{1.5} = 0.107, \text{ and}$$
$$K = K_{inlet} + \frac{f_D \cdot L}{D_h} + K_{elbows} + K_{outlet} \quad \textbf{(A.8.5b)}$$
$$K = 1.5 + 0.107 + 2.4 + 0.75 = 4.757$$

where:

$K_{inlet}$ = 1.5
$K_{elbows}$ = 2.4
$K_{exit}$ = 0.75
$K$ = 4.757

(2) Assume a $P_{red}$ value = 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 8.2.2,

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left[1 + 1.54 \cdot (0.25)^{4/3}\right] \cdot 200 \cdot (25)^{3/4} \cdot \sqrt{\frac{8}{P_{red}} - 1} \quad \textbf{(A.8.5c)}$$

$$A_{v0} = 0.735 \text{ m}^2$$

(4) From Equation 8.2.3,

$$A_{v1} = 0.735 \cdot \left[1 + 0.6 \cdot (4-2)^{0.75} \cdot \exp(-0.95 \cdot P_{red}^2)\right] \quad \textbf{(A.8.5d)}$$

$$A_{v1} = 1.02 \text{ m}^2$$

(5) From Equation 8.5.1(b), and using the intended vent area of 1.77 $m^2$,

$$E_1 = \frac{1.77 \cdot 12}{25} \quad \textbf{(A.8.5e)}$$

$$E_1 = 0.85$$

(6) From Equation 8.5.1(c), and using the installed vent area of 1.77 $m^2$,

$$E_2 = \frac{10^4 \cdot 1.77}{\left[1 + 1.54 \cdot (0.25)^{4/3}\right] \cdot 200 \cdot (25)^{3/4}} \quad \textbf{(A.8.5f)}$$

$$E_2 = 6.37$$

(7) From Equation 8.5.1(a), with $A_{v4}$ equal to $A_{v1}$, assuming no increase for turbulence, inertia, or partial volume

$$A_{vf} = (1.02) \cdot \left[1 + 1.18 \cdot (0.85)^{0.8} \cdot (6.37)^{0.4}\right] \cdot \sqrt{\frac{4.757}{1.5}} \quad \textbf{(A.8.5g)}$$

$$A_{vf} = 5.77 \text{ m}^2$$

(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 $P_{red}$ = 3.52 barg.

(9) From Equation 8.5.10 and its conditions, Equations A.8.5h and A.8.5i show that there is no deflagration-to-detonation-transition (DDT) propensity for this particular application:

$$L_{eff} \le \min\left[\frac{10{,}000 \cdot 1.5}{200}, \frac{11{,}000}{200}\right] \quad \textbf{(A.8.5h)}$$

$$L_{eff} \le \min\ [75{,}55] \le 55$$

$$L_{dusty} = (8 - 3.52) \cdot \frac{25}{1.77} = 63 \text{ m} \quad \textbf{(A.8.5i)}$$

Since $L_{duct}$ = 12 m,
$L_{eff}$ = min [12, 63] = 12 m ≤ 55 m
Therefore DDT is not expected.

**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.8.8** 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. 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. [113] See also A.7.6.4.1.

**A.8.8.2** If the vented material exits from the vent horizontally, the horizontal length of the fireball 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.

**A.8.8.3** 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 [117].

**A.8.9** Even with complete retention of flame and particulates, 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 [111].

**A.8.10** 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. 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].

Equations 8.2.2 and 8.2.3 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 Equations 8.2.2 and 8.2.3.

**A.8.10.1** 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, *Standard on Explosion Prevention Systems*.

**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

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, *Standard on Explosion Prevention Systems*.
(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 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 (3 psi), and the maximum operating pressure in the system is 0.05 bar (0.73 psi). The system handles a St-2 dust. It is further assumed that the dryer and dust collector are equipped with adequate deflagration vents.

As recommended by 9.2.4, *A* should be located, respectively, 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/sec (20 ft/sec). 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);

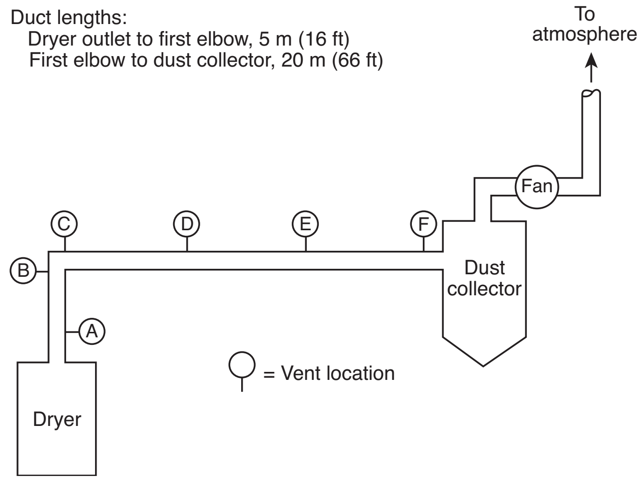



**FIGURE A.9.2 Diagram for Example.**

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 (3 psi) for $P_{red}$. The vent release pressure should not exceed half $P_{red}$ and, therefore, cannot exceed 0.1 bar (1.5 psi).

**A.9.2.4** See Example in A.9.2.

**A.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.

**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** 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 (7.3 psi) 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** 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 (2.5 psi), where the vents are designed to open at 0.05 bar (0.73 psi), 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.

**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.

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 very specific to their application and are intended only as examples. Each situation necessitates an 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

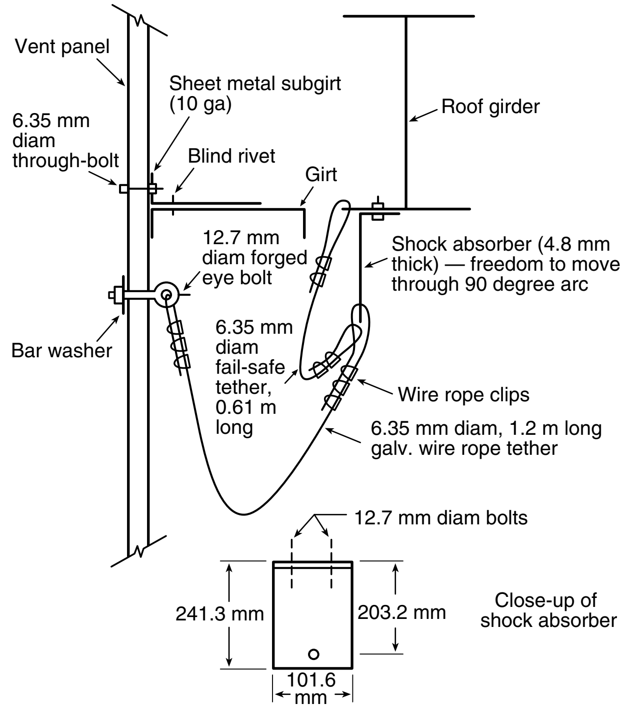



**FIGURE A.10.4(a) An Example of a Restraint System for Double-Wall Insulated Metal Vent Panels.**

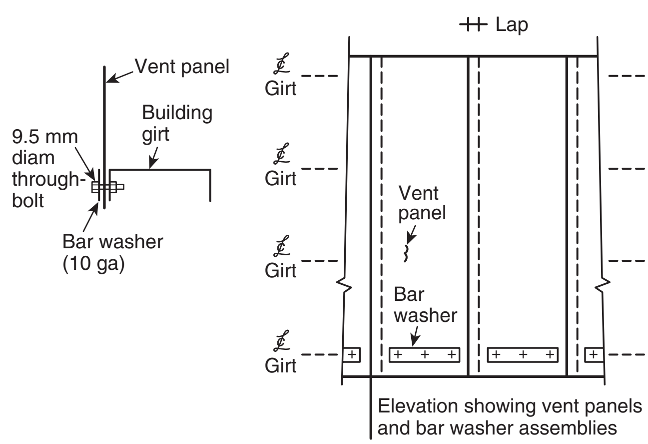



**FIGURE A.10.4(b) An Example of a Restraint System for Single-Wall Metal Vent Panels.**

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.

**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. They can become projectile hazards.

**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.)*

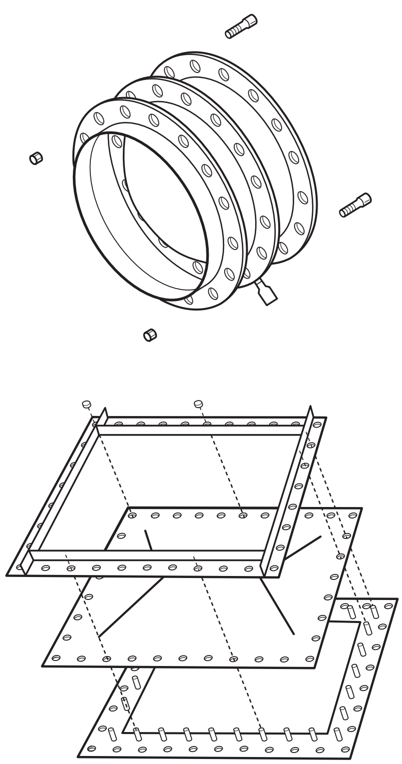


**FIGURE A.10.5.2 Typical Rupture Diaphragm.**

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.10.6** Deflagration venting systems have been developed that have a rupture membrane for venting and a flame-arresting element. 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. *(See Section 6.9 and Figure A.10.6.)*

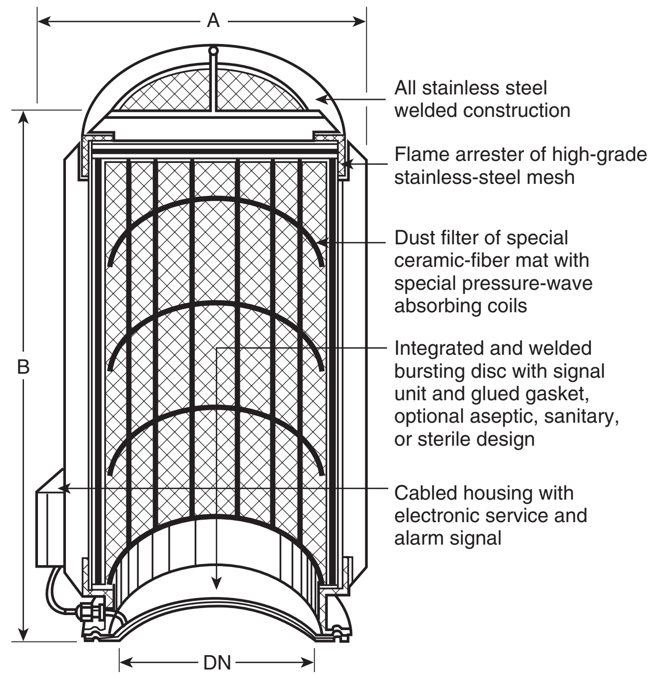



**FIGURE A.10.6 Example of Flame-Arresting and Particulate-Retention Vent System.**

**A.10.6.3** It is essential that the user work closely with the manufacturer to ensure that all of the parameters are addressed for a safe, reliable installation.

**A.11.2** 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, *Product Safety Signs and Labels.*

**A.11.4** Sample annual inspection form is shown in Figure A.11.4.

**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 (for example, hurricanes or snow and ice accumulations).

## VENT CLOSURE INFORMATION FORM

Date: ____________________

### CONTACT INFORMATION

Company name: ____________________ Responsible person: ____________________

Address: ____________________ Title: ____________________

City: ____________ State: _____ Zip code: ________ Telephone: ____________________

Telephone: ____________________ Report writer: ____________________

Equipment/process protected: ________________________________________

Vent ID number: ____________________ Vent location: ____________________

Vent size: ____________________ Vent manufacturer: ____________________

Vent type: ____________________ Vent model number: ____________________

Vent opening pressure: ____________________ 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: ____________________ ❑ psig ❑ or barg

### 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: ____________________ psig @ ____________

Normal operating temperature: ❑ ________ °F ❑ ________ °C

Maximum operating pressure: ____________________ psig @ ____________

Maximum operating temperature: ❑ ________ °F ❑ ________ °C

Maximum vacuum conditions: ❑ ________ psig ❑ ________ in. W.C.

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**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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**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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**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, please have a process engineer or user/supervisor address your findings as you have described below:

________________________________________

________________________________________

________________________________________

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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**FIGURE A.11.4** ***Continued***

**A.11.5** 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.11.8.2** 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:

$$P = \frac{n \cdot R \cdot T}{V} \qquad \textbf{(B.1.2.1)}$$

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.)*

**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 to the ratio of the density of the unburned gas to the density of the burned gas.

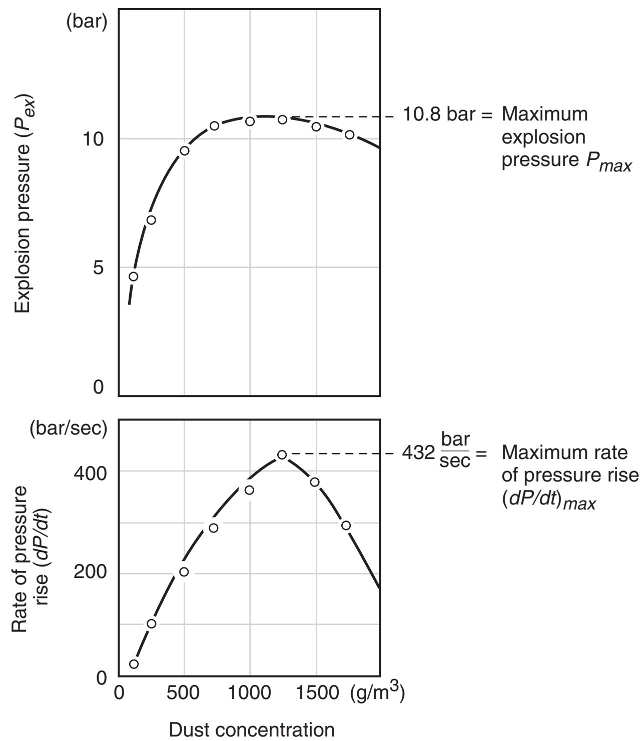


**FIGURE B.1.2.3 Variation of Deflagration Pressure and Deflagration Index with Concentration for Several Dusts. (Adapted from Bartknecht [51])**

**Table B.1.2.4 Hazard Classes of Dust Deflagrations**

| Hazard Class | $K_{St}$ (bar-m/sec)* | $P_{max}$ (bar)* |
|---|---|---|
| St-1 | ≤200 | 10 |
| St-2 | 201–300 | 10 |
| St-3 | >300 | 12 |

Notes:
(1) The application of Figure H.2(a) through Figure H.2(k) is limited to an upper $K_{St}$ value of 800.
(2) 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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts.*

**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, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.* (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.

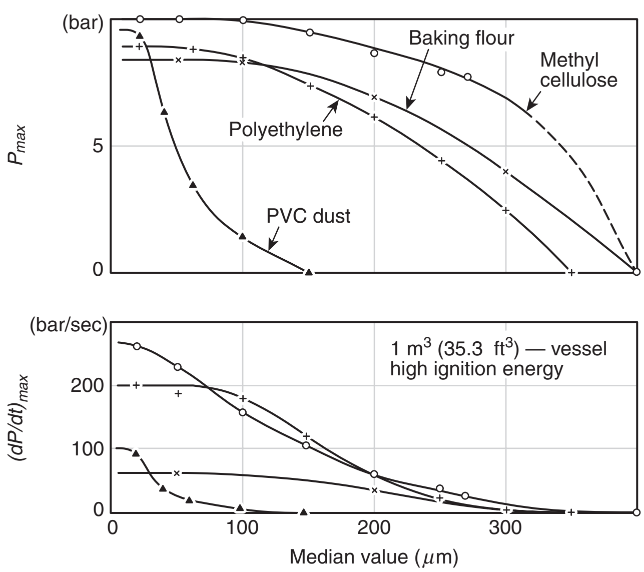


**FIGURE B.2.4.1 Effect of Particle Size of Dusts on the Maximum Pressure and Maximum Rate of Pressure Rise. [3]**

**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.

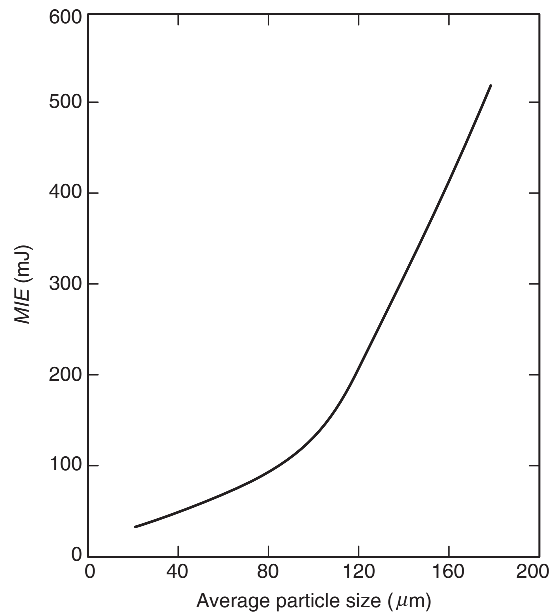


**FIGURE B.2.4.2.1 Effect of Average Particle Diameter of a Typical Agricultural Dust on the Minimum Ignition Energy. (Unpublished data courtesy of U.S. Mine Safety and Health Administration.)**

**B.2.4.2.2** 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.

**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, and 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.)*

**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/m³ to 50 g/m³, 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

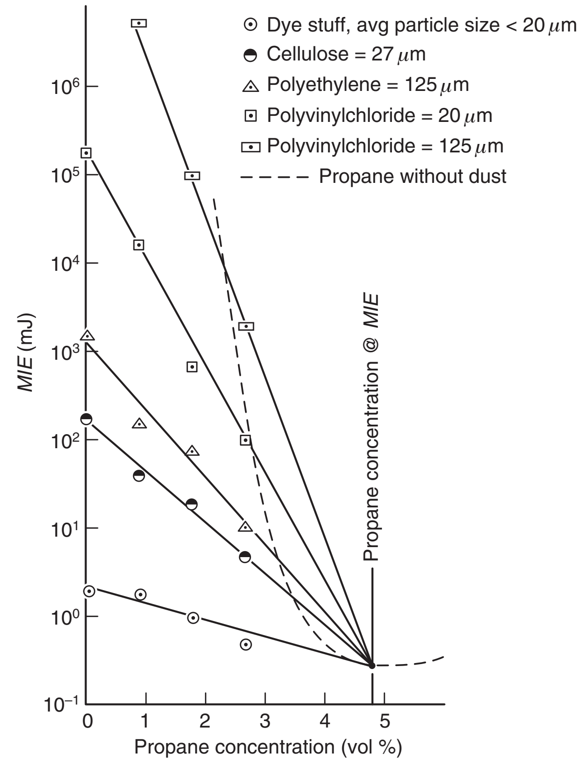


**FIGURE B.2.5.1 Lowest *MIE* of Hybrid Mixtures Versus Propane Content.**

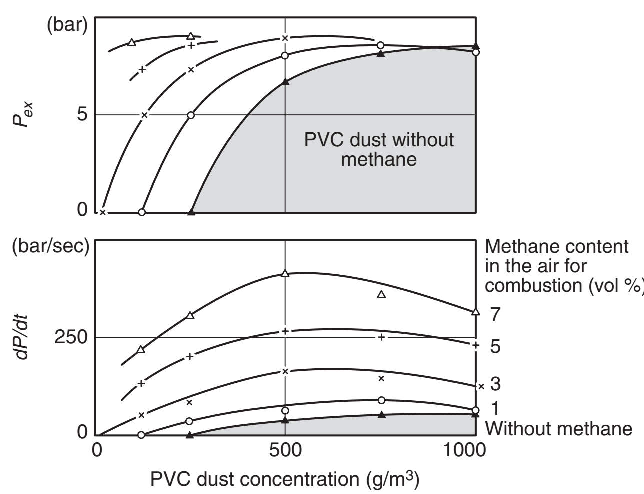


**FIGURE B.2.5.2 Deflagration Data for Hybrid Mixtures of Polyvinyl Chloride Dust and Methane Gas in Air [4].**

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.

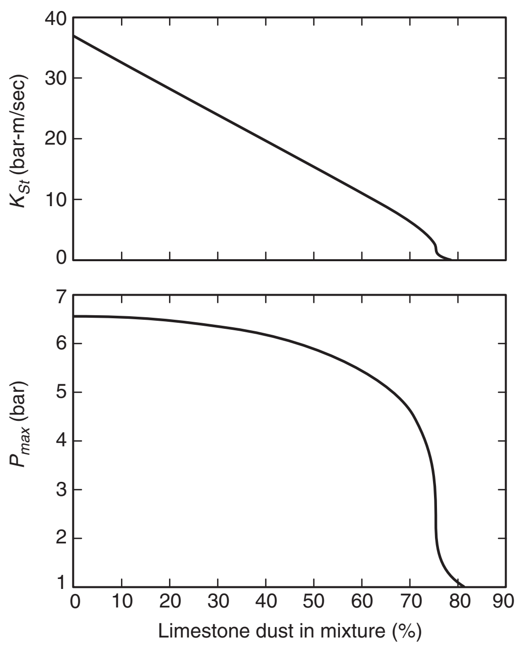


**FIGURE B.4.2.1 Effect of Added Inert Dust on Deflagration Data for Coal Dust in Air [109].**

**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 minimum ignition energy, *MIE*. The minimum ignition energy 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].

**B.5.2** An ignition source such as a spark or a flame can travel from one enclosure to another. A grinding spark (i.e., a hot, glowing particle) 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.

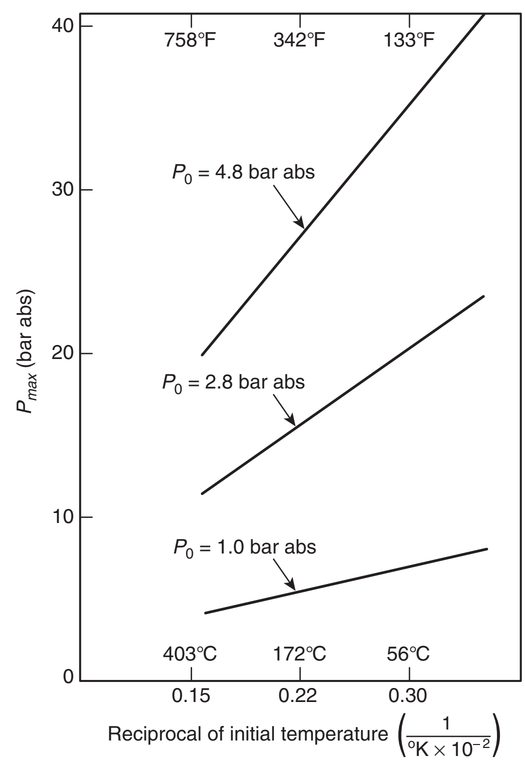


**FIGURE B.6 Effect of Initial Temperature on the Maximum Deflagration Pressure of Near-Stoichiometric Mixtures of Methane–Air at Three Initial Pressures, $P_0$. [19]**

**B.7 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.

**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.

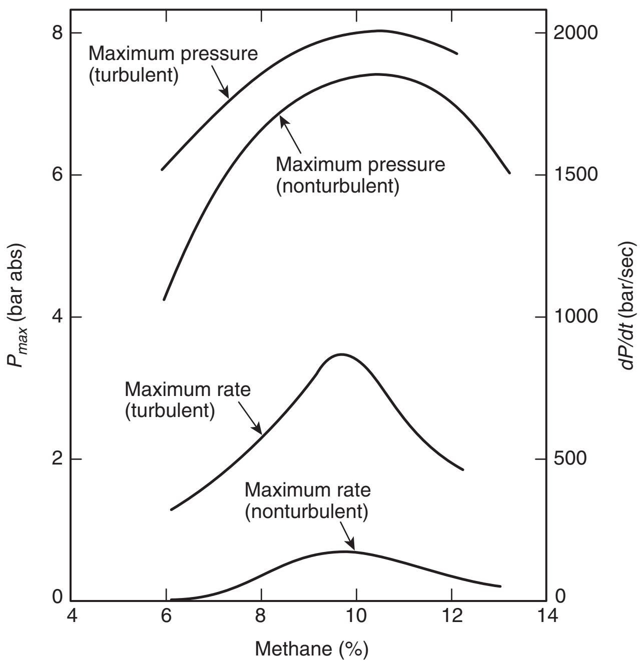


**FIGURE B.7.2 Effect of Turbulence on the Maximum Pressure and Rate of Pressure Rise for Methane–Air Mixtures. (Adapted from [20] and [21])**

**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 Indices of Dusts and Gases

*This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.*

**C.1 General Comments.** This annex discusses how the test procedure relates to the venting of large enclosures, but the test procedure is not described in detail. ASTM E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, sets forth a method for determining the maximum pressure and the rate of pressure rise of combustible dusts [96]. Because gases are not addressed in ASTM E 1226, test procedures are discussed in this annex.

ASTM E 2019, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*, and ASTM E 582, *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. *(See Figure C.1.)*

**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.** Figure H.1(a) through Figure H.1(g) and Figure H.2(a) through Figure H.2(k), presented in this standard, and those in VDI 3673 [104] 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 $K_G$ or $K_{St}$ index) needs to be experimentally obtained for use with Figure H.1(a) through Figure H.1(g) and Figure H.2(a) through Figure H.2(k). If the volume and mechanical constraints of the enclosure to be protected are known, the user can then determine the venting needed from the figures.

**C.3.1 The $K_G$ and $K_{St}$ Indices.** The test dusts used during the large-scale tests were classified according to the maximum rate of pressure rise that was 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 on which Figure H.1(a) through Figure H.1(g) and Figure H.2(a) through Figure H.2(k) are based.

It is possible that the $K_G$ index can similarly be determined in a 1 $m^3$(35 $ft^3$) vessel, but published $K_G$ values correspond to tests made in smaller vessels. The variable $K_G$ is known to be volume-dependent and should not be considered a constant. *(See Figure C.1.)* Its use is restricted to normalizing data gathered under a fixed set of test conditions.

**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. Figure H.1(a) through Figure H.1(g) are based on a series of gas mixtures that were used in the full-scale tests. The actual $K_G$ values are not critical in the calibration of gases, because it is possible to compare the maximum rate of pressure rise of a particular gas mixture with those of the gas mixtures represented by Figure H.1(a) through Figure H.1(g). If all values are measured under identical conditions in a vessel that meets certain criteria *(see Section C.4)* and adjusted as indicated in Annex E, the figures can be used. 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 $K_G$ and $K_{St}$ Indices.** 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.

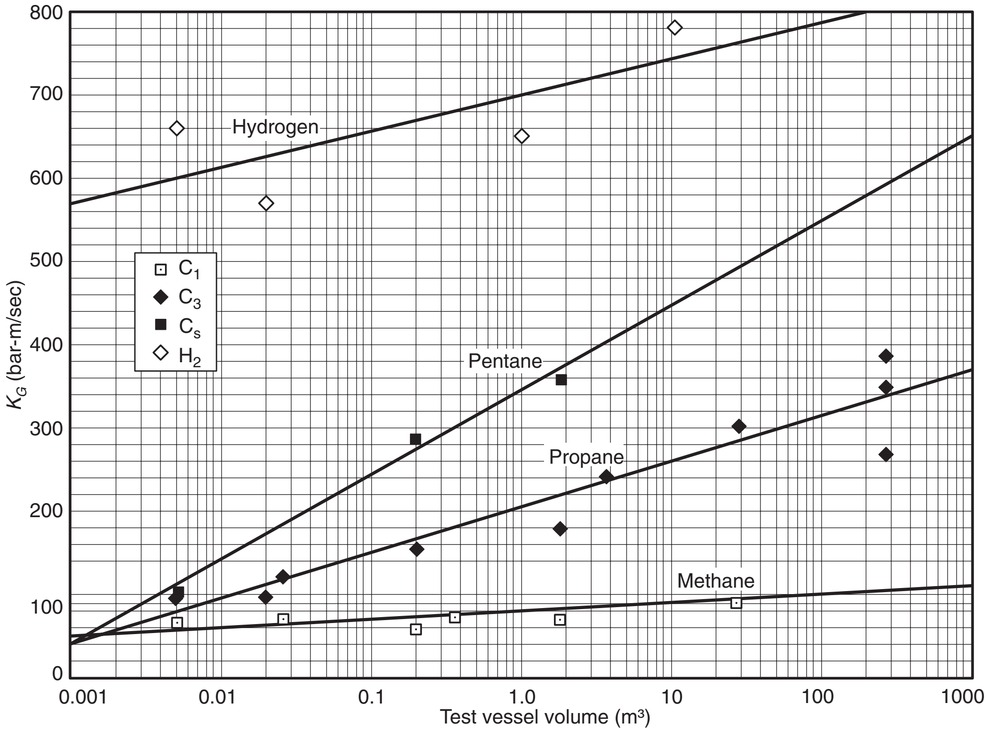


**FIGURE C.1 Effect of Test Volume on $K_G$ Measured in Spherical Vessels.**

$$\left(\frac{dP}{dt}\right)_{max} \cdot \left(V^{1/3}\right) = K \qquad \textbf{(C.3.3)}$$

where:
$P$ = pressure (bar)
$t$ = time (sec)
$V$ = volume ($m^3$)
$K$ = normalized $K_G$ or $K_{St}$ index (bar-m/sec)

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 $K_G$ or $K_{St}$ 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 8300 psi/sec (572 bar/sec). Substituting these values for the variables in Equation C.3.3, the normalized index equals 572 $(0.026)^{1/3}$, or 169 bar-m/sec.

**C.3.4 Effect of Volume on $K_G$ and $K_{St}$.** In the case of many initially quiescent gases, the normalized $K_G$ index is found not to be constant but to increase with vessel volume. Figure C.1 shows the variation of $K_G$ with vessel volume for methane, propane, and pentane as measured in spherical test vessels [77]. The increase in $K_G$ is related to various flame acceleration effects, as described in [44], [78], and [79]. Therefore, $K_G$ values that are measured in vessels of different sizes cannot be compared directly, even if all other factors affecting $K_G$ are held constant. Any $K_G$ measurement should be made in a spherical vessel at least 5 L in volume *(see Section C.4)*, and the values obtained should be corrected based on the methods in Annex E.

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 12.9 psi to 15.6 psi (0.89 bar to 1.08 bar), 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 11.5 psi (0.79 bar abs). 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.** 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 $K_G$ measurements in small vessels.

Standardized gas mixtures, as identified in Section E.2, can be initially tested in the system. Verification should be made that each gas mixture is well mixed and quiescent immediately prior to ignition. The maximum rates of pressure rise are measured systematically for several compositions close to the stoichiometric mixture until the maximum $K_G$ value has been determined. A table of $K_G$ values is then established for the standardized gases as measured in the test vessel. The table values are not necessarily the same as the $K_G$ values listed in Annex E.

To subsequently apply the venting requirements to a test gas, the maximum $K_G$ value for the test gas first has to be determined under conditions identical to those used for standardization. The test material is compared with standardized gases that have $K_G$ values above and below the test value as measured in the test vessel. The vent recommendations are then determined by application of the recommendations for the standardized gases.

A database in which $K_G$ values are given for a wide variety of gases that have been tested under the standardized conditions should be established for the test equipment. $K_G$ values should not be reported unless the database, or, at a minimum, the $K_G$ 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.)*

Although Figure H.1(a) through Figure H.1(g) deal with deflagrations of gases in air, it can be necessary to predict the effect of other oxidants such as chlorine. The $K_G$ concept should not be extended to such cases, except where considerable expertise can be demonstrated by the test facility. Many gaseous mixtures are incompatible with the test vessel material and with any trace contaminants within it, including traces of humidity. Expert opinion should be sought in the application of such test data to the protection of large enclosures.

**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. Due to the physical factors that influence the deflagration properties of dusts, Figure H.2(a) through Figure H.2(k) do not identify the dusts that are involved in large-scale testing, except by their measured $K_{St}$ values. 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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, 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 E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, 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], ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts, 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 (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 E 1515, *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/sec.

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 Fundamental Burning Velocities for Select Flammable Gases in Air

*This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.*

**D.1 General.** The values of fundamental burning velocity given in Table D.1(a) are based on NACA Report 1300 [82]. For the purpose of this guide, a reference value of 46 cm/sec for the fundamental burning velocity of propane has been used. The compilation given in Perry's *Chemical Engineers' Handbook* [83] is based on the same data (NACA Report 1300) but uses a different reference value of 39 cm/sec for the fundamental burning velocity of propane. The reason for using the higher reference value (46 cm/sec) is to obtain closer agreement with more recently published data as presented in Table D.1(b).

**Table D.1(a) Fundamental Burning Velocities of Selected Gases and Vapors**

| Gas | Fundamental Burning Velocity (cm/sec) | Gas | Fundamental Burning Velocity (cm/sec) |
|---|---|---|---|
| Acetone | 54 | Ethyl acetate | 38 |
| Acetylene | 166* | Ethylene oxide | 108 |
| Acrolein | 66 | Ethylenimine | 46 |
| Acrylonitrile | 50 | Gasoline (100-octane) | 40 |
| Allene (propadiene) | 87 | *n*-Heptane | 46 |
| Benzene | 48 | Hexadecane | 44 |
| *n*-butyl- | 37 | 1,5-Hexadiene | 52 |
| tertbutyl- | 39 | *n*-Hexane | 46 |
| 1,2-dimethyl- | 37 | 1-Hexene | 50 |
| 1,2,4-trimethyl- | 39 | 1-Hexyne | 57 |
| 1,2-Butadiene (methylallene) | 68 | 3-Hexyne | 53 |
| 1,3-Butadiene | 64 | HFC-23 Difluoromethane | 6.7 |
| 2,3-dimethyl- | 52 | HFC-143 1, 1, 2-Trifluoroethane | 13.1 |
| 2-methyl- | 55 | HFC-143a 1, 1, 1-Trifluoroethane | 7.1 |
| *n*-Butane | 45 | HFC-152a 1, 1-Difluoroethane | 23.6 |
| 2-cyclopropyl- | 47 | Hydrogen | 312 * |
| 2,2-dimethyl- | 42 | Isopropyl alcohol | 41 |
| 2,3-dimethyl- | 43 | Isopropylamine | 31 |
| 2-methyl- | 43 | Jet fuel, grade JP-1 (average) | 40 |
| 2,2,3-trimethyl- | 42 | Jet fuel, grade JP-4 (average) | 41 |
| Butanone | 42 | Methane | 40* |
| 1-Butene | 51 | diphenyl- | 35 |
| 2-cyclopropyl- | 50 | Methyl alcohol | 56 |
| 2,3-dimethyl- | 46 | 1,2-Pentadiene (ethylallene) | 61 |
| 2-ethyl- | 46 | cis-1,3-Pentadiene | 55 |
| 2-methyl- | 46 | trans-1,3-Pentadiene (piperylene) | 54 |
| 3-methyl- | 49 | 2-methyl-(cis or trans) | 46 |
| 2,3-dimethyl-2-butene | 44 | 1,4-Pentadiene | 55 |
| 2-Buten 1-yne (vinylacetylene) | 89 | 2,3-Pentadiene | 60 |
| 1-Butyne | 68 | *n*-Pentane | 46 |
| 3,3-dimethyl- | 56 | 2,2-dimethyl- | 41 |
| 2-Butyne | 61 | 2,3-dimethyl- | 43 |
| Carbon disulfide | 58 | 2,4-dimethyl- | 42 |
| Carbon monoxide | 46 | 2-methyl- | 43 |
| Cyclobutane | 67 | 3-methyl- | 43 |
| ethyl- | 53 | 2,2,4-trimethyl- | 41 |
| isopropyl- | 46 | 1-Pentene | 50 |
| methyl- | 52 | 2-methyl- | 47 |
| Methylene | 61 | 4-methyl- | 48 |
| Cyclohexane | 46 | cis-2-Pentene | 51 |
| methyl- | 44 | 1-Pentene | 63 |
| Cyclopentadiene | 46 | 4-methyl- | 53 |
| Cyclopentane | 44 | 2-Pentyne | 61 |
| methyl- | 42 | 4-methyl- | 54 |
| Cyclopropane | 56 | Propane | 46* |
| cis-1,2-dimethyl- | 55 | 2-cyclopropyl- | 50 |
| trans-1,2-dimethyl- | 55 | 1-deutero- | 40 |
| ethyl- | 56 | 1-deutero-2-methyl- | 40 |
| methyl- | 58 | 2-deutero-2-methyl- | 40 |
| 1,1,2-trimethyl- | 52 | 2,2-dimethyl- | 39 |
| trans-Decalin (decahydronaphthalene) | 36 | 2-methyl- | 41 |
| *n*-Decane | 43 | 2-cyclopropyl | 53 |
| 1-Decene | 44 | 2-methyl- | 44 |
| Diethyl ether | 47 | Propionaldehyde | 58 |
| Dimethyl ether | 54 | Propylene oxide (1,2-epoxypropane) | 82 |
| Ethane | 47 | 1-Propyne | 82 |
| Ethene (ethylene) | 80* | Spiropentane | 71 |
| | | Tetrahydropyran | 48 |
| | | Tetralin (tetrahydronaphthalene) | 39 |
| | | Toluene (methylbenzene) | 41 |

*Gases that have been critically examined in [84] or [85] with regard to fundamental burning velocity. Table D.1(b) compares the selected values from these references with those in Table D.1(a).

**Table D.1(b) Comparison of Fundamental Burning Velocities for Selected Gases, Fundamental Burning Velocity (cm/sec)**

| Gas | Table D.1(a) | Andrews and Bradley [84] (in air) | Andrews and Bradley [84] (in oxygen) | France and Pritchard [85] (in air) |
|---|---|---|---|---|
| Acetylene | 166 | 158 | 1140 | — |
| Ethylene | 80 | 79 | — | 0 |
| Hydrogen | 312 | 310 | 1400 | 347 |
| Methane | 40 | 45 | 450 | 43 |
| Propane | 46 | — | — | 46 |

## Annex E 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.*

**E.1 $K_G$ Values.** As stated in Annex C, the $K_G$ value is not constant and varies depending on test conditions such as type and amount of ignition energy, volume of test vessel, and other test conditions. Thus, a single value of $K_G$ for a particular set of test conditions is only one among a continuum of values that vary over the range of test conditions.

Figure C.1 provides $K_G$ values for methane, propane, and pentane over a range of vessel sizes [77].

Table E.1 provides $K_G$ 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).

A $K_G$ value for a flammable gas can be approximated from a known $K_G$ value for another flammable gas by the following equation:

$$(K_G)_2 = (K_G)_1 \cdot \frac{(S_u)_2}{(S_u)_1} \quad \textbf{(E.1)}$$

The values for $P_{max}$ for the two gases can be measured by actual test under near-identical conditions, or both can be calculated for adiabatic combustion conditions. However, one $P_{max}$ cannot be calculated while the other is measured by test. Optimum mixture is a mixture of the composition that yields the highest maximum pressure during combustion. Usually this is not a stoichiometric mixture but a mixture that is slightly richer in fuel gas than stoichiometric. Equation E.1 produces the most accurate values where the two flammable gases have similar values of $K_G$.

**E.2 Using New $K_G$ Data.** A method for developing $K_G$ values has not been standardized. As such, values that are determined by a laboratory can deviate from those employed by Bartknecht in developing the correlation coefficients for the vent area equation recommended for use with flammable gases. To maintain consistency in the application of the vent area equations in Chapter 7, $K_G$ data should be adjusted for equivalency with the Bartknecht data as shown in Table E.2. The procedure uses the Bartknecht $K_G$ values for methane (55) and propane (100) as points of reference. The following procedure is recommended.

**Table E.1 Flammability Properties of Gases 5 L (0.005 $m^3$) sphere; E = 10 J, normal conditions [101]**

| Flammable Material | $P_{max}$ (bar) | $K_G$ (bar-m/sec) |
|---|---|---|
| Acetophenone[a] | 7.6 | 109 |
| Acetylene | 10.6 | 1415 |
| Ammonia[b] | 5.4 | 10 |
| β-Naphthol[c] | 4.4 | 36 |
| Butane | 8.0 | 92 |
| Carbon disulfide | 6.4 | 105 |
| Diethyl ether | 8.1 | 115 |
| Dimethyl formamide[a] | 8.4 | 78 |
| Dimethyl sulfoxide[a] | 7.3 | 112 |
| Ethane[a] | 7.8 | 106 |
| Ethyl alcohol | 7.0 | 78 |
| Ethyl benzene[a] | 7.4 | 96 |
| Hydrogen | 6.8 | 550 |
| Hydrogen sulfide | 7.4 | 45 |
| Isopropanol[a] | 7.8 | 83 |
| Methane | 7.1 | 55 |
| Methanol[a] | 7.5 | 75 |
| Methylene chloride | 5.0 | 5 |
| Methyl nitrite | 11.4 | 111 |
| Neopentane | 7.8 | 60 |
| Octanol[a] | 6.7 | 95 |
| Octyl chloride[a] | 8.0 | 116 |
| Pentane[a] | 7.8 | 104 |
| Propane | 7.9 | 100 |
| South African crude oil | 6.8–7.6 | 36–62 |
| Toluene[a] | 7.8 | 94 |

[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).

**E.2.1** Develop $K_G$ values for propane and methane using the same equipment and method as employed for obtaining data on other gases of interest.

**E.2.2** Compute the linear adjustment coefficients, *A* and *B*, as follows:

$$B = \frac{\left[K_G(\text{propane}) - K_G(\text{methane})\right]_{WB}}{\left[K_G(\text{propane}) - K_G(\text{methane})\right]_{New}} \quad \textbf{(E.2.2a)}$$

$$A = K_G(\text{propane})_{WB} - B \cdot K_G(\text{propane})_{New} \quad \textbf{(E.2.2b)}$$

where:
*WB* = W. Bartknecht data
*New* = New data

**E.2.3** The adjusted value of $K_G$ that is determined by the new method is calculated as follows:

$$K_{G(adjusted)} = A + B \cdot K_{G\ (New)} \quad \textbf{(E.2.3)}$$

Figure E.2.3 shows the correlation for the data reported in Table E.2.

**Table E.2 Gas Explosibility Data as Measured and Adjusted Based on Bartknecht [110]**

| Gas | As Measured | Adjusted | $P_{max}$ (bar) |
|---|---|---|---|
| 1,1-Difluoroethane | 59 | 75 | 7.7 |
| Acetone | 65 | 84 | 7.3 |
| Dimethyl ether | 108 | 148 | 7.9 |
| Ethane | 78 | 103 | 7.4 |
| Ethyl alcohol | 78 | 103 | 7.0 |
| Ethylene | 171 | 243 | 8.0 |
| Isobutane | 67 | 87 | 7.4 |
| Methane | 46 | 55 | 6.7 |
| Methyl alcohol | 94 | 127 | 7.2 |
| Propane | 76 | 100 | 7.3 |
| Hydrogen | 638 | * | 6.5 |

Note: Adjusted $K_G$ = –14.0 + 1.50 $K_G$ (as measured).
*Not recommended due to excessive extrapolation.

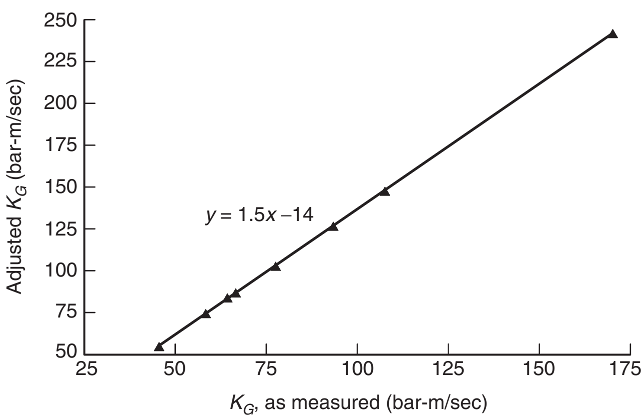


**FIGURE E.2.3 Reported $K_G$ Data. [111]**

## 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) | $K_{St}$ (bar-m/sec) | 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 |

**Table F.1(b) Carbonaceous Dusts**

| Material | Mass Median Diameter (μm) | Minimum Flammable Concentration (g/m³) | $P_{max}$ (bar) | $K_{St}$ (bar-m/sec) | Dust Hazard Class |
|---|---|---|---|---|---|
| Charcoal, activated | 28 | 60 | 7.7 | 14 | 1 |
| Charcoal, wood | 14 | 60 | 9.0 | 10 | 1 |
| Coal, bituminous | 24 | 60 | 9.2 | 129 | 1 |
| Coke, petroleum | 15 | 125 | 7.6 | 47 | 1 |
| Lampblack | <10 | 60 | 8.4 | 121 | 1 |
| Lignite | 32 | 60 | 10.0 | 151 | 1 |
| Peat, 22% $H_2O$ | — | 125 | 84.0 | 67 | 1 |
| Soot, pine | <10 | — | 7.9 | 26 | 1 |

**Table F.1(c) Chemical Dusts**

| Material | Mass Median Diameter (μm) | Minimum Flammable Concentration (g/m³) | $P_{max}$ (bar) | $K_{St}$ (bar-m/sec) | Dust Hazard Class |
|---|---|---|---|---|---|
| Adipic acid | <10 | 60 | 8.0 | 97 | 1 |
| Anthraquinone | <10 | — | 10.6 | 364 | 3 |
| Ascorbic acid | 39 | 60 | 9.0 | 111 | 1 |
| Calcium acetate | 92 | 500 | 5.2 | 9 | 1 |
| Calcium acetate | 85 | 250 | 6.5 | 21 | 1 |
| Calcium stearate | 12 | 30 | 9.1 | 132 | 1 |
| Carboxy- methyl-cellulose | 24 | 125 | 9.2 | 136 | 1 |
| Dextrin | 41 | 60 | 8.8 | 106 | 1 |
| Lactose | 23 | 60 | 7.7 | 81 | 1 |
| Lead stearate | 12 | 30 | 9.2 | 152 | 1 |
| Methyl-cellulose | 75 | 60 | 9.5 | 134 | 1 |
| Paraformaldehyde | 23 | 60 | 9.9 | 178 | 1 |
| Sodium ascorbate | 23 | 60 | 8.4 | 119 | 1 |
| Sodium stearate | 22 | 30 | 8.8 | 123 | 1 |
| Sulfur | 20 | 30 | 6.8 | 151 | 1 |

**Table F.1(d) Metal Dusts**

| Material | Mass Median Diameter (μm) | Minimum Flammable Concentration (g/m³) | $P_{max}$ (bar) | $K_{St}$ (bar-m/sec) | Dust Hazard Class |
|---|---|---|---|---|---|
| Aluminum | 29 | 30 | 12.4 | 415 | 3 |
| Bronze | 18 | 750 | 4.1 | 31 | 1 |
| Iron carbonyl | <10 | 125 | 6.1 | 111 | 1 |
| Magnesium | 28 | 30 | 17.5 | 508 | 3 |
| Phenolic resin | 55 | — | 7.9 | 269 | 2 |
| Zinc | 10 | 250 | 6.7 | 125 | 1 |
| Zinc | <10 | 125 | 7.3 | 176 | 1 |

**Table F.1(e) Plastic Dusts**

| Material | Mass Median Diameter (μm) | Minimum Flammable Concentration ($g/m^3$) | $P_{max}$ (bar) | $K_{St}$ (bar-m/sec) | Dust Hazard Class |
|---|---|---|---|---|---|
| (poly) Acrylamide | 10 | 250 | 5.9 | 12 | 1 |
| (poly) Acrylonitrile | 25 | — | 8.5 | 121 | 1 |
| (poly) Ethylene (low-pressure process) | <10 | 30 | 8.0 | 156 | 1 |
| Epoxy resin | 26 | 30 | 7.9 | 129 | 1 |
| Melamine resin | 18 | 125 | 10.2 | 110 | 1 |
| Melamine, molded (wood flour and mineral filled phenol-formaldehyde) | 15 | 60 | 7.5 | 41 | 1 |
| Melamine, molded (phenol-cellulose) | 12 | 60 | 10.0 | 127 | 1 |
| (poly) Methyl acrylate | 21 | 30 | 9.4 | 269 | 2 |
| (poly) Methyl acrylate, emulsion polymer | 18 | 30 | 10.1 | 202 | 2 |
| Phenolic resin | <10 | 15 | 9.3 | 129 | 1 |
| | 55 | | 7.9 | 269 | 2 |
| (poly) Propylene | 25 | 30 | 8.4 | 101 | 1 |
| Terpene-phenol resin | 10 | 15 | 8.7 | 143 | 1 |
| Urea-formaldehyde/ cellulose, molded | 13 | 60 | 10.2 | 136 | 1 |
| (poly) Vinyl acetate/ ethylene copolymer | 32 | 30 | 8.6 | 119 | 1 |
| (poly) Vinyl alcohol | 26 | 60 | 8.9 | 128 | 1 |
| (poly) Vinyl butyral | 65 | 30 | 8.9 | 147 | 1 |
| (poly) Vinyl chloride | 107 | 200 | 7.6 | 46 | 1 |
| (poly) Vinyl chloride/vinyl acetylene emulsion copolymer | 35 | 60 | 8.2 | 95 | 1 |
| (poly) Vinyl chloride/ethylene/vinyl acetylene suspension copolymer | 60 | 60 | 8.3 | 98 | 1 |

## Annex G Calculation Method for Correction Factor Due to Increased Vent Panel Mass

*This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.*

**G.1 General.** The following procedure can be used to assess the impact of the vent panel mass on $P_{red}$.

**G.1.1 Introduction.** The mass of vent panels is a factor that can limit the effectiveness of the venting process. To properly assess the influence panel mass contributes, other factors must also be considered, such as the reactivity of the dust, the enclosure volume and the number, shape, size, and type of deflagration vents utilized. The procedures for determining the effects of vent panel inertia on deflagration venting are presented in this section. The theoretical development uses mostly absolute pressures, instead of the gauge pressures used in the remainder of this document, and new pressure terms are defined. Pressures are used in bar, bar-abs, and pascals-abs; thus the reader is cautioned to note units of measure directly following each equation.

**G.1.2** The reduced deflagration pressure is first calculated using Equation 8.2.2, based on low-mass vents. Corrections for vessel $L/D$ and partial volume can then be added. This will be an iterative solution for the $P_{red}$ resulting from the assumed vent area. Next, the correction factors for inertia effects are calculated.

**G.1.3** The inertia of the panel can manifest itself in the following two ways:

(1) As a new factor in the effective vent relief pressure, $p_{vi}$, higher than the nominal static value, $p_v$
(2) As a higher reduced pressure, $p_{ri}$, after full vent deployment with respect to the $p_{ri0}$ in the absence of inertia.

The highest pressure during the vented deflagration can occur either at the point of vent relief or later after vent deployment. As inertia of the panel affects both pressures, both effects have to be calculated and the higher value, $p_{vi}$ or $p_{ri}$, used as the reduced pressure produced in the vented deflagration.

**G.1.3.1** The inertia correction is limited to the following:

(1) Vent panel density, $\sigma_v < 200$ kg/m$^2$
(2) Nominal static relief pressure, $p_v < 0.5$ bar

**G.1.4** Both inertia effects are evaluated using two dimensionless parameters, Σ and Γ. However, one term in the parameters is different, that is, the dust reactivity. In the first case, the deflagration index, $K_{St}$, is used to determine $\Sigma_{K_{St}}$ and $\Gamma_{K_{St}}$. In the second case, the effective mixture reactivity, $K$, is used to determine $\Sigma_K$ and $\Gamma_K$.

**G.1.5** The deflagration index, $K_{St}$, of a dust is basically the maximum rate of pressure rise generated in a confined deflagration. The effective mixture reactivity is a parameter based on $K_{St}$, but it contains two corrections to account for the effects of the deflagration vent relief pressure and the volume of the protected enclosure. The vent relief pressure correction is the following:

$$K_{St,v} = K_{St} \cdot \left[1 + 1.75 \cdot \left(\frac{\Delta p_v}{p_0}\right)\right] \quad \textbf{(G.1.5a)}$$

where:
$K_{St,v}$ = deflagration index with vent relief pressure correction
$K_{St}$ = deflagration index (bar-m/sec)
$\Delta p_v$ = vent relief pressure (bar) = $P_{stat}$
$p_0$ = initial pressure (bar-abs)

The volume correction for Equation G.1.5a is the following:

$$K = K_{St,v} \cdot \left(\frac{V}{10 \text{ m}^3}\right)^{0.11} \quad \textbf{(G.1.5b)}$$

where:
$K$ = volume correction to deflagration index
$V$ = enclosure volume (m$^3$)

This volume correction is applied only where the enclosure volume is greater than 10 m$^3$; otherwise $K = K_{St,v}$.

**G.1.6** The shape factor for the vent(s) is as follows:

For square panels, $c_s = 1$.
For circular panels, $c_s = 0.886$.
For rectangular panels, apply the following equation:

$$c_s = \frac{1+\alpha}{2\sqrt{\alpha}} \quad \textbf{(G.1.6)}$$

where α = the ratio of the rectangle's smaller side to its longer side

**G.1.7** Calculate $\Sigma_{K_{St}}$ and $\Sigma_K$ using Equation G.1.7a and Equation G.1.7b.

$$\Sigma_{K_{St}} = \frac{\sigma_v}{\left(n^{1/2}\right)\cdot\left(c_s\right)\cdot\left(\alpha_{cd}^{1/2}\right)\cdot\left(p_0\right)\cdot\left(V^{1/3}\right)} \cdot \left(\frac{K_{St}}{\Delta p_m}\right)^{5/2} \quad \textbf{(G.1.7a)}$$

$$\Sigma_K = \frac{\sigma_v}{\left(n^{1/2}\right)\cdot\left(c_s\right)\cdot\left(\alpha_{cd}^{1/2}\right)\cdot\left(p_0\right)\cdot\left(V^{1/3}\right)} \cdot \left(\frac{K}{\Delta p_m}\right)^{5/2} \quad \textbf{(G.1.7b)}$$

where:
$\Sigma_{K_{St}}, \Sigma_K$ = dimensionless parameters
$\sigma_v$ = vent panel density (kg/m$^2$)
$n$ = number of equal-sized panels
$c_s$ = shape factor
$\alpha_{cd}$ = constant = 232.5 m/sec
$P_0$ = initial pressure (pascals absolute, N/m$^2$)
$V$ = enclosure volume (m$^3$)
$K_{St}$ = deflagration index (bar-m/sec)
$K$ = effective mixture reactivity (bar-m/sec)
$\Delta p_m$ = unvented pressure rise (bar) = $p_m - p_0$

**G.1.7.1** For hinged vent closures, increase the value of vent panel density, $\sigma_v$, by 33 percent.

**G.1.8** Calculate $\Gamma_{K_{St}}$ and $\Gamma_K$ using Equation G.1.8a and Equation G.1.8b.

$$\Gamma_{K_{St}} = \alpha_{cd} \cdot \left(\frac{A_v}{V^{2/3}}\right)\cdot\left(\frac{\Delta p_m}{K_{St}}\right) \quad \textbf{(G.1.8a)}$$

$$\Gamma_K = \alpha_{cd} \cdot \left(\frac{A_v}{V^{2/3}}\right)\cdot\left(\frac{\Delta p_m}{K}\right) \quad \textbf{(G.1.8b)}$$

where:
$\Gamma_{K_{St}}, \Gamma_K$ = dimensionless parameters
$A_v$ = vent area (m$^2$)

**G.1.9** Calculate the pressure function, $f(P_v)$, using Equation G.1.9a and Equation G.1.9b.

$$P_v = \frac{p_v - p_0}{p_m - p_0} \quad \textbf{(G.1.9a)}$$

$$f\left(P_v\right) = \left(1000 \cdot P_v\right)^{0.5} \quad \textbf{(G.1.9b)}$$

where:
$P_v$ = pressure ratio
$p_v$ = vent panel static relief pressure (bar-abs)
$p_0$ = initial pressure (bar-abs)
$p_m$ = unvented deflagration pressure (bar-abs)

**G.1.10** Calculate the panel inertia parameter, η, using Equation G.1.10.

$$\eta = \frac{2}{3} - \frac{1}{60} \cdot \left\{ max\left[1, f\left(P_v\right)\right] + 3.2 \cdot \left(\frac{m \cdot g \cdot \sigma_v}{p_v - p_0}\right) \cdot f\left(p_v\right) \right\} \quad \textbf{(G.1.10)}$$

where:
η = panel inertia parameter
$m$ = vent gravity coefficient, assisting or slowing vent opening as defined in Table G.1.10.
$g$ = gravitational acceleration (m/sec$^2$)
$p_v$ = vent panel static relief pressure (pascals absolute, N/m$^2$)
$p_0$ = initial pressure (pascals absolute, N/m$^2$)

**Table G.1.10 Value of Vent Gravity Coefficient**

| Panel Characteristics | Value of *m* |
|---|---|
| Horizontal panel, on top of the vessel | 1 |
| Other orientations | 0 |

**G.1.11** The new effective vent relief pressure with inertia can be determined as follows:

$$p_{vi} = p_v + 0.21 \cdot \left( \frac{\Sigma_{K_{St}}}{\Gamma_{K_{St}}^{1/2}} \right)^{\eta} \cdot \Delta p_m \qquad \textbf{(G.1.11)}$$

where:

$p_{vi}$ = effective vent relief pressure with inertia (bar-abs)
$p_v$ = vent panel static relief pressure, $P_{stat} + 1$ (bar-abs)
$\Delta p_m$ = unvented pressure rise (bar) = $p_m - p_O$

**G.1.12** The new reduced pressure after full vent deployment can be determined as follows, depending on the value of $\Gamma_K$:

$$\text{For } \Gamma_K \leq 1; p_{ri} = p_{r0} + (p_m - p_0) \cdot (\Sigma_K)^{3/5} \cdot (0.26 \cdot \Gamma_K)$$

$$\text{For } 1 < \Gamma_K < 3; p_{ri} = p_{r0} + (p_m - p_0) \cdot (\Sigma_K)^{3/5} \cdot (0.26) \cdot (\Gamma_K - 3) \cdot (0.25 - 0.75 \cdot \Gamma_K) \qquad \textbf{(G.1.12)}$$

$$\text{For } \Gamma_K \geq 3; p_{ri} = p_{r0}$$

where:

$p_{ri}$ = the reduced pressure developed with inertia (bar-abs)
$p_{r0}$ = the reduced pressure developed with low-mass vents, $P_{red}$ +1 (bar-abs)
$p_m$ = unvented deflagration pressure, $P_{max} + 1$ (bar-abs)
$p_0$ = initial pressure (bar-abs)

**G.1.13** Compare the results obtained in Equations G.1.11 and G.1.12. The larger of the two results, $p_{vi}$ or $p_{ri}$, represents the new maximum reduced deflagration pressure (in bar-abs) due to the vent panel inertia effect. The value of $p_{vi}$ or $p_{ri}$ must be converted to gauge pressure as $P_{red}$ to iterate Equation 8.2.2. If the calculated pressure exceeds the enclosure strength, the user should repeat the calculation with a larger vent area.

**G.2 Example Problem.** Determine the maximum pressure developed by a deflagration when the conditions are as follows:

(1) $V = 100\ m^3$ (L/D≤2)
(2) $K_{St} = 200$ bar-m/sec
(3) $P_0 = 1$ bar-abs
(4) $P_{max} = 9$ bar-abs
(5) $\sigma = 24.4\ kg/m^2$
(6) $n$ = 4 (equal square panels vertically mounted, not hinged)
(7) $A_v = 6\ m^2$ (total for 4 vents)
(8) $P_{stat} = 0.05$ bar

The first step is to determine the reduced deflagration pressure developed if zero-mass vents were used.

From Equation 8.2.2, solve for $\prod$:

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

Solve for Π:

$$\Pi = P_{red} / P_{max}$$

$$\Pi = \frac{1}{1 + \left( \frac{A_{v0}}{1 \cdot 10^{-4} \cdot (1 + 1.54 \cdot P_{stat}^{4/3}) \cdot K_{St} \cdot V^{3/4}} \right)^2}$$

$$\Pi = \frac{1}{1 + \left( \frac{6}{1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot (0.05)^{4/3}\right) \cdot (200) \cdot (100)^{3/4}} \right)^2}$$

$$= 0.0116$$

The reduced pressure is then calculated by

$$P_{red} = \Delta p_m \cdot \Pi$$
$$= (9 - 1) \cdot (0.0116) = 0.0928 \text{ bar}$$

To solve Equation G.1.11, we must first determine the values of $\Sigma_{K_{St}}$, $\Gamma_{K_{St}}$, and η:

$$\Sigma_{K_{St}} = \frac{\sigma_v}{(n^{1/2}) \cdot (c_s) \cdot (\alpha_{cd}^{1/2}) \cdot (p_0) \cdot (V^{1/3})} \cdot \left( \frac{K_{St}}{\Delta p_m} \right)^{5/2}$$

$$= \frac{24.4}{(2) \cdot (1) \cdot (15.25) \cdot (10^5) \cdot (4.64)} \cdot \left( \frac{200}{8} \right)^{5/2} = 0.0054$$

$$\Gamma_{K_{St}} = \alpha_{cd} \left( \frac{A_v}{V^{2/3}} \right) \cdot \left( \frac{\Delta p_m}{K_{St}} \right)$$

$$= 232.5 \cdot \frac{6}{21.54} \cdot \frac{8}{200} = 2.59$$

From Equation G.1.9a,

$$P_v = \frac{p_v - p_0}{p_m - p_0}$$

$$= \frac{1.05 - 1}{9 - 1} = 0.00625$$

and from Equation G.1.9b,

$$f(P_v) = (1000 \cdot P_v)^{0.5}$$
$$= \sqrt{1000 \cdot 0.00625} = 2.5$$

$$\eta = \frac{2}{3} - \frac{1}{60} \cdot \left\{ max\left[1, f(P_v)\right] + 3.2 \cdot \left( \frac{m \cdot g \cdot \sigma_v}{P_v - P_0} \right) \cdot f(P_v) \right\}$$

$$= \frac{2}{3} - \frac{1}{60} \cdot (2.5 + 0) = 0.625$$

Now we can solve Equation G.1.11:

$$p_{vi} = p_v + 0.21 \cdot \left( \frac{\Sigma_{K_{St}}}{\Gamma_{K_{St}}^{1/2}} \right)^{\eta} \cdot \Delta p_m$$

$$p_{vi} = (0.05 + 1) + 0.21 \cdot \left( \frac{0.0054}{2.59^{1/2}} \right)^{0.625} \cdot (9 - 1)$$

$$= 1.098 \text{ bar-abs}(0.098 \text{ bar})$$