

NFPA 68

Guide for

Venting of Deflagrations

2002 Edition

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This edition of NFPA 68, Guide for Venting of Deflagrations, was prepared by the Technical Committee on Explosion Protection Systems and acted on by NFPA at its November Association Technical Meeting held November 10–14, 2001, in Dallas, TX. It was issued by the Standards Council on January 11, 2002, with an effective date of January 31, 2002, and supersedes all previous editions.

This edition of NFPA 68 was approved as an American National Standard on January 31, 2002.

Origin and Development of NFPA 68

NFPA 68, Guide for Venting of Deflagrations, 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 represents a complete revision of the guide and includes updated and enhanced treatment for deflagration venting design for dusts and hybrid mixtures. The revision includes new vent design equations based upon the methodology developed by Factory Mutual Research Corporation. In addition to the generalized correlation for dusts, there are new methods to evaluate the effects of vent ducts, partial volumes, vent panel inertia, and initially elevated pressures. All design guidelines for gas mixtures have been combined into a single chapter and the document has undergone Manual of Style revision as well.

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Committee Scope: This Committee shall have primary responsibility for documents on explosion protection systems for all types of equipment and for buildings, except pressure venting devices designed to protect against overpressure of vessels such as those containing flammable liquids, liquefied gases, and compressed gases under fire exposure conditions, as now covered in existing NFPA standards.

This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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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, Annex J lists the complete title and edition of the source documents for both mandatory and nonmandatory extracts. 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 appropriate technical committee.

Information on referenced publications can be found in Chapter 2 and Annexes G, I, and J.

Chapter 1 Administration

1.1 Scope.

1.1.1 This guide 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. A deflagration can result from the ignition of a flammable gas, mist, or combustible dust.

1.1.2 This guide should be used as 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.

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

1.1.4* This guide 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.

1.1.5 This guide does not apply to emergency vents for runaway exothermic reactions or self-decomposition reactions.

1.1.6 This guide does not apply to pressure relief devices on equipment such as oil-insulated transformers. It also does not apply to pressure relief valves on tanks, pressure vessels, or domestic (residential) appliances.

1.2 Purpose.

The purpose of this guide is to provide the user with criteria for venting of deflagrations. It is important to note that venting does not prevent a deflagration; venting can, however, minimize the destructive effects of a deflagration.

1.3 Application.

1.3.1* This guide applies where the need for deflagration venting has been established. Nothing in this guide is intended to require the installation of vents on any enclosure.

1.3.2 It is not intended that the provisions of this guide be applied to facilities, equipment, structures, or installations with deflagration venting that were existing or approved for construction or installation prior to the effective date of the document, except in those cases where it is determined that the existing situation involves a distinct hazard to life or property.

1.4 Conversion Factors.

The conversion factors in Table 1.4 are useful for understanding the data presented in this guide.

Table 1.4 Conversion Factors

Parameter	Unit	Equivalent
Length	1 m	3.28 ft
	39.4 in.	
	1 in.	2.54 cm
	1 ft	30.5 cm
	1 m	1.00×10^{-6} m
	1 m ²	10.8 ft ²
Area	1 in. ²	6.45 cm ²
	1 L	61.0 in. ³
Volume	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
Pressure		231 in. ³
		0.134 ft ³
	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	
Energy	1 kg/cm ²	14.2 psi
	1 kg/m ²	0.205 lb/ft ² (psf)
	1 J	1.00 W-sec
	1 Btu	1055 J
	1 J	0.738 ft-lb
KG and KSt 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 1.4:

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
 oz = ounce
 N = newton
 Pa = pascal
 psf = pounds per square foot
 psi = pounds per square inch
 sec = second
 m = micron (micrometer)
 W = watt

1.5 Symbols.

The following symbols are defined for the purpose of this guide.

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)
KG	=	Deflagration index for gases (bar-m/sec)
K _r	=	Reaction force constant (lb)
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)

1.6 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 guide and should be considered part of the recommendations of this document.

2.2 NFPA Publications.

National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 69, Standard on Explosion Prevention Systems, 1997 edition.

NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, 2000 edition.

2.3 Other Publications.

2.3.1 API Publication.

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

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

2.3.2 ASME Publication.

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

ASME Boiler and Pressure Vessel Code, 1998.

2.3.3 ASTM Publication.

American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.
ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts, 1994.
Chapter 3 Definitions

3.1 General.

The definitions contained in this chapter apply to the terms used in this guide. Where terms are not included, common usage of the terms applies.

3.2 Official NFPA Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

3.2.3 Guide. A document that is advisory or informative in nature and that contains only nonmandatory provisions. A guide may contain mandatory statements such as when a guide can be used, but the document as a whole is not suitable for adoption into law.

3.2.4 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.

3.2.5* 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.

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

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 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. [211:1.5]

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

3.3.4 Deflagration Index. Value indicated by the use of variable, K. (See 3.3.15 and 3.3.16.)

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

3.3.6 Dust. Any finely divided solid, 420 m or 0.017 in. or less in diameter (that is, material capable of passing through a U.S. No. 40 standard sieve).

3.3.7* Enclosure. A confined or partially confined volume.

3.3.8 Explosion. The bursting or rupturing of an enclosure or a container due to the development of internal pressure from a deflagration. [69:1.9]

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

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

3.3.10.1* Lower Flammable Limit (LFL). The lowest concentration of a combustible substance in a gaseous oxidizer that will propagate a flame.

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

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

3.3.12 Flash Point. The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitable mixture with air near the surface of a liquid, as specified by test.

3.3.13 Fundamental Burning Velocity. See 3.3.1.1.

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

3.3.15* KG. The deflagration index of a gas cloud.

3.3.16* KSt. The deflagration index of a dust cloud.

3.3.17 Maximum Pressure (Pmax). The maximum pressure developed in a contained deflagration of an optimum mixture.

3.3.18* 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.

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

3.3.20 Mixture.

3.3.20.1 Hybrid Mixture. A mixture of a flammable gas with either a combustible dust or a combustible mist.

3.3.20.2* 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.

3.3.20.3 Stoichiometric Mixture. A balanced mixture of fuel and oxidizer such that no excess of either remains after combustion.

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

- 3.3.22 Rate of Pressure Rise (dP/dt). The increase in pressure divided by the time interval necessary for that increase to occur.
- 3.3.22.1* 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.
- 3.3.23 Reduced Pressure (P_{red}). The maximum pressure developed in a vented enclosure during a vented deflagration.
- 3.3.24 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).
- 3.3.25 Strength.
- 3.3.25.1 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} .
- 3.3.25.2 Ultimate Strength. The pressure that results in the failure of the weakest structural component of an enclosure.
- 3.3.26 Vapor. See 3.3.14, Gas.
- 3.3.27 Vent. An opening in an enclosure to relieve the developing pressure from a deflagration.
- 3.3.28 Vent Closure. A pressure-relieving cover that is placed over a vent.

Chapter 4 Fundamentals of Deflagration

4.1 Scope.

This chapter addresses the essential points that pertain to deflagrations in air, which result in the rapid development of pressure in enclosures.

4.2 General.

4.2.1 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

4.2.2 Deflagration Pressure.

4.2.2.1 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:

(4.1)

where:

R = universal gas constant

4.2.2.2 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 B.) The value of P_{max} for most ordinary fuels is 6 to 10 times the absolute pressure at the time of ignition.

4.2.3 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, $(dP/dt)_{max}$. The deflagration index, K , is computed from the maximum rate of pressure rise attained by combustion in a closed vessel with volume, V , as follows:

(4.2)

4.2.3.1 The value of $(dP/dt)_{max}$ is the maximum for a particular fuel concentration, referred to as the optimum concentration. (See examples in Figure 4.2.3.1.) The deflagration index is K_G for gases and K_{St} for dusts.

FIGURE 4.2.3.1 Variation of Deflagration Pressure and Deflagration Index with Concentration for Several Dusts. (Adapted from [51].)

4.2.4 Based on the K_{St} values, dusts have been categorized into three hazard classes (St-1, St-2, and St-3). These classes give an indication of the relative explosibility hazard and deflagration vent sizing requirements, as shown in Table 4.2.4.

Table 4.2.4 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 7.2.6(a) through Figure 7.2.6(q) is limited to an upper K_{St} value of 800.
2. See Annex E for examples of K_{St} values.

* K_{St} and P_{max} are determined in approximately spherical calibrated test vessels of at least 20 L (5.3 gal) capacity per ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts.

4.2.5 Burning Velocity and Flame Speed.

4.2.5.1 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 C.)

4.2.5.2 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.

4.2.6 Deflagrations that occur in enclosures that are not strong enough to accommodate the pressure could result in explosions, damage to the enclosure, and injury to nearby personnel.

4.2.7 Venting is one means of limiting the pressure generated in an enclosure by a deflagration. By releasing expanding gases through an opening engineered for the purpose, it is possible to limit the pressure generated to a reduced maximum pressure, P_{red} , that is below a pressure that can cause unacceptable damage to the enclosure.

4.3 Fuel.

4.3.1 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.

4.3.2 Concentration. The concentration of a gaseous fuel in air is usually expressed in volume percent (vol %) or mole percent (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/m³).

4.3.3 Flammable Gas.

4.3.3.1* 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.

4.3.3.2 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.

4.3.4 Combustible Dust.

4.3.4.1 Solid particulates smaller than 420 μ m (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 4.3.4.1.

FIGURE 4.3.4.1 Effect of Particle Size of Dusts on the Maximum Pressure and Maximum Rate of Pressure Rise. [3]

4.3.4.2 Particle Size.

4.3.4.2.1 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 4.3.4.2.1 illustrates this effect.

FIGURE 4.3.4.2.1 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.)

4.3.4.2.2 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.

4.3.4.3 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.

4.3.4.4 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.

4.3.4.5 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.

4.3.4.6 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 cannot usually be prevented by maintaining high dust cloud concentrations.

4.3.4.7 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 B.5.)

4.3.5 Hybrid Mixture.

4.3.5.1 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 the gas is below its lower flammable limit and the dust is below its lower flammable limit. Careful evaluation of the ignition and deflagration characteristics of the specific mixtures is necessary. (See Figure 4.3.5.1.)

FIGURE 4.3.5.1 Lowest MIE of Hybrid Mixtures versus Propane Content.

4.3.5.2 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 4.3.5.2.)

FIGURE 4.3.5.2 Deflagration Data for Hybrid Mixtures of Polyvinyl Chloride Dust and Methane Gas in Air. [4]

4.3.5.3 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.

4.3.6 Mist.

4.3.6.1 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.

4.3.6.2 Combustible mists ignite not only at temperatures above the flash point of the liquid, but also at temperatures below the flash point [62,63,64,65]. The design of deflagration venting for many combustible mists can be based on Equation 6.5, using the KG for propane of 100 bar-m/sec.

4.4 Oxidant.

4.4.1* 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.

4.4.2 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 guide is confined to those cases where the oxidizing medium is normal atmospheric air consisting of 21 volume percent oxygen unless specifically noted otherwise.

4.5 Inert Material.

4.5.1* Inert Gases. Inert gases can be used to reduce the oxidant concentration. Nitrogen and carbon dioxide are commonly used inerting gases.

4.5.2 Inert Powder.

4.5.2.1 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 4.5.2.1 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 4.5.2.1 Effect of Added Inert Dust on Deflagration Data for Coal Dust in Air. [109]

4.5.2.2 Some inert powders in small concentrations, such as silica, can be counterproductive because they can increase the dispersibility of the combustible dust.

4.5.3 Presence of Moisture (Water Content).

4.5.3.1 An increase in the moisture content of a dust can increase the minimum energy necessary for ignition, ignition temperature, and flammable limit. An increase in the moisture content of a dust also can decrease the maximum rate of pressure rise. Moisture in a dust can inhibit the accumulation of electrostatic charges.

4.5.3.2 Moisture in the air (humidity) surrounding a dust particle has no significant effect on a deflagration once ignition occurs.

4.5.3.3 A moisture addition process should not be used as the basis for reducing the size of deflagration vents. 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.

4.6 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).

4.6.1* 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].

4.6.2 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.

4.6.3 The location of the ignition source within an enclosure can affect the rate of pressure rise. In the case of 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 results in a higher rate of pressure rise than ignition in the center of the enclosure.

4.6.4 Simultaneous multiple ignition sources intensify the deflagration that results in an increased dP/dt .

4.7 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 4.7.) This effect can be substantial in cases of vapor explosions at cryogenic temperatures.

FIGURE 4.7 Effect of Initial Temperature on the Maximum Deflagration Pressure of Near-Stoichiometric Mixtures of Methane-Air at Three Initial Pressures, P_0 . [19]

4.8 Effect of Turbulence.

4.8.1 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.

4.8.2 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 4.8.2 illustrates the effects of turbulence and of fuel concentration.

FIGURE 4.8.2 Effect of Turbulence on the Maximum Pressure and Rate of Pressure Rise for Methane–Air Mixtures. (Adapted from [20] and [21].)

4.8.3 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.

Chapter 5 Fundamentals of Venting of Deflagrations

5.1 Basic Concepts.

5.1.1* 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.

5.1.2 Nothing in this guide is intended to prohibit the use of an enclosure with relieving walls, or a roof, provided the potential for damage and injury are addressed.

5.1.3 The vent areas can be reduced from those specified in Chapters 6 and 7 if large-scale tests show that the resulting damage is acceptable to the user and the authorities having jurisdiction.

5.1.4 The design of deflagration vents and vent closures necessitates consideration of many variables, only some of which have been investigated in depth. The calculated vent area depends on several factors including the size and strength of the enclosure, the characteristics of the fuel/oxidant mixture, and the design of the vent itself. The design techniques use one or more empirical factors that allow simplified expressions for the vent area. The design factors are the result of analyses of numerous actual venting incidents and venting tests that have allowed certain correlations to be made. The user of this guide is urged to give special attention to all precautionary statements.

5.1.5 The rate of pressure rise is an important parameter that is used in the design of deflagration venting. 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.

5.1.6 Vents are provided on an enclosure to limit pressure development, P_{red} , to a level acceptable to the user and the authority having jurisdiction. The level of pressure development can be considered acceptable where no damage to the enclosure is likely, or where some degree of permanent deformation is tolerable.

5.1.7 As the vent area increases, the reduced pressure for a given static activation pressure of the vent closure decreases. Open vents are more effective than covered vents. Vents with lightweight closures are more responsive than those with heavy closures.

5.2 Consequences of a Deflagration.

5.2.1 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 [20 cm (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). Unless an enclosure is designed to withstand the expected deflagration pressure, venting or methods outlined in NFPA 69, Standard on Explosion Prevention Systems, should be considered.

5.2.2 Limited data are available on the reaction forces experienced by the structural elements of an enclosure during a deflagration. Designs should be based on the specifics of each enclosure, the material of the enclosure construction, and the resistance of the enclosure to mechanical and thermal shock; the effects of vents (including the magnitude and duration of consequential thrust forces) also should be considered. The enclosure design should be based on its ability to withstand the maximum pressure attained during venting, P_{red} , of the deflagration.

5.2.3 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 Section 7.10.) 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.

5.2.4 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.

5.2.5 Deflagration vents should not be located in positions that allow the vented material to be picked up by air intakes.

5.3 Enclosure Strength.

5.3.1 The force exerted on an enclosure by a deflagration varies over time. Work by Howard and Karabinis [30] indicates that the enclosure is assumed to respond as if the peak deflagration pressure, P_{red} , is applied as a static load, provided a degree of permanent deformation (but not a catastrophic failure) can be accepted.

5.3.2 Where designing an enclosure to prevent catastrophic failure while still allowing a degree of inelastic deformation, the normal dead and live loads should not be relied on to provide restraint. Structural members should be designed to support the total load.

5.3.3 Design Pressure Selection Criteria.

5.3.3.1 Commonly, design standards allow P_{red} to be selected for up to two-thirds of the ultimate strength for equipment, provided deformation of the equipment can be tolerated; or P_{red} can be selected for up to two-thirds of the yield strength for equipment where deformation cannot be tolerated.

5.3.3.2* The design pressure of a ductile high-strength enclosure is selected based on the following conditions as defined by Equation 5.1 or Equation 5.2:

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

(5.1)

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

(5.2)

where:

P_{es} = enclosure design pressure [bar (psi)] to resist P_{red}

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

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

5.3.4 Ductile design considerations should be used. For materials subject to brittle failure, such as cast iron, special reinforcing should be considered. If such reinforcing is not used, the maximum allowable design stress should not exceed 25 percent of the ultimate strength.

5.3.5 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.

5.3.6 Venting should be sufficient to prevent the maximum pressure that develops within the enclosure, P_{red} , from exceeding enclosure strength, P_{es} .

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

5.3.8 Care should 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. All structural elements and supports should be considered. For example, floors and roofs are not usually designed to be loaded from beneath. However, a lightweight roof can be considered sacrificial, provided its movement can be tolerated and provided its movement is not hindered by ice or snow.

5.3.9* The supporting structure for the enclosure should be strong enough to withstand any reaction forces that develop as a result of operation of the vent. The equation for these reaction forces has been established from test results [46]. The following equation applies only to enclosures without vent ducts:

(5.3)

where:

F_r = maximum reaction force resulting from combustion venting [kN (lbf)]

$a = 120$ (1.2)

A_v = vent area [m^2 (in. 2)]

P_{red} = maximum pressure developed during venting [bar (psi)]

5.3.9.1 The total thrust force can be considered equivalent to a force applied at the geometric center of the vent. The installation of vents of equal area on opposite sides of an enclosure cannot be depended upon 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 thrust forces.

5.3.9.2* Knowing the duration can aid in the design of certain support structures for enclosures with deflagration vents.

Reference [113] 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. The duration calculated by the following equation is shown to represent the available duration data within a minus 37 percent and a plus 118 percent.

(5.4)

where:

t_f = duration of pressure pulse after vent opening [sec (sec)]

$b = 4.3 \times 10^{-3} (1.3 \times 10^{-3})$

P_{max} = maximum pressure developed in an unvented explosion [bar (psi)]

P_{red} = maximum pressure developed during venting [bar (psi)]

V = vessel volume [m^3 (ft 3)]

A_v = area of vent (without vent duct) [m^2 (ft 2)]

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

(5.5)

where:

I = total impulse experienced by supporting structure [kN-sec (lbf-sec)]

$c = 62$ (0.62)

A_v = vent area [m²(in.²)]

Pred = maximum pressure developed during venting [bar (psi)]

t_f = duration of pressure pulse after vent opening [sec (sec)]

5.3.9.4* The equivalent static force that a structure supporting a vented enclosure experiences during deflagration venting is expressed by the following equation, where DLF is the dynamic load factor:

(5.6)

where:

F_s = equivalent static force experienced by supporting structure [kN (lbf)]

$a = 120$ (1.2) from Equation 5.3

DLF = 2

A_v = vent area [m² (in.²)]

Pred = maximum pressure developed during venting [bar (psi)]

5.4 Vent Variables.

5.4.1 The Pred 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.

5.4.2 For silos and other enclosures that can be vented at only one end, the maximum effective vent area is the enclosure cross-section.

5.4.3 For enclosures that can be vented at more than one point along the major axis, the vents can be distributed along the major axis and sized based on the L/D between vents. The maximum effective vent area at any point along the major axis is the enclosure cross section.

5.4.4 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.

5.4.5 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.

5.4.6 The addition of a vent discharge duct can substantially increase the pressure developed in a vented enclosure. (See Section 5.8.)

5.5 Vent Operation.

5.5.1 Vents should function dependably. Closures should not be hindered by deposits of snow, ice, paint, corrosion, or debris, or by the buildup of deposits on their inside surfaces. Closures should not be bonded to the enclosure by accumulations of paint. The materials that are used should be chosen to minimize corrosion. Clear space should be maintained on both sides of a vent to enable operation without restriction and without impeding a free flow through the vent.

5.5.2 Vent closures should be maintained in accordance with Chapter 10 and the manufacturers' recommendations.

5.6 Basic Considerations for Venting.

5.6.1 Chapter 6 provides guidance on gases and mists in high-and low-strength enclosures. Chapter 7 addresses dusts and hybrid mixtures in any enclosure, and Chapter 8 addresses gases and dusts in pipes, ducts, and elongated vessels.

5.6.2 The equations in Chapters 6 and 7 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.

5.6.3 The material discharged from an enclosure during the venting of a deflagration should be directed outside to a safe location. Property damage and injury to personnel due to material ejection during venting can be minimized or avoided by locating vented equipment outside buildings and away from normally occupied areas. (See 5.2.3.)

5.6.4 The vent opening should be free and clear and should not be impeded. 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.

5.6.4.1 In some cases, it is necessary to provide restraining devices to keep vent panels or closures from becoming missile hazards.

5.6.4.2 Restraining devices should not impede the operation of the vent or vent closure device. (See Chapter 9.)

5.6.4.3 The provision of a barrier is an alternative means of protection.

5.6.5 Appropriate signs should be posted to provide warning as to the location of a vent.

5.6.6 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.

5.6.7* 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].

5.6.8 Reaction forces that result from venting should also be considered in the design of the equipment and its supports. (See 5.3.9.)

5.6.9 Ducts that are used to direct vented gases from the vent to the outside of a building should be of noncombustible construction and should be strong enough to withstand the expected P_{red} . Ducts should be as short as possible and should not have any bends. (See Sections 5.8, 6.5, and 7.5.)

5.6.10* Situations can occur in which it is not possible to provide calculated deflagration venting as described in Chapters 6 and 7. Such situations do not justify the exclusion of all venting. The maximum practical amount of venting should be provided, since some venting should reduce the damage potential. In addition, consideration should be given to other protection and prevention methods.

5.6.11* 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.

5.6.12 It is not possible to vent a detonation successfully.

5.6.13 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.

5.6.14 For a given vent area, a greater mass per unit area (higher inertia) of a vent closure results in a higher maximum pressure during venting. Similarly, hinged vent closures can increase the maximum pressure during the venting process by reducing the rate at which the available vent area opens with time.

5.6.14.1 The vent closure should be designed to function as rapidly as is practical. The mass of the closure should be as low as possible to reduce the effects of inertia. The total mass of the movable part of the vent closure assembly should not exceed 12.2 kg/m² (2.5 lb/ft²). Counterweights should not be used, because they add to the inertia of the closure. Insulation added to panels is to be included in the total mass. Table 5.6.14.1 demonstrates the effect of vent mass on P_{red} .

Table 5.6.14.1 Reduced Pressure (P_{red}) Developed During Deflagration Venting Influenced by Mass of Vent Closure — 5 Percent Propane in Air, Enclosure Volume = 2.6 m³ [95]

Vent Closure Mass		Static Opening Pressure (P_{stat})		(m-bar)	
(m-bar)	Vent Closure Response Time (m-sec)	Reduced (P_{red})		(m-bar)	
lb/ft ²	kg/m ²				
0.073	0.3563	103	14.5	156	
0.68	3.32	96	31.0	199	
2.29	11.17	100	42.6	235	
4.26	20.79	100	54.0	314	

Notes:

1. $L/D = 2.3$.
2. Test series reported = #17, #1, #3, and #4.
3. $A_v = 6.0$ ft² (0.56 m²).

5.6.14.2 Where gases have K_G values no greater than those for methane or ammonia, and where there are no internal turbulence inducers, the vent area correlations for low-strength enclosures presented in this guide can be used without correction if the mass of the closure divided by the area of the vent opening does not exceed 39 kg/m² (8 lb/ft²).

5.6.14.3 A vent closure should have low mass to minimize inertia, thereby reducing opening time. If the total mass of a closure divided by the area of the vent opening does not exceed 12.2 kg/m² (2.5 lb/ft²), all vent area correlations presented in this guide can be used without correction [112]. For vent devices with greater mass per unit area, test data show that corrections to vent area could be required. To determine this correction, full scale deflagration testing can be performed at the appropriate service conditions. For dusts, Annex F provides an analytical method to evaluate the effect on vent performance.

5.6.14.4 The effect of higher vent closure inertia and hinged vent closures is determined by testing and is usually expressed as an efficiency factor [104]. Design changes can be made to compensate for such inefficiencies by increasing the venting area, or by increasing the enclosure strength, or both. A vent closure should have no counterweights; counterweights add inertia.

5.6.14.5 Deflagration vents with hinged closures are less effective than open vents or vents with lightweight rupture diaphragms. The efficiency of a specific hinged closure is dependent on its design details and can be measured experimentally [104]. In view of the reduced efficiency of hinged enclosures, lightweight rupture diaphragms are recommended. However, based on industrial experience, acceptable vent performance can be achieved with hinged closures, 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 mechanisms such as corrosion, sticky process materials, or paint.

5.6.14.6 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} , P_{stat} , 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 inertia-less 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:

(5.7)

where:

E = venting efficiency

A_2 = vent area for inertia-less vent closure

A_1 = vent area for hinged vent closure

5.6.15 A vent closure should withstand exposure to the materials and process conditions within the enclosure that is being protected. It should also withstand ambient conditions on the nonprocess side.

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

5.6.17 A vent closure should reliably withstand pressure fluctuations that are below P_{stat} . It should also withstand vibration or other mechanical forces to which it can be subjected.

5.6.18 A vent closure should be inspected and properly maintained in order to ensure dependable operation. In some cases, ensuring dependable operation can necessitate replacing a vent closure. (See Chapter 10.)

5.7 Correlating Parameters for Deflagration Venting.

5.7.1 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].

5.7.2 The equations supersede techniques that are based on a linear relationship of vent area to enclosure volume. The area-to-volume techniques for vent sizing are no longer recommended in this guide.

5.7.3 Consideration of the L/D ratio of enclosures is important in the design of deflagration venting. For long pipes or process ducts or low-pressure enclosures whose L/D ratio is 5 or greater, the deflagration vent design should be based on the information in Chapter 8.

5.8 Effects of Vent Discharge Ducts.

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

5.8.2 The use of vent ducts results in an increase in P_{red} . A vent duct should have a cross section at least as great as that of the vent itself. The increase in pressure due to the use of a vent duct as a function of duct length is shown for gases in Figure 5.8.2. 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 where using a vent duct of an equivalent cross section [93], but this effect is difficult to quantify because of limited test data. Vent ducts and nozzles with total lengths of less than one hydraulic diameter do not need correction.

FIGURE 5.8.2 Maximum Pressure Developed during Venting of Gas, with and without Vent Ducts. [101]

5.8.3 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.

5.9 Location of Deflagration Vents Relative to Air Intakes.

Deflagration vents should not be located where the vented material can be picked up by air intakes.

5.10 Venting with Flame Arresting and Particulate Retention.

5.10.1 There are situations 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. When faced with this situation, a device that operates on the principles of flame arresting and particulate retention can provide increased workplace safety. 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.

5.10.2 Particulate retention devices should be listed and should be considered only for use within the tested range of K_{St} , dust loading, dust type, enclosure volume, and P_{red} . The retention of particulates results in a loss of venting efficiency. The vent area calculated in Chapters 6 and 7 should be adjusted using experimentally determined efficiency values. (See Section 9.7.)

5.10.3 Venting indoors affects the building that houses the protected equipment due to increased pressurization of the surrounding volume. (See also 7.9.3.)

5.10.4 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. The areas adjacent to the discharge point should be clear of combustible dusts. (See also 5.6.4.)

5.11 Effects of Initial Turbulence and Internal Appurtenances for Enclosures with Initial Pressure Near Atmospheric.

5.11.1 Gas.

5.11.1.1 In many industrial enclosures, the gas phase is present in a turbulent condition. 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 that of initially quiescent hydrogen. Therefore, the K_{G} value for hydrogen should be used in the venting equation for initially turbulent gases that have K_{G} values, in the quiescent state, that are close to or less than that of propane.

5.11.1.2 The susceptibility of deflagration to detonation transition in a turbulent system increases with an increase in the values of the fundamental burning velocity. (See Annex B.) In particular, compounds that have K_{G} values close to that of hydrogen are highly susceptible to detonation when ignited under turbulent conditions.

5.11.2 Enclosure Appurtenances. Internal appurtenances within a vented enclosure can cause turbulence [55,102].

5.11.3 Dusts. The values of P_{max} and K_{St} for dusts are determined from tests that are conducted on turbulent dust clouds. The equations given herein for calculating the vent area for dust deflagrations use the values of P_{max} and K_{St} that have been so determined.

5.12 Deflagration of Mists.

The design of deflagration venting for mists can be based on the propane venting equation. For more detail on mists, see 4.3.6.

5.13 Venting Deflagrations of Flammable Gases Evolved from Solids.

In certain processes, flammable gases can evolve 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 results. (See Section 7.10.)

5.14 Venting of Deflagrations in Ducts.

Most deflagrations of flammable gas mixtures inside ducts occur at initial internal pressures that are nearly atmospheric. The venting of deflagrations in such ducts is discussed in Chapter 8.

5.15 Hybrid Mixtures.

Special considerations are given to hybrid mixtures in Section 7.10. 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. An alternate approach is to conduct tests to determine the equivalent K_{St} using worst-case conditions and to apply the appropriate dust-venting equation.

Chapter 6 Venting Deflagrations of Gas Mixtures and Mists

6.1 Introduction.

6.1.1 This chapter applies to the design of deflagration vents for enclosures that contain a gas or mist. It is intended that this chapter be used with the information contained in the rest of this guide. In particular, Chapters 5, 9, and 10 should be reviewed before applying the information in this chapter.

6.1.2 No venting recommendations are currently available for fast-burning gases with fundamental burning velocities greater than 1.3 times that of propane, such as hydrogen. 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 alternate measures that should be used.

6.1.3 The vent area should be distributed as symmetrically and as evenly as possible.

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

6.2.1 Section 6.2 applies 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). Equation 6.1 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 5.2.3 and 5.2.4. 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 6.1. It is therefore recommended that building vents should be used in addition to taking measures to minimize the potential for flammable gas accumulations in enclosures.

6.2.2* The recommended venting equation for low-strength structures is as follows:

(6.1)

where:

A_v = vent area [m² (ft²)]

C = venting equation constant (see Table 6.2.2)

A_S = internal surface area of enclosure [m² (ft²)]

P_{red} = maximum pressure developed in a vented enclosure during a vented deflagration [bar (psi)]

Table 6.2.2 Fuel Characteristic Constant for Venting Equation

Fuel	Metric C (bar) ^{1/2}	English C (psi) ^{1/2}
Anhydrous ammonia	0.013	0.05
Methane	0.037	0.14
Gases with fundamental burning velocity less than 1.3 times that of propane*	0.045	0.17

* Includes hydrocarbon mists and organic flammable liquids.

6.2.2.1 P_{red} , in this application, is not to exceed P_{es} (in bar or psi, not to exceed 0.1 bar or 1.5 psi).

6.2.3 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 Section 5.6 for other general vent considerations). For elongated enclosures, the vent area should be applied as evenly as possible with respect to the longest dimension. If the available vent area is restricted to one end of an elongated enclosure, the ratio of length to diameter should not exceed 3. For cross sections other than those that are circular or square, the effective diameter can 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. Therefore, for enclosures with venting restricted to one end, the venting equation reflects constraints as follows:

(6.2)

where:

L_3 = longest dimension of the enclosure [m (ft)]

A = cross-sectional area [m² (ft²)] normal to the longest dimension

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

6.2.3.1 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, then the L/D of the enclosure should not exceed 2, or the following equation should be used:

(6.3)

6.2.3.2 Where the dimensional constraints on the enclosure are not met, the alternate methods described in Chapters 6 through 8 should be considered for solutions.

6.2.4 Venting Equation Constant. The value of C in Equation 6.1 characterizes the fuel and reconciles the dimensional units. Table 6.2.2 specifies some recommended values of C . These values of C pertain to air mixtures.

6.2.4.1 The values of C in Table 6.2.2 were determined by enveloping data. If suitable large-scale tests are conducted for a specific application, an alternate value of C can be determined.

6.2.4.2 The data cited in [28] and [30 through 45] are mostly for aliphatic gases. It is believed that liquid mists can be treated in the same manner as aliphatic gases, provided the fundamental burning velocity of the vapor is less than 1.3 times that of propane.

6.2.4.3 No recommendations for hydrogen are currently available. Unusually high rates of combustion (including detonation) have been observed in actual practice during turbulent hydrogen combustion. As conditions become severe, combustion rates approach those of detonation for other fast-burning fuels. In addition, as rates of pressure rise increase, the inertia of vent closures becomes more critical (see 6.2.8.2 and 5.6.14). Even if detonation does not occur, it can be impossible to vent fast deflagrations successfully in some cases.

6.2.5 Calculation of Internal Surface Area.

6.2.5.1 The internal surface area, AS , is the total area that constitutes the perimeter surfaces of the enclosure that is being protected. Nonstructural internal partitions that cannot withstand the expected pressure are not considered to be part of the enclosure surface area. The enclosure internal surface area, AS , in Equation 6.1 includes the roof or ceiling, walls, floor, and vent area and can be based on simple geometric figures. Surface corrugations are neglected, as well as minor deviations from the simplest shapes. Regular geometric deviations such as saw-toothed roofs can be "averaged" by adding the contributed volume to that of the major structure and calculating AS for the basic geometry of the major structure. The internal surface of any adjoining rooms should be included. Such rooms include adjoining rooms separated by a partition incapable of withstanding the expected pressure.

6.2.5.2 The surface area of equipment and contained structures should be neglected.

6.2.6 Enclosure Strength. The user should refer to 3.3.25.1 and Sections 5.3 and 6.1 for specific remarks relating to enclosure strength.

6.2.7 Methods to Reduce Vent Areas. In some circumstances, the vent area calculated by using Equation 6.1 exceeds the area available for the installation of vents. When such situations arise, one of the techniques in 6.2.7.1, 6.2.7.2, or 6.2.7.3 should be used to obtain the needed protection.

6.2.7.1 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 6.3 should be followed.

6.2.7.2 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, AS . The new wall should be designed in accordance with Section 5.3.

6.2.7.3 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 Table 6.2.2. (See 6.2.4.1.)

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

6.2.7.5 The vent area can 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. The tests should be conducted with the highest anticipated turbulence levels and with the proposed wall lining material and thickness.

6.2.8 Vent Design. See also Section 5.4.

6.2.8.1 Where inclement weather or other environmental considerations are a problem, open vents can be used and are recommended. In most cases, vents are covered by a vent closure. The closure should be designed, constructed, installed, and maintained so that it releases readily and moves out of the path of the combustion gases. The closure should not become a hazard when it operates.

6.2.8.2 The total weight of the closure assembly, including any insulation or hardware, should be as low as practical to minimize the inertia of the closure. See 5.6.14 for restrictions on vent closure weight where using Equation 6.1 without consideration for vent closure efficiency.

6.2.8.3* The construction material of the closure should be compatible with the environment to which it is to be exposed. Some closures, on activation, are blown away from their mounting points. Brittle materials can fragment, producing missiles. Each installation should be evaluated to determine the extent of the hazard to personnel from such missiles. Additionally, it should be recognized that the vented deflagration can discharge burning gases, posing a personnel hazard.

6.2.8.4 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 due to 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 6.2.8.5 should be recognized, and strengthened internal structural elements should be provided.

6.2.8.5 For low-strength enclosures P_{red} should always exceed P_{stat} by at least 0.02 bar (0.35 psi).

6.2.8.6 If an enclosure is subdivided into compartments by walls, partitions, floors, or ceilings, then each compartment that contains a deflagration hazard should be provided with its own vent closure(s).

6.2.8.7 The vent closure(s) should cover only the vent area needed for the compartment being protected.

6.2.8.8 Each closure should be designed and installed to move freely without interference by obstructions such as ductwork or piping. Such a design ensures that the flow of combustion gases is not impeded by an obstructed closure. (See 5.5.1.)

6.2.8.9 A vent closure can open if personnel fall or lean on it. If injury can result from such an event, guarding should be provided to prevent personnel from falling against vent closures.

6.2.8.10 The criteria for the design of roof-mounted closures are basically the same as those for wall closures. Measures should be taken to protect the closures against accumulations of snow and ice. However, a lightweight roof can be considered sacrificial, provided its movement can be tolerated and provided its movement is not hindered by ice or snow.

6.2.8.11 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. In such cases, it is necessary to strengthen the structural members of the compartment so that the reduced vent area available is equivalent to the vent area needed. The minimum pressure needed for the weakest structural member is obtained by substituting the values for the available area, the internal surface area, and the applicable C value for the variables in Equation 6.1 and then calculating P_{red} , the maximum allowable overpressure. The vent area should still be distributed as evenly as possible over the building's skin.

6.2.8.12 If the only available vent area is located in an end wall of an elongated building or structure, such as a silo, an evaluation should be made to determine whether Equation 6.3 can be validly applied.

6.2.9 Sample Calculations.

6.2.9.1 Consider a 20 ft × 30 ft × 20 ft (6.1 m × 9.2 m × 6.1 m) (length × width × height) dispensing room for Class I flammable liquids. The anticipated flammable liquids have fundamental burning velocities less than 1.3 times that of propane [see Table C.1(a)]. 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 0.05 bar (0.69 psi). For most flammable liquids, Table 6.2.2 specifies a venting equation constant, C, of 0.17. The internal surface area of the room, 297 m² (3200 ft²), is determined by the following equation:

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

6.2.9.1.2 If the wall strength were increased to resist a P_{red} of 0.072 bar (1.04 psi), a vent area of 50 m² (533 ft²) 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 0.048 bar (0.69 psi).

6.2.9.2 Consider the building illustrated in Figure 6.2.9.2, 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 propane. The maximum P_{red} that this building can withstand has been determined by structural analysis to be 3.45 kPa (0.5 psi).

FIGURE 6.2.9.2 Building Used in Sample Calculation (Not to Scale) (Version I).

6.2.9.3 Divide the building into sensible geometric parts (Parts 1 and 2) as shown in Figure 6.2.9.3.

FIGURE 6.2.9.3 Building Used in Sample Calculation (Not to Scale) (Version II).

6.2.9.4 Calculate the total internal surface area of each part of the building.

Part 1 Surface Area (A S 1)

Floor = 51.8 m × 9.15 m = 474 m²

(170 ft × 30 ft = 5100 ft²)

Roof = 51.8 m × 9.65 m = 499 m²

(170 ft × 31.6 ft = 5372 ft²)

Rear wall = 51.8 m × 6.1 m = 316 m²

(170 ft × 20 ft = 3400 ft²)

Front wall = (36.6 m × 9.15 m) + (15.25 m × 3.05 m) = 381 m²

[(120 ft × 30 ft) + (50 ft × 10 ft)] = 4100 ft²

Side walls

(rectangular part) = 2 × 9.15 m × 6.1 m = 111 m²

(2 × 30 ft × 20 ft = 1200 ft²)

Side walls

(triangular part) = 9.15 m × 3.05 m = 28 m²

(30 ft × 10 ft = 300 ft²)

Total Part 1: A S1 = 1809 m² (19,472 ft²)

Part 2 Surface Area (A S 2)

Floor = 15.25 m × 9.15 m = 139 m²

(50 ft × 30 ft = 1500 ft²)

Roof = 15.25 m × 9.15 m = 139 m²

(50 ft × 30 ft = 1500 ft²)

Front wall = 15.25 m × 6.1 m = 93 m²

(50 ft × 20 ft = 1000 ft²)

Side walls = 2 × 9.15 m × 6.1 m = 111 m²

(2 × 30 ft × 20 ft = 1200 ft²)

Total Part 2: AS2 = 483 m² (5200 ft²)

6.2.9.4.1 Thus, the total internal surface area for the whole building, A_S , is expressed as follows:
Total Surface Area (A_S)

6.2.9.5 Calculate the total vent area, A_v , needed using Equation 6.1:

where:

$C = 0.17 \text{ psi}^{1/2}$ (0.045 bar)^{1/2} from Table 6.2.2

$A_S = 2292 \text{ m}^2$ (24,672 ft²)

$P_{red} = 3.45 \text{ kPa}$ (0.5 psi)

6.2.9.5.1 Substituting these values:

6.2.9.5.2 The total vent area needed of 551 m² (5932 ft²) 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.

6.2.9.5.3 Total vent area of Part 1:

6.2.9.5.4 Total vent area of Part 2:

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

6.2.9.6.1 In Part 1, the vent area needed [435 m² (4682 ft²)] can be obtained by using parts of the front, rear, and side walls or by using the building roof.

6.2.9.6.2 In Part 2, the vent area needed [116 m² (1250 ft²)] can be obtained by using parts of the front and side walls or by using the building roof.

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

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

6.3.1 This section applies to enclosures such as vessels or silos that are capable of withstanding P_{red} of more than 1.5 psi (0.1 bar).

6.3.2 Basic Principles.

6.3.2.1 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 this subsection.

6.3.2.2 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.

6.3.2.3 The user should refer to 3.3.25.1 and Section 5.3 for specific comments relating to enclosure strength.

6.3.2.4 The vent should be designed to prevent the deflagration pressure inside the vented enclosure from exceeding two-thirds of the enclosure strength. This criterion anticipates that the enclosure could bulge or otherwise deform.

6.3.2.5 Vent closures should open dependably. Their proper operation should not be hindered by deposits of snow, ice, paint, sticky materials, or polymers. Their operation should 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.

6.3.2.6 When a rupture diaphragm device of low mass-to-area ratio vents a deflagration, the vent closure ruptures in the predetermined pattern and provides an unrestricted opening. Due to the device's low inertia, it contributes little to the P_{red} that develops during the venting. However, if a similar venting device has a substantial mass/area, the inertia can cause an increase in P_{red} under certain conditions. Vent closures should, therefore, have a low mass per unit area to minimize inertia in order to reduce opening time. This recommendation has been confirmed by tests with flammable gases and dusts [30,98,99]. An example is given in Table 5.6.14.1. Further guidance on the effects of higher inertia vent closures is provided in 5.6.14.1.

6.3.2.7 Vent closures should withstand exposure to the materials and process conditions within the enclosure that is being protected. They should also withstand ambient conditions on the nonprocess side.

6.3.2.8 Vent closures should reliably withstand fluctuating pressure differentials that are below the design release pressure. They should also withstand any vibration or other mechanical forces to which they can be subjected.

6.3.3 Vent Area Calculations.

6.3.3.1 The technical literature reports extensive experimental work on venting of deflagrations in enclosures up to 250 m³ (8830 ft³) in volume [3,49–52]. As a result, a series of equations has been developed for calculating the necessary vent areas for enclosures.

6.3.3.2 The venting equations are based on deflagrations in which the oxidant is air. They do not apply to venting where another gas is the oxidant.

6.3.3.3 The length-to-diameter ratio, L/D , of the enclosure determines the equation(s) that is to be used for calculating the necessary vent area. For noncircular enclosures, the value that is to be used for diameter is the equivalent diameter given by the following equation:

(6.4)

where:

D = diameter

A^* = cross-sectional area normal to the longitudinal axis of the space

6.3.3.4 For L/D values of 2 or less, Equation 6.5, from [101], is to be used for calculating the necessary vent area, A_v , in m²:

(6.5)

where the following constraints apply:

KG	550 bar-m/sec
Pred	2 bar and at least 0.05 bar > Pstat
Pstat	0.5 bar
V	(1000 m ³)

Initial pressure before ignition 0.2 bar

6.3.3.4.1 Equation 6.5 is derived from tests made under the following conditions:

- (1) Volumes of test vessels: 2.4 m³, 10 m³, 25 m³, and 250 m³; L/D of test vessels approximately 1
- (2) Initial pressure: atmospheric
- (3) Pstat: 0.1 bar to 0.5 bar
- (4) Ignition energy: 10 J
- (5) Stationary gas mixture at time of ignition
- (6) No turbulence inducers

6.3.3.5* For L/D values from 2 to 5, and for Pred no higher than 2 bar, the vent area, Av, calculated from Equation 6.5, is increased by adding more vent area, A, calculated from Equation 6.6 as follows:

(6.6)

6.3.3.5.1 Equation 6.6 is subject to the limitations stated in 6.3.3.4. For long pipes or process ducts where L/D is greater than 5, the guidelines in Chapter 8 should be used.

6.3.3.6 In addition to calculating the vent area using Equations 6.5 and 6.6, the vent area can be determined by the use of the graphs in Figure 6.3.3.6(a) through Figure 6.3.3.6(g), which are based on Equations 6.5 and 6.6. The restrictions given for Equation 6.5 apply equally to the graphs. The graphs can be used as a primary means for determining vent area, or they can be used as a backup to verify the vent area calculated by the two equations. Similarly, the equations can be used to verify the vent area determined by the graphs.

FIGURE 6.3.3.6(a) Vent Sizing for Gas. Pstat = 0.1 bar.

FIGURE 6.3.3.6(b) Vent Sizing for Gas. Pstat = 0.2 bar.

FIGURE 6.3.3.6(c) Vent Sizing for Gas. Pstat = 0.5 bar.

FIGURE 6.3.3.6(d) Elongated Vessel Correction. Factor B — for Gas.

FIGURE 6.3.3.6(e) Volume Correction. Factor C — for Gas (0 m³–10 m³).

FIGURE 6.3.3.6(f) Volume Correction. Factor C — for Gas (10 m³–100 m³).

FIGURE 6.3.3.6(g) Volume Correction. Factor C — for Gas (100 m³–1000 m³).

6.3.3.7 Instructions and an example for using the graphs in Figure 6.3.3.6(a) through Figure 6.3.3.6(g) are as follows.

(A) Factor A. Select the graph [Figure 6.3.3.6(a) through Figure 6.3.3.6(g)] with the appropriate Pstat in the caption. Plot a line from the KG value at the bottom up to the Pred line and then read across to the left to determine Factor A.

(B) Factor B. If the vessel has an L/D greater than 2, and if Pred is less than 2, determine the value of Factor B. Use the graph in Figure 6.3.3.6(d). Plot a line from the L/D ratio up to the KG line, and then read across to the left to determine Factor B. If the length-to-diameter is 2 or less, Factor B is equal to 1.0. For values of L/D greater than 5, use Chapter 8.

(C) Factor C. Use one of the graphs, Figure 6.3.3.6(e), Figure 6.3.3.6(f), or Figure 6.3.3.6(g). Plot a line from the volume value up to the graph line and then read across to the left to determine Factor C. Using the three factors, determine the vent size as follows:

(6.7)

(D) Example Problem. Determine the vent size needed to protect an enclosure from a gas deflagration when the conditions are as follows:

- (1) KG = 150 bar-m/sec
- (2) Pstat = 0.2 bar
- (3) Pred = 0.4 bar
- (4) V = 30 m³
- (5) L/D = 4.4
- (6) Factor A = 8.65 m
- (7) Factor B = 2.15 m
- (8) Factor C = 0.45 m
- (9) Av = Factor A × Factor B × Factor C

$$= 8.65 \times 2.15 \times 0.45 = 8.37 \text{ m}^2$$

6.3.3.8 The most accurate value of KG is determined directly by test, as outlined in Annex B. If testing cannot be done to determine KG for a particular gas, KG can be approximated by ratioing from the KG of propane (100 bar-m/sec) on the basis of the corresponding fundamental burning velocity (see Annex C) of propane (46 cm/sec) and the fundamental burning velocity of the gas in question. (See Table D.1 for KG values.)

6.3.3.8.1 If testing cannot be done to determine KG for a particular gas, KG can be approximated by using a ratio from the KG of propane (100 bar-m/sec) on the basis of the corresponding fundamental burning velocity of the gas in question. (See Table D.1 for KG values.)

6.3.3.8.2 KG Values. The maximum rate of pressure rise can be normalized to determine the KG value (see Section B.1). It should, however, be noted that the KG 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 KG values. Although the KG value provides a means of comparing the maximum rates of pressure rise of known and unknown gases, it should be used only as a basis for deflagration vent sizing 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 D includes sample calculations for KG values.

6.3.3.9 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.

6.4 Venting of Gas or Mist Deflagration in High-Strength Enclosures with High L/D Ratio.

For long pipes or process ducts whose L/D is greater than 5, the deflagration vent design should be based on the information in Chapter 8.

6.5 Effects of Vent Ducts.

6.5.1 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 Figure 6.3.3.6(a) through Figure 6.3.3.6(g) are based on venting deflagrations to atmosphere without vent ducts.

6.5.2 Where using Equations 6.5 and 6.6 with vent ducting, a lower value should be used in place of P_{red} . The lower value, P'_{red} , can be determined for gases using Figure 5.8.2, or it can be calculated using Equations 6.8 and 6.9. It should be noted that P_{red} is still the maximum pressure developed in a vented deflagration. P'_{red} is not an actual pressure.

6.5.3 Testing has been done with 3 m (10 ft) and 6 m (20 ft) duct lengths. Until more test data are available, duct lengths shorter than 3 m (10 ft) should be considered to be 3 m (10 ft) for calculation purposes. The effect of ducts longer than 6 m (20 ft) has not been investigated. If longer ducts are needed, P'_{red} should be determined by appropriate tests.

6.5.4 The equations of the curves in Figure 5.8.2 are as follows.

6.5.4.1 For vent ducts with lengths of less than 3 m (10 ft),

(6.8)

where:

P'_{red} = a pseudo-value for P_{red} for use in Equation 6.5 for calculating vent areas for gases when a vent duct is used [bar (psi)]

6.5.4.2 For vent ducts with lengths of 3 m to 6 m (10 ft to 20 ft),

(6.9)

where:

P'_{red} = a pseudo-value for P_{red} for use in Equation 6.5 for calculating vent areas for gases when a vent duct is used [bar (psi)]

6.5.5 The vented material discharged from an enclosure during a deflagration should be directed to a safe outside location to avoid injury to personnel and to minimize property damage. (See Section 5.8.)

6.5.6 If it is necessary to locate enclosures that need deflagration venting inside buildings, vents should not discharge within the building. Flames and pressure waves that discharge from the enclosure during venting represent a threat to personnel and could damage other equipment. Therefore, vent ducts should be used to direct vented material from the enclosure to the outdoors.

6.5.7 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.

6.5.8 A vent duct should have a cross section at least as great as that of the vent itself. 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 5.6.14.5.

6.5.9 Vent ducts should be as straight as possible. In general, any bends can cause increases in the pressure that develops during venting. If bends are unavoidable, they should be as shallow-angled as practical (that is, they should have as long a radius as practical).

6.5.10 Where vent ducts vent through the roof of an enclosure, consideration should be given to climatic conditions. (See Section 5.5.)

6.6 Effects of Initial Turbulence and Internal Appurtenances for Enclosures with Initial Pressures Near Atmospheric.

6.6.1 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.

6.6.2 If the gas system is initially turbulent, the rate of deflagration increases [3,35]. In such a case, Equations 6.5 and 6.6 do not apply directly. It has been found that initially turbulent methane and propane exhibit high values. Therefore, the hydrogen KG (550 bar-m/sec) should be used for venting initially turbulent gases that have values, in the quiescent state, that are close to or less than that of propane.

6.6.3 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 potential for

detonation exists, alternate solutions, such as those in NFPA 69, Standard on Explosion Prevention Systems, should be considered.

6.7 Effects of High Ignition Energy.

6.7.1 The amount and type of ignition energy can affect the effective flame speed and the venting. The exact amount of ignition energy that can occur in enclosures cannot normally be predicted. In many industrial cases, however, the ignition energy can be quite high.

6.7.2 Where two enclosures are 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 high 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 sequence has been investigated by Bartknecht, who discovered that the effects can be large [3,101]. Pressures that develop in the pipeline itself can also be quite high, especially if the deflagration changes to detonation. When such conditions prevail in equipment design, refer to [57] and [66].

6.8 Effects of Initial Elevated Pressure.

6.8.1 For a given vent size, the maximum pressure that develops during the venting of a deflagration (P_{red}) varies as a function of the initial absolute pressure raised to an exponential power, n . For this calculation, as described in 6.8.2, the ratio of the absolute pressure when the vent closure opens to the absolute pressure at the time is assumed to be constant. The recommended values of the exponent vary inversely with the ratio of the vent area, A_v , to the $2/3$ power of the enclosure volume, V ; that is, n varies inversely with $A_v/V^{2/3}$. This is shown in Figure 6.8.1. The solid lines for propane and hydrogen were developed from the data in [59]. References [61] and [79] support the exponent value of 1.5 for propane. The line for propane can be used for gases that have KG values no higher than 1.3 times that for propane. The line for ethylene represents an untested interpolation. The extension of broken lines represents extrapolation. Figure 6.8.1 should not be extrapolated beyond $A_v/V^{2/3} = 0.35$.

FIGURE 6.8.1 Value of Exponent, n , as a Function of $A_v/V^{2/3}$. [59]

6.8.2 For calculations that involve elevated pressure, the following procedure should be used.

6.8.2.1 Calculate the maximum pressure developed during the venting from the initially elevated pressure by using the following equation:

$$(6.10)$$

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 6.5 and 6.6 (converted to bar abs)

P_2 = elevated initial pressure before ignition (bar abs)

P_1 = atmospheric pressure (1.0 bar abs)

6.8.2.2 The value that is used for P_2 should be chosen carefully to represent the likely maximum pressure at which a flammable gas mixture can exist at the time of ignition. It can be the normal operating pressure. 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.

6.8.2.3 Venting from enclosures at initially elevated pressures results in severe discharge conditions. The enclosure should be located to accommodate the blast wave.

6.8.2.4 Example Problem. Determine maximum pressure during venting for the following values:

(1) V (enclosure volume) = 2.0 m³

(2) A_v (vent area) = 0.45 m²

(3) (from Figure 6.8.1) = 1.23

(4) P_{max} = maximum operating pressure at time of ignition = 2.125 bar

(5) P_{stat} (vent closure opening pressure) = 2.75 bar

(6) material in enclosure = propane/air

(7) KG (propane) = 100 bar-m/sec

(A) Perform the following calculation:

for use in Equations 6.5 and 6.6 or the graphs in Figure 6.3.3.6(a) through Figure 6.3.3.6(c).

(B) Determine the area for venting. In this example, the vent area, A_v , is given as 0.45 m².

(C) Determine the value of n from Figure 6.8.1. In this example, n is 1.23.

(D) Establish P_{red} , using Equations 6.5 and 6.6 or the graphs in Figure 6.3.3.6(a) through Figure 6.3.3.6(c) for the following conditions:

(1) $V = 2.0$ m³

(2) $A_v = 0.45$ m²

(3) $P_{stat} = 0.2$ bar

(E) Given $P_{red} = 0.6$ bar, determine $P_{red,1}$, which is P_{red} in absolute pressure:

(F) Calculate $P_{red,2}$, using Equation 6.10:

6.8.3 As in any vent calculation procedure, any one variable (e.g., A_v , P_{stat} , P_{red}) can be determined, provided the other variables remain constant. Thus, the exact sequence of steps depends on the variable to be determined. The procedure and example in 6.8.2 assume that actual P_{stat} and A_v are fixed. However, the method for accounting for elevated initial

pressure can also be used if a different set of variables is fixed, but the steps would be performed in a different sequence than is specified in 6.8.2.1 through 6.8.2.2.

6.9 Effects of Initial Temperature.

The effect of initial temperature is discussed in Section 4.7. In most cases, an increase in initial temperature results in an increase in the maximum rate of pressure rise and a decrease in the pressure generated by combustion in an unvented enclosure. While rates of pressure rise are observed to increase at elevated temperature, which suggests that an increase in vent area is needed, research on vents at elevated temperature shows that increased initial temperature does not result in increased values of P_{red} [60].

6.10 Effects of Combination of Variables.

Data used to determine precisely how combinations of variables affect the maximum pressure that develops during venting (P_{red}) are insufficient.

6.11 Deflagration of Foams of Combustible Liquids.

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 liquid phase is then released from pressure when the formation of a foam occurs, the gas phase in the bubbles can be 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.

6.12 Venting Deflagrations of Flammable Gases Evolved from Solids.

In certain processes, combustible gases can evolve from solid materials. If the solid is itself combustible and is dispersed in the gas/oxidant mixture, as can be the case in a fluidized bed dryer, a hybrid mixture results. (See Section 7.10.)

6.13 Venting of Deflagrations in Conveying and Ventilating Ducts.

Most deflagrations of combustible gas mixtures inside ducts occur at initial internal pressures that are nearly atmospheric. The venting of deflagrations in such ducts is discussed in Chapter 8.

6.14 Pressures External to Vented Enclosures.

A vented deflagration develops pressures that can damage external structures. An example of external pressure is shown in Table 6.14 [95,101]. In extreme cases, such pressures have been shown to be as high as P_{red} within 1 m (3.3 ft) of the vented enclosures, and they can vary depending on the distance from the vent opening.

Table 6.14 Pressures External to a Vent [95]

Distance from Vent to External Obstruction Surface		External Vent Pressure, Percent P_{red}				Measured P_{red}		Pressure Measured at External
m	ft	bar	psi	bar	psi			
0.63	2.1		0.144	2.09		0.070	1.02	48
1.00	3.3		0.172	2.49		0.060	0.87	35
2.00	6.6		0.160	2.32		0.020	0.29	13

where the following test conditions apply:

$V = 2.6 \text{ m}^3$

$A_v = 0.55 \text{ m}^2$

$P_{stat} = 0.1 \text{ bar}$

Fuel = 5 percent propane in air

Chapter 7 Venting of Deflagrations of Dusts and Hybrid Mixtures

7.1 Introduction.

This chapter applies to all enclosures handling combustible dusts or hybrid mixtures. It is intended that this chapter be used with the information contained in the rest of this guide. In particular, Chapters 5, 6, 9, and 10 should be reviewed before applying the information in this chapter.

7.1.1 Some sections of [104] are reproduced in this chapter. Additional technology from other sources appears as noted in the text.

7.1.2 The variable K_{St} is a measure of the deflagration severity of a dust and should be as established by the test requirements of ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts. The K_{St} values established are sample specific. Chapter 4 should be referenced for variables affecting test results and Section B.5 should be referenced for dust testing.

7.1.3 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.)

7.2 Venting by Means of Low Inertia Vent Closures, Such as Rupture Diaphragms.

7.2.1 The length-to-diameter ratio, L/D , of the enclosure determines the equation(s) that is to be used for calculating the necessary vent area. For noncircular enclosures, the value that is to be used for diameter is the equivalent diameter given by Equation 6.4:

where:

A^* = the cross-sectional area normal to the longitudinal axis of the space

7.2.2 For L/D values of 2 or less, Equation 7.1 is to be used to calculate the necessary vent area, A_v , in m^2 . Equation 7.1 is subject to the limitations specified in 7.2.2(1), (2), and (3). Equation 7.1 applies to initial pressures before ignition of 1 bar absolute ± 0.2 bar.

(7.1)

where:

A_v = vent area (m²)

P_{stat} = static burst pressure of the vent (bar)

K_{St} = deflagration index (bar-m/sec)

V = hazard volume (m³)

= P_{red} / P_{max}

P_{red} = reduced pressure after deflagration venting (bar)

P_{max} = maximum pressure of a deflagration (bar)

7.2.2.1* The following limitations are applicable to Equation 7.1:

(1) P_{max} 5 bar

(2) K_{St} 10 bar-m/sec

(3) V 0.1 m³ to 10,000 m³

(4) P_{stat} 0.5 bar

7.2.3 For L/D values greater than 2 and less than 6, the vent area, A_v , calculated in 7.2.2 is increased by adding incremental vent area, A , as calculated from the following equation:

(7.2)

where:

L = enclosure length or height, i.e., longest dimension

D = enclosure equivalent diameter as defined in 7.2.1

7.2.4 For situations where vents can be distributed along the major axis of the enclosure, Equations 7.1 and 7.2 can be applied where L is the spacing between vents along the major axis.

7.2.5 No test data are available for P_{max} values above 12 bar (174 psi) or for K_{St} values higher than 800. This guide does not apply to such dusts, and reference should be made to deflagration prevention measures, such as in NFPA 69, Standard on Explosion Prevention Systems.

7.2.6 In addition to calculating the vent area using Equations 7.1 and 7.2, the vent area can be determined by the use of the graphs in Figure 7.2.6(a) through Figure 7.2.6(k), which are based on Equations 7.1 and 7.2. The restrictions noted for the equations apply equally to the graphs. The graphs can be used as a primary means for determining vent area, or they can be used as a backup to verify the vent area calculated by Equations 7.1 and 7.2.

FIGURE 7.2.6(a) Vent Sizing for Dusts ($50K_{St} < 300$).

FIGURE 7.2.6(b) Vent Sizing for Dusts ($300K_{St}$).

FIGURE 7.2.6(c) Vent Sizing for Dusts (0-10 m³).

FIGURE 7.2.6(d) Vent Sizing for Dusts (10-100 m³).

FIGURE 7.2.6(e) Vent Sizing for Dusts (100-1000 m³).

FIGURE 7.2.6(f) Vent Sizing for Dusts (1000-10,000 m³).

FIGURE 7.2.6(g) Vent Sizing for Dusts (< 0.05).

FIGURE 7.2.6(h) Vent Sizing for Dusts ($0.05 < 0.2$).

FIGURE 7.2.6(i) Vent Sizing for Dusts (> 0.2).

FIGURE 7.2.6(j) Vent Sizing for Dusts.

FIGURE 7.2.6(k) Vent Sizing for Dusts.

7.2.6.1 Instructions and an example for using the graphs in Figure 7.2.6(a) through Figure 7.2.6(k) follow.

(A) Factor A. Use one of the graphs in Figure 7.2.6(a) or Figure 7.2.6(b). Plot the line from the K_{St} value at the bottom up to the P_{stat} line and then read across to the left to determine Factor A.

(B) Factor B. Use one of the graphs in Figure 7.2.6(c), Figure 7.2.6(d), Figure 7.2.6(e), or Figure 7.2.6(f). Plot a line from the volume up to the graph line and then read across to the left to determine Factor B.

(C) Factor C. Calculate r , the ratio of P_{red} to P_{max} . Use one of the graphs in Figure 7.2.6(g), Figure 7.2.6(h), or Figure 7.2.6(i). Plot a line from r at the bottom up to the graph line and then read across to the left to determine Factor C.

(D) Factor D. Calculate the parameter $(1/P_{red} - 1/P_{max})$. Use one of the graphs in Figure 7.2.6(j) or Figure 7.2.6(k). If using Figure 7.2.6(j), plot the line from the parameter, $(1/P_{red} - 1/P_{max})$, up to the appropriate L/D line and then read across to the left to determine Factor D. If using Figure 7.2.6(k), plot the line from the L/D ratio up to the appropriate parametric line and then read across to the left to determine Factor D. Using the four factors, determine vent size as follows:

(E) Example Problem. Determine the vent size needed to protect an enclosure from a dust deflagration when the conditions are as follows:

(1) $P_{max} = 10$ bar

(2) $K_{St} = 350$ bar-m/sec

- (3) $P_{stat} = 0.2$ bar
- (4) $P_{red} = 0.6$ bar
- (5) $V = 25$ m³
- (6) $L/D = 3.0$
- (7) From Figure 7.2.6(b), Factor A = 0.04
- (8) From Figure 7.2.6(d), Factor B=11
- (9) $= 0.6/10 = 0.06$
- (10) From Figure 7.2.6(h), Factor C=4.0
- (11) $(1/P_{red} - 1/P_{max}) = 1/0.6 - 1/10 = 1.67 - 0.1 = 1.57$
- (12) From Figure 7.2.6(j), Factor D=1.6
- (13) $A_v = \text{Factor A} \times \text{Factor B} \times \text{Factor C} \times \text{Factor D}$
 $= 0.04 \times 11 \times 4.0 \times 1.6 = 2.8$ m² (Use of Equations 7.1 and 7.2 gives an area of 2.9 m². Due to resolution of graphs, the answers may differ slightly.)

7.3 Effects of Partial Volume.

Dust concentrations in some process equipment and buildings are inherently limited to only a fraction of the enclosure volume. When the volume fill fraction, X_r , can be determined for a worst-case explosion scenario, the minimum required vent area is calculated from the following equation:

(7.3)

where:

A_{vpv} = vent area for partial volume deflagration

A_{v0} = vent area for full volume deflagration as determined from Equations 7.1 and 7.2

X_r = fill fraction >

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

7.3.1 If X_r , deflagration venting is not needed. Figure 7.3.1 illustrates the limits of partial volume corrections. At low normalized reduced pressures, \bar{p} , the vent ratio approaches the fill fraction to the 1/6th power. When fill fraction approaches X_r , both the vent ratio and the necessary vent area approach zero. Subsections 7.3.2 and 7.3.3 provide guidance on the determination of the fill fraction for process vessels and for buildings, respectively.

FIGURE 7.3.1 Partial Volume Vent Area Reduction.

7.3.2 Process Equipment Partial Volumes. The fill fraction in a spray dryer depends on the dryer design. In the case of a top-loading conical dryer without any recirculation or co-feed of dry product, measurements have indicated that the dry powder concentrations exist only in the bottom portion of the dryer, which typically occupies 20 percent to 35 percent of the total dryer volume. However, if there is recirculation of the dry product, the fill fraction should be taken as 1.0. Furthermore, if the solvent is flammable, hybrid deflagration K_{St} values should be determined.

7.3.2.1 In applications such as a spray dryer or fluidized bed dryer, the specific fill fraction to be used for vent design should be based on measurements with representative equipment and process materials. In these applications, the determination of X_r should be documented and submitted to the authority having jurisdiction for review and concurrence. The K_{St} value to be used in vent design should account for elevated dryer operating temperatures.

7.3.2.2 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 $= 0.50/10 = 0.050$. Using Equation 7.1,

7.3.2.3 The partial volume vent area for this application is as follows:

7.3.2.3.1 Therefore vent panels with a total vent area of at least 1.09 m² should be installed on the conical lower section of the dryer.

7.3.3* Building Partial Volumes. This subsection applies to large process buildings in which there is a dust explosion hazard associated with combustible material deposits on the floor and other surfaces, and with the material contained in process equipment. The minimum required deflagration vent area for the building dust explosion hazard should be based either on the full building volume, or on a partial volume determined as follows.

(A) 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 should be obtained from measured floor areas, A_{fs} , that are each 0.37 m² (4 ft²) or larger.

(B) Weigh each sample and calculate the average mass, \bar{m} (gram), of the floor samples.

(C) Collect at least two representative samples from measured sample areas, A_{ss} , on other surfaces with dust deposits.

These surfaces on any plane might include beams, shelves, and external surfaces of process equipment and structures.

Calculate the total area, A_{sur} , of these surfaces with dust deposits.

(D) Weigh each sample and calculate the average mass, \bar{m} (gram), of the surface samples.

(E) Determine the total mass, M_e , of combustible dust that could be released from the process equipment in the building.

(F) 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} .

(G) Using the highest values of P_{max} and K_{St} , the building volume, V , and $= P_{red} / P_{max}$, use Equation 7.1 to calculate the vent area, A_{v0} , needed if the full building volume were filled with combustible dust.

(H) Calculate the worst-case building partial volume fraction, X_r , from the following equation:

(7.4)

(1) The lowest value of c_w for the various samples should be used in the calculation. If a measured value of c_w is not available, a value of 200 g/m³ can be used in this equation.

(2) If measured values of λ and μ 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 can be used, based on a dust layer bulk density of 800 kg/m³ and a layer thickness of 0.8 mm = 1/32 inch over the entire floor area and other surfaces defined in (C). The approximate value corresponding to these values is 640 g/m².

(I) If the calculated $X_r > 1$, the minimum required vent area is equal to A_{v0} .

(1) If $X_r \leq 1$, no deflagration venting is needed.

(2) If $1 > X_r > 0.1$, the minimum required vent area, A_{vpv} , is calculated from Equation 7.3:

7.4 Effects of Initially Elevated Pressure.

For enclosures that may contain homogenous dust-air mixtures at an elevated pressure (greater than 0.2 bar and less than or equal to 4 bar) prior to ignition, the following equation is to be used to calculate the necessary vent area:

(7.5)

where:

A_v = vent area (m²)

P_{stat} = static burst pressure of the vent (bar)

$P_{initial}$ = enclosure pressure to ignition (bar)

$P_{effective}$ = $P_{initial}$

K_{St} = deflagration index (determined at initially atmospheric pressure) (bar-m/sec)

V = enclosure volume (m³)

$P_{effective}$ = $(P_{red} - P_{effective}) / (P_{Emax} - P_{effective})$

P_{red} = reduced pressure (bar)

P_{Emax} = $[(P_{max} + 1)(P_{initial} + 1) / (1 \text{ bar abs}) - 1]$ maximum

pressure of an unvented deflagration at initially

elevated pressure (bar)

P_{max} = Maximum pressure of an unvented deflagration

initially at atmospheric pressure (bar)

7.5 Effects of Vent Ducts.

For cubical vessels and homogeneous dust-air mixtures initially at atmospheric pressure, the effect of vent ducts can be calculated from the following equation.

(7.6)

where:

P'_{red} = a pseudo-value for P_{red} for use in Equations 7.1 and 7.2 for calculating vent areas for dusts when a vent duct is used [bar (psi)]

A_v = vent area (m²) also equal to duct cross-sectional area

V = vessel volume (m³)

L_D = vent duct length (m)

D_v = vent duct length (m) = $2(A_v)^{1/2}$

7.5.1 The length of the duct, L_s , at which further increases in length have no or little effect on the reduced explosion pressure is given by the following equation:

(7.7)

7.5.1.1 Equation 7.7 is valid for the pressure range 0.1 bar P'_{red} 2 bar. The value of P_{stat} is 0.1 bar.

7.6 Combination Rules and Limitations for NFPA 68 Dust Models.

Model Application

Vent Ducts 0.8 P_0 1.2 bars abs

Panel Density 2.5 lb/ft²

Allow Partial Volume

1 L/D 6

(calculate vent duct effect last)

Partial Volume Allow Vent Duct

Panel Density 2.5 lb/ft²

0.8 P_0 1.2 bars abs

1 L/D 6

(calculate vent duct effect last)

Elevated Initial Pressure No Vent Duct

Panel Density 2.5 lb/ft²

0.2 P_0 4 bar g

Full Volume Deflagration

1 L/D 6

(calculate elevated initial pressure effect last)

Panel Inertia 0.8 P_0 1.2 bar-a

No Vent Duct
2.5 lb/ft² < Panel density < 41 lb/ft²
Allow Partial Volume
1 L/D 6

7.7 Bins, Hoppers, and Silos.

7.7.1 Deflagration venting for bins, hoppers, and silos should be from the top or the upper side, above the maximum level of the material contained, and should be directed to a safe outside location (see Section 7.9). Deflagration venting can be through vent closures located in the roof or sidewall, or by making the entire enclosure top a vent. In all cases, the total volume of the enclosure should be assumed to contain a suspension of the combustible dust in question. No credit should be taken for the enclosure being partly full of settled material.

7.7.1.1 The effective vent area located on the sidewalls of silos cannot exceed the cross-sectional area of the silo (see 5.4.2).

7.7.2 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. For a multiple application, the closures should be placed symmetrically to minimize the effects of potential reaction forces (see 5.3.9). Care should 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. Dust piled above the bottoms of vent closures can hinder venting.

7.7.3 Deflagration venting can be accomplished by means of vent closures located in the roof of the enclosure. The vent operation procedures outlined in Section 5.5 are to be followed.

7.7.4 The entire enclosure top can be made to vent deflagrations. 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. Roof panels are to be as lightweight as possible and are not to be attached to internal roof supports. API 650, Welded Steel Tanks for Oil Storage, should be referenced for guidelines for the design of a frangible, welded roof joint. Although frangible roof design in accordance with API 650 is not intended to serve as deflagration venting, experience shows that such roofs have successfully vented deflagrations. A frangible roof design is not recommended for use as the inner roof on enclosures that have a headhouse or penthouse. Equipment, piping, and other attachments should not be connected to the roof directly, as they could restrict the roof's operation as a vent closure. The remaining portions of the enclosure, including anchoring, should be designed to resist the calculated P_{red} , based on the vent area provided. (See Section 5.3.)

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

7.8.1 Dust collectors are a special case for deflagration venting. Obstructions such as cloth bags or cartridges can interfere with the venting process. Two venting alternatives are acceptable.

(1) Locate all of the venting area below the bottom of the bags, filters, or cartridges, as shown in Figure 7.8.1(a). For this case, the vent area can 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 such that the bottom of the vent (s) is below the bottom of the bags, as shown in Figure 7.8.1(b). For this case, the volume used to calculate the vent area should be the entire volume (clean and dirty) below the tube sheet.

FIGURE 7.8.1(a) Venting of Dust Collectors — Alternative Arrangement 1.

FIGURE 7.8.1(b) Venting of Dust Collectors — Alternative Arrangement 2.

7.8.1.1 A key assumption made for the two alternatives in 7.8.1 is that the clean air plenum above the tube sheet is essentially free of dust accumulations. If the clean air plenum contains dust, then a separate vent on the clean air side should be calculated based on the clean air side volume.

7.8.1.2 Installing vents above the bottom of the filter media, as shown in Figure 7.8.1.2, is not recommended.

FIGURE 7.8.1.2 Venting of Dust Collectors — Arrangement Not Recommended.

7.9 Flame Clouds from Dust Deflagrations.

Normally, when dust deflagrations occur, there is 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. 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. Personnel enveloped by such a fireball are unlikely to survive. The potentially large size of the fireball that extends from the dust deflagration vent should be considered in the location of vents and vent ducts.

7.9.1 Fireball Dimensions. In the case of dust deflagration venting, the distance, D , is expressed by Equation 7.8. If the vented material exits from the vent horizontally, the horizontal length of the fireball is anticipated. The height of the fireball can be the same dimension, with half the height located below the center of the vent and half the height located above. 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.

(7.8)

where:

D = maximum flame distance from vent opening [m (ft)]

V = enclosure volume [m³ (ft³)]

7.9.2 External Pressure Effects.

7.9.2.1 When a dust deflagration is vented from an enclosure, pressure effects are created in the atmosphere external to the enclosure. Such pressure effects are due to the effects of both the vented products and the further deflagration of excess flammable dust. There are two pressure maximums (peaks), one from the venting process and one from the deflagration of the dust-air mixture external to the enclosure. Only limited data are available for correlation to approximate the amount of

the latter pressure. The maximum value of the pressure exists at a distance of about one-fifth of the maximum length, D , of the fireball as calculated in Equation 7.8.

7.9.2.2 Conditions.

7.9.2.2.1 Where venting is from a cubic vessel, $P_{max,a}$ value is indicated approximately by Equation 7.9 [108]:
(7.9)

where:

$P_{max,a}$	=	external pressure (bar)
P_{red}	=	reduced pressure (bar)
A_v	=	vent area (m ²)
V	=	enclosure volume (m ³)
KSt	<	200 bar-m/sec
P_{max}		9 bar

7.9.2.2.2 For longer distances, r (in meters), the maximum external pressure, $P_{max,r}$, is indicated approximately by Equation 7.10:

(7.10)

where:

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

7.9.2.2.3 Equations 7.8, 7.9, and 7.10 are valid for the following conditions:

- (1) Enclosure volume: $0.3 \text{ m}^3 \leq V \leq 10,000 \text{ m}^3$
- (2) Reduced pressure: $P_{red} \leq 1 \text{ bar}$
- (3) Static activation pressure: $P_{stat} \leq 0.1 \text{ bar}$
- (4) Deflagration index: $KSt \leq 200 \text{ bar-m/sec}$

7.9.3 Venting Internal to a Building with Flame Arresting and Particulate Retention. 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]. Expected overpressure should be compared to the building design, and building venting should be considered to limit overpressures. The resulting pressure increase in an unvented building can be estimated from the following:

- (1) $P = 1.74 P_0 (V_1/V_0)$
- (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) P = pressure rise in the building (in same units as P_0)

7.10 Hybrid Mixtures.

7.10.1 Hybrid mixtures of flammable gases or combustible dusts can be ignitable even if both constituents are below their respective lower flammable limits. The properties of hybrid mixtures are discussed in [3] and [104]. Certain dusts that do not form combustible mixtures by themselves could do so if a flammable gas were added, even if the latter were at a concentration below its lower flammable limit. The minimum ignition energy of a hybrid mixture is typically less than that of a dust alone. (See 4.3.5.)

7.10.2 The effective KSt value of most combustible dusts is raised by the admixture of a flammable gas, even if the gas concentration is below the lower flammable limit. The increase in value, in turn, leads to an increase in the vent area needed. For hybrid mixtures, tests should be used to determine the equivalent KSt using worst-case conditions, and the applicable dust equation also should be used. 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, Equation 7.1 should be used, with $P_{max} = 10 \text{ bar}$ and $KSt = 500 \text{ bar-m/sec}$.

7.11 Deflagration Venting of Enclosures Interconnected with Pipelines.

7.11.1 Equations 7.1 and 7.2 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 results 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 7.1 and 7.2.

7.11.2* 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 are recommended [104]. (Interconnecting pipelines with inside diameters greater than 0.3 m (1 ft) or longer than 6 m (20 ft) are not covered in this guide.)

- (1) The venting device for the enclosure should be designed for a $P_{stat} < 0.2 \text{ bar}$.
- (2) Enclosures of volumes within 10 percent of each other should be vented as determined by Equations 7.1 and 7.2.
- (3) If enclosures have volumes that differ by more than 10 percent, the vents for both enclosures should be designed as if P_{red} equals 1 bar or less. The enclosure should be designed with P_{es} equal to minimum 2 bar.
- (4) If it is not possible to vent the enclosure with the smaller volume in accordance with this guide, then the smaller enclosure should be designed for the maximum deflagration pressure, P_{max} , and the vent area of the larger enclosure with the larger volume should be doubled.
- (5) The larger enclosure should 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 8 Venting of Deflagrations of Gases and Dusts in Pipes and Ducts Operating at or near Atmospheric Pressure

8.1 Scope.

This chapter applies to systems handling gases and dusts and operating at pressures up to 0.2 bar (3 psi). This chapter does not apply to vent discharge ducts. This chapter applies to pipes, ducts, and elongated vessels with length-to-diameter ratios of 5 or greater for gases and 6 or greater for dusts.

8.2 General.

8.2.1 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.

8.2.2 Compared to the venting of vessels, 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 [3], [68 through 76], [105], and [106]. Deviations from the guidelines should provide more vent area than recommended.

8.2.3 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.

8.2.4 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.

8.3 Design Guidelines.

8.3.1 These guidelines are based on providing vent area equal to the total cross-sectional area at each vent location. The vent area needed can be accomplished by using one, or more than one, vent at each location. The cross-sectional area is the maximum effective vent area at each vent location. For noncircular cross sections, the hydraulic diameter is equal to $4 A/p$, where A is the cross-sectional area and p is the perimeter of the cross section.

8.3.2 Multiple vent locations can be provided along the length of the pipe or duct to reduce the maximum pressure during a deflagration.

8.3.3 Deflagration vents should be located close to possible ignition sources where these sources can be identified (for example, in-line blowers or rotating equipment).

8.3.4 Pipes or ducts connected to a vessel in which a deflagration can occur also need deflagration protection. Such protection can be accomplished by installing a vent with an area equal to the cross-sectional area of the pipe or duct. It should be located on the pipe or duct no more than two pipe or duct diameters from the point of connection to the vessel.

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

8.3.6 In order to use the correlations presented later in this chapter, the weight of deflagration vent closures should not exceed 12.2 kg/m^2 (2.5 lb/ft^2) of free vent area.

8.3.7 The static burst pressure of the vent closures should be as far below P_{red} as practical and should be consistent with operating pressures.

8.3.8 Deflagration vents should discharge to a location that cannot endanger personnel.

8.3.9 Consideration should be given to reaction forces that develop during venting. (See 5.3.9.)

8.4 Vent Placement to Prevent Run-up to Detonation.

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

8.4.2 From the ignition location, 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.

8.4.3* The curves in Figure 8.4.3 should 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 provided. If L/D ratios greater than those shown in the figure are present, there is a risk that detonation can occur.

FIGURE 8.4.3 Maximum Allowable Distance, Expressed as Length-to-Diameter Ratio, for a Smooth, Straight Pipe or Duct.

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

8.5.1 General. If the length of a pipe or duct is greater than the L/D indicated in Figure 8.4.3, a single vent cannot provide enough vent area (see Section 8.6). Figure 8.4.3 includes safety factors for typical long-radius elbow systems. While very few conveying pipes are either straight or smooth, Figure 8.4.3 can be used for most applications. It does not apply where conveying pipes have sharp elbows or orifice plates along their lengths.

8.5.2 System Flow Velocity 2 m/sec or Less — Flammable Gases. The maximum pressure during deflagration venting, P_{red} , in a pipe or duct that conveys propane can be estimated from Figure 8.5.2. Figure 8.5.2 can also be used with gases that have a fundamental burning velocity of less than 60 cm/sec. Figure 8.5.2 provides curves for three different pipe diameters. For other pipe diameters, P_{red} can be determined by interpolation. The distance between ignition location and vent location is expressed as an L/D ratio. The L/D ratio is used in conjunction with the appropriate curves to estimate the P_{red} .

FIGURE 8.5.2 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.

8.5.3 System Flow Velocity 2 m/sec or Less — Dusts. The maximum pressure during deflagration venting, P_{red} , in a pipe or duct that conveys dusts can be estimated from Figure 8.5.3. Figure 8.5.3 provides curves for three different K_{St} values. For dusts having other K_{St} , P_{red} can be determined by interpolation.

FIGURE 8.5.3 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.

8.5.4 System Flow Velocity Greater than 2 m/sec or Gases with Velocity Greater than 60 cm/sec. For system flow velocities greater than 2 m/sec and for gases with fundamental burning velocities greater than 60 cm/sec (2 ft/sec), a single vent is not recommended. Additional vent area should be provided by using multiple vent locations.

8.5.5 Initial Velocity Greater than 20 m/sec, or Gases Having Burning Velocities More Than 1.3 Times That of Propane, or Dusts with $K_{St} > 300$. For these situations, vents should be placed no more than 1 m to 2 m (3.3 ft to 6.6 ft) apart.

8.5.6 Turbulence-Producing Devices. For ducts or pipes containing turbulence-producing devices, as described in 8.3.5, vents should be placed as specified in 8.3.5. Additional vents, as specified elsewhere in Section 8.5, can also be necessary.

8.6 Use of Multiple Deflagration Vents on a Pipe or Duct.

8.6.1 Figure 8.6.1 should 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 8.6.1 applies to system flow velocities up to 20 m/sec (66 ft/sec). It is applicable to dusts with a K_{St} less than or equal to 300 bar-m/sec and to propane.

FIGURE 8.6.1 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.

8.6.2 For gases other than propane, the maximum pressure during deflagration and the distances between vents can be calculated using Equations 8.1 and 8.2. The equations are limited to fundamental burning velocities below 60 cm/sec (2 ft/sec).

(8.1)

(8.2)

where:

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

$P_{red,p}$ = 2.5 psi — maximum pressure for propane

L_x = distance between vents for gas (m or ft)

L_p = distance between vents for propane (m or ft)

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

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

8.7 Examples.

8.7.1 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 8.4.3, 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 8.5.3, 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.

8.7.2 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?

8.7.2.1 Check the maximum allowable length. From Figure 8.4.3, 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.

8.7.3 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. What is 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)? Figure 8.6.1 specifies that the vents should be placed no more than 7.6 m (25 ft) apart. In order to meet this recommendation, a vent should be placed at each end, and 13 additional vents should be evenly spaced along the duct.

8.7.4 Deflagration vents should be provided for the ducts in the system shown in Figure 8.7.4. The gas flow through the system is 100 m³/min (3500 ft³/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.

FIGURE 8.7.4 Diagram for Example.

8.7.4.1 As recommended by 8.3.4 and 8.3.5, A and B should be located, respectively, within two vent diameters of the dryer outlet and no more than three vent diameters upstream of the first elbow. C should be located at three diameters distance. F should be located at a position approximately two diameters upstream of the dust collector inlet, based on 8.3.3.

8.7.4.2 Additional venting is needed for the 20 m (66 ft) section. The flow of 100 m³/min corresponds to a velocity of 6 m/sec (20 ft/sec). Therefore, Figure 8.6.1 should be used. According to Figure 8.6.1, the vents should be placed at intervals no greater than 11 vent diameters, or approximately 6.5 m (21 ft) apart. The distance between vents C and F is 17.2 m (56 ft); therefore, two additional vents (D and E) at approximately equal spacing meet the need.

8.7.4.3 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} . According to 8.3.7, the vent release pressure should not exceed half P_{red} and, therefore, cannot exceed 0.1 bar (1.5 psi).

Chapter 9 Description of Deflagration Vents and Vent Closures

9.1 General.

9.1.1 Open Vent — No Closure. Many types of deflagration vents and vent closures are available. This chapter provides some basic information on vent design and performance.

9.1.2 Some vent types and vent closure assemblies are commercially available and can be purchased ready to install. Others can be custom-fabricated on site by the user. The following descriptions can be used as a basis for the selection or design of vent and vent closures.

9.2 Normally Open Vents.

9.2.1 Open Vent — No Closure. The most effective deflagration vent is an unobstructed opening that has no closure. Open vents are an option wherever equipment or rooms do not need to be totally closed. However, there are comparatively few situations where operations with an inherent deflagration hazard can be conducted in open equipment.

9.2.2 Louvered Openings. 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. This obstruction increases P_{red} and should be accounted for in the system design. The pressure drop through the louvered vent should be determined by gas flow calculations, and P_{red} should be adjusted.

9.2.3 Hangar-Type Doors. Large hangar-type or overhead doors can be installed in the walls of rooms or buildings that contain a deflagration hazard. The doors can be opened to provide sizeable unobstructed vents during the operation of a process or of equipment in which there is an inherent deflagration hazard. However, the opening is considered to be a vent only when the door is not in place. Interlocks with process systems that create a deflagration hazard should be provided to ensure that the doors are open when the process is in operation.

9.3 Normally Closed Vents.

9.3.1 It is the responsibility of the vent closure manufacturer or designer to document the value and tolerance of the P_{stat} of a vent closure where installed according to the manufacturer's recommendation in the intended application. If the vent is custom fabricated on site, the manufacturer or designer should provide the same documentation.

9.3.2 Testing should 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. This recommendation applies to all types of closure mechanisms, including pull-through fasteners; shear bolts; spring-loaded, magnetic, and friction latches; and rupture diaphragms.

9.3.2.1 Large panel closures that are installed on buildings or other large low-strength enclosures cannot be tested as a complete assembly. For these closures, the designer should document that the entire assembly releases at the P_{stat} specified. The documentation should include the design P_{red} , P_{stat} , enclosure surface area, closure area, Factor C as used in the design, types of fasteners, spacing, and quantity. The design records and installation drawings should be maintained by the building owner and operator.

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

9.3.3 The vent closure should be designed to release at as low a pressure as practical and should be compatible with the service conditions to which it is to be exposed. Vent closures should be designed for their expected temperature range.

9.3.4 The vent closure should be identified as a deflagration pressure-relieving device and should be marked with the release pressure.

9.3.5 The closure should 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.

9.4 Types of Building or Room Vent Closures.

The following types of vent closures are intended for use with large low-strength enclosures such as those covered by Chapter 6.

9.4.1 Hinged Doors, Windows, and Panel Closures. Hinged doors, windows, and panel closures are designed to swing outward and have latches or similar hardware that automatically release under slight internal pressure. Friction, spring-loaded, or magnetic latches of the type used for doors on industrial ovens are the usual type of hardware. For personnel safety, the door or panel should be designed to remain intact and to stay attached. Materials that tend to fragment and act as shrapnel should not be used.

9.4.2 Shear and Pull-Through Fasteners. 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. Shear and pull-through fasteners can be used where the vent design calls for large vent areas, such as the entire wall of a room.

9.4.2.1 The shear-type fastener is designed to break from the shear stress that develops in the fastener when the pressure from a deflagration pushes laterally on the vent closure.

9.4.2.2 The pull-through type of fastener uses a collapsible or deformable washer to hold the closure panel in place. The force of the deflagration on the closure panel causes the washer to be pulled through the mounting hole, and the panel can then be pushed away from the vent opening.

9.4.2.3 Vent closures and relief devices that fail under tension or shear can necessitate the use of forces for operation under dynamic conditions that are higher than those used for operation under the static conditions at which they are usually tested. Such higher forces can be incompatible with the design recommendations of the vent system.

9.4.3 Friction-Held Closures.

9.4.3.1 Some commercially available vent closure assemblies use a flexible diaphragm that is surrounded or encircled at its edges by a restraining frame. When a deflagration occurs, the pressure deforms the diaphragm, pushing it from its frame [see Figure 9.4.3.1(a) and Figure 9.4.3.1(b)]. This type of vent closure assembly is well suited for large structures such as rooms,

buildings, conveyor enclosures, silos, dust collectors, and baghouses. It is also particularly suited to ductwork that operates at or close to atmospheric pressure.

FIGURE 9.4.3.1(a) Exploded View of Manufactured Vent Closure.

FIGURE 9.4.3.1(b) Typical Applications for Manufactured Vent Closures.

9.4.3.2 At locations where personnel or equipment can be struck by flying vent closures, tethering of the vent closure or other safety measures are recommended.

9.4.4 Weak Roof or Wall Construction. An entire roof or wall, or a portion of a roof or wall, can be designed to fail under slight pressure. Suitable lightweight panels can be used in this type of vent closure.

9.4.5 Large-Area Panels. Large-area panels can be in a single layer or in multiple layers (insulated sandwich panel). The text and figures in Section 9.5 refer to tests carried out on metal-faced panels [30]. Alternate methods for other types of panels necessitate careful engineering design, and testing of a complete assembly is recommended.

9.5 Restraints for Large Panels.

9.5.1 Where large, lightweight panels are used as vent closures, it is usually necessary to restrain the vent closures so that they do not become missile hazards. The restraining method shown in Figure 9.5.1 illustrates one method that is particularly suited for conventional single-wall metal panels. The key feature of the system includes a 5 cm (2 in.) wide, 10-gauge bar washer. The length of the bar is equal to the panel width, less 5 cm (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 (in.) diameter through-bolts.

FIGURE 9.5.1 An Example of a Restraint System for Single-Wall Metal Vent Panels.

9.5.1.1 The restraining techniques shown are very specific to their application. They are intended only as examples. Each situation necessitates an individual design. Any vent restraint design should be documented by the designer.

9.5.1.2 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.

9.5.1.3 Any hardware added to a vent closure is to be included when determining the total mass of the closure, subject to 5.6.14.

9.5.2 Where the vent closure panel is a double-wall type (such as an insulated sandwich panel), the restraint system shown in Figure 9.5.1 is not recommended. 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.

9.5.3 The restraint system shown in Figure 9.5.3 is recommended for double-wall panels. For successful functioning, the panel area is limited to 3.1 m² (33 ft²), and its mass is limited to 12.2 kg/m² (2.5 lb/ft²).

FIGURE 9.5.3 An Example of a Restraint System for Double-Wall Insulated Metal Vent Panels.

9.5.3.1 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.

9.5.3.2 Forged eyebolts are necessary. Alternatively, a "U" bolt can be substituted for the forged eyebolt.

9.5.3.3 A shock absorber device with a fail-safe tether is provided. 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.

9.6 Equipment Vent Closures.

9.6.1 Hinged Devices.

9.6.1.1 Hinged doors or covers can be designed to function as vent closures for many kinds of equipment. The hinge should be designed to offer minimum frictional resistance and to ensure that the closure device remains intact during venting. Closures that are held shut with spring-loaded, magnetic, or friction latches are most frequently used for this form of protection.

9.6.1.2 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 missile hazards.

9.6.1.3 Hinged devices can be used on totally enclosed mixers, blenders, dryers, and similar equipment. It is difficult to vent equipment of this type if the shell, drum, or enclosure revolves, turns, or vibrates. Charging doors or inspection ports can be designed to serve this purpose where their action does not endanger personnel. Special attention should be given to the regular maintenance of hinge and spring-loaded mechanisms to ensure proper operation.

9.6.1.4 If a hinged vent closure is followed by a vent duct, special consideration should be given to the clearance between the front edge of the closure panel and the duct wall throughout the course of the opening arc. The clearance should not hinder flow during the venting while the vent closure is swinging open. The amount of clearance needed from the front edge of the hinged closure, in the closed position, to the wall of the vent duct is approximately half of the length of the hinged closure from the hinge to the front edge.

9.6.1.5 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. Vacuum breakers can be installed to prevent inward deformation, provided they are either built strongly enough to withstand the P_{red} during venting, or provided they break away like rupture diaphragms to leave a clear opening.

9.6.1.6 Figure 9.6.1.6 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.

FIGURE 9.6.1.6 Graph to Determine the Vacuum Relief Area for Vacuum Vents on Enclosures. [104]

9.6.2 Rupture Diaphragm Devices.

9.6.2.1 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 9.6.2.1.)

FIGURE 9.6.2.1 Typical Rupture Diaphragm.

9.6.2.2 Some materials that are used as rupture diaphragms can balloon, tear away from the mounting frame, or otherwise open randomly, leaving the vent opening partially blocked on initial rupture. Although such restrictions can be momentary, delays of only a few milliseconds in relieving deflagrations of dusts or gases that have high rates of pressure rise can cause extensive damage to equipment. Therefore, only rupture diaphragms with controlled opening patterns that ensure full opening on initial rupture should be utilized.

9.7 Flame-Arresting Vent Systems and Particulate Retention Vent Systems.

9.7.1 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 5.10 and Figure 9.7.1.)

FIGURE 9.7.1 Example of Flame-Arresting and Particulate Retention Vent System.

9.7.2 Flame-arresting vent systems and particulate retention vent systems should be listed for their application and should be used within the specifications of their listings.

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

9.7.4 Limitations. The following limitations apply:

(1) Where a flame-arresting vent system and a particulate retention vent system are used inside a building, care should be taken to ensure safe installation. Considerations 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 vent system and a particulate retention vent system should be sized to ensure that Pred remains within the enclosure design limits. 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.

Chapter 10 Inspection and Maintenance

10.1 General.

10.1.1 This chapter covers the inspection and maintenance procedures necessary for proper function and operation of vent closures for venting deflagrations.

10.1.2 The occupant of the property in which the deflagration vent closures are located is responsible for inspecting and maintaining such devices.

10.2 Special Terms.

The following terms are defined for the purposes of this chapter.

10.2.1 Inspection. Inspection is visual verification that the vent closure is in place and able to function as intended.

Verification is achieved by ensuring that the vent closure is properly installed and identified (see 9.3.4), that it has not operated or been tampered with, and that no condition exists that can hinder its operation.

10.2.2 Maintenance. Maintenance consists of preventive and remedial actions taken to ensure the proper operation of vent closures.

10.3 Inspection Frequency and Procedures.

10.3.1 Acceptance inspections and applicable tests should be conducted after installation to establish that the vent closures have been installed according to the manufacturers' specifications and accepted industry practices. A vent closure should be clearly marked as an explosion relief device. The relief path should be unobstructed and should not lead to areas where personnel can be harmed by the relief pressure and fireball. (See 6.5.6, Section 7.9, and 7.9.1.)

10.3.2 Vent closures should be inspected on a regular basis. 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.

10.3.3 Inspections should be conducted following any activity that can adversely affect the operation and the relief path of a vent closure (for example, after process changes, hurricanes, snow accumulations, or maintenance changes) and should also be conducted following maintenance turnarounds.

10.3.4 Inspection frequency and procedures should be carried out according to the manufacturers' recommendations.

10.3.5 Inspection procedures and frequency should be in written form and should include provisions for periodic testing, where practical.

10.3.6 To facilitate inspection, the access to, and the visibility of, vent closures should not be obstructed.

10.3.7 Any seals or tamper indicators that are found to be broken, any obvious physical damage or corrosion, and any other defects found during inspection should be corrected immediately.

10.3.8 Any structural changes or additions that can compromise the effectiveness of vent closures or create a hazard to personnel or equipment should be reported and corrected immediately.

10.4 Maintenance.

Vent closures should receive appropriate preventive maintenance as recommended by the manufacturer.

10.5 Recordkeeping.

A record should be maintained that indicates the date and the results of each inspection and the date and description of each maintenance activity. The records of at least the previous three inspections should be kept.

Annex A Explanatory Material

Annex A is not a part of the recommendations 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.1.1.4 For further information, see NFPA 30, Flammable and Combustible Liquids Code.

A.1.3.1 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.

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

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

A.3.3.9 Flame Speed. Flame speed is dependent on turbulence, the equipment geometry, and the fundamental burning velocity.

A.3.3.10.1 Lower Flammable Limit (LFL). LFL is also known as minimum explosible concentration (MEC).

A.3.3.15 KG. See 4.2.3.

A.3.3.16 KSt. See 4.2.3.

A.3.3.18 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.3.3.20.2 Optimum Mixture. The optimum mixture is not always the same for each combustion property that is measured.

A.3.3.21 Oxidant. Oxygen in air is the most common oxidant.

A.3.3.22.1 Maximum Rate of Pressure Rise [(dP/dt)max]. See Annex B.

A.4.3.3.1 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.)

A.4.4.1 For further information, see NFPA 69, Standard on Explosion Prevention Systems.

A.4.5.1 For further information, see NFPA 69, Standard on Explosion Prevention Systems.

A.4.6.1 Currently no ASTM standard method is available for use in determining the minimum ignition energies of dusts (as exists for gases). Although several test methods for dusts have been developed by different companies and organizations, the equivalency of such test results is in question. Reference [92] is a review of ignition energy test methods that have been developed for dusts and gases.

A.5.1.1 For further information, see NFPA 69, Standard on Explosion Prevention Systems.

A.5.3.3.2 Figure A.5.3.3.2 shows a curve that is a general representation of a stress-strain curve for low-carbon steel.

FIGURE A.5.3.3.2 Stress-Strain Curve for Low-Carbon Steel.

A.5.3.9 The example of the calculation of reaction force, F_r , during venting, is for the following conditions:

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

The example of the calculation of duration of thrust force, t_f , resulting from venting of a dust deflagration, is for the following conditions:

- (1) $K_{St} = 160 \text{ bar-m/sec}$
- (2) $V = 20 \text{ m}^3$
- (3) $P_{red} = 0.4 \text{ bar}$
- (4) $A_v = 1.4 \text{ m}^2$
- (5) $t_f =$
- (6) $t_f = 0.57 \text{ sec}$

A.5.3.9.2 The example of the calculation of duration of thrust force, t_f , resulting from venting of a dust deflagration is for the following conditions using Equation 5.4:

- (1) $KSt = 160 \text{ bar-m/sec}$
- (2) $V = 20 \text{ m}^3$
- (3) $P_{max} = 8 \text{ bar}$
- (4) $P_{red} = 0.4 \text{ bar}$
- (5) $A_v = 1.4 \text{ m}^2$
- (6) $t_f = (0.0043)(8/0.4)^{0.5}(20/1.4)$
- (7) $t_f = 0.27 \text{ sec}$

A.5.3.9.3 The example of the calculation of total impulse, I , resulting from venting of a dust deflagration is for the following conditions using Equation 5.6:

- (1) $c = 62$
- (2) $P_{red} = 0.4 \text{ bar}$
- (3) $A_v = 1.4 \text{ m}^2$
- (4) $t_f = 0.27 \text{ sec}$ (from A.5.3.9.2)
- (5) $I = (62)(1.4)(0.4)(0.27)$
- (6) $I = 9.4 \text{ kN-s} = 9400 \text{ N-s}$

A.5.3.9.4 The example of the calculation of equivalent static force, F_s , resulting from venting of a dust deflagration is for the following conditions using Equation 5.6:

- (1) $a = 120$
- (2) $DLF = 2$
- (3) $A_v = 1.4 \text{ m}^2$
- (4) $P_{red} = 0.4 \text{ bar}$
- (5) $F_s = (120)(2)(1.4)(0.4)$
- (6) $F_s = 134 \text{ kN}$

Note that a dynamic load factor (DLF) of 2 is conservative for most situations. Experienced users may choose to substitute a value specific to their design. 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.

A.5.6.7 For further information, see NFPA 69, Standard on Explosion Prevention Systems.

A.5.6.10 For further information, see NFPA 69, Standard on Explosion Prevention Systems.

A.5.6.11 Data in reference 45 show the effects of using 5 cm (2 in.) thick glass wool linings for propane deflagrations in a 5.2 m³ (184 ft³) test vessel that is equipped with a 1 m² (10.8 ft²) 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 in [37] illustrate the effects of a 7.6 cm (3 in.) thick mineral wool lining for natural gas deflagrations that are centrally ignited in a 22 m³(777 ft³) test vessel that is equipped with a 1.1 m² (11.8 ft²) 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 m³ (2260 ft³) 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 [43]. 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 [44], that are not influenced by enclosure wall linings can have a greater influence on P_{red} in other situations.

A.6.2.2 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 of calculating vent area.

A.6.2.8.3 For further information, see National Association of Corrosion Engineers Handbook.

A.6.3.3.5 Equation 6.6 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 7.1 is applicable.
- (2) Gases with higher values of KG are more prone to flame acceleration in elongated vessels.
- (3) Limited data on flame speeds and pressures are available in Section 5.1 of [101] for propane deflagrations in an open-ended vessel with L/D of approximately 5.

A.7.2.2.1 Unlike its counterparts in previous editions of NFPA 68, Equation 7.1 was derived as a best fit to test data (half of the data was underpredicted and half of the data was overpredicted) with optimum concentrations of various dusts. There is no safety factor in it other than the understanding that most accidental dust deflagrations occur at nonoptimum conditions. This equation applies to both low-strength and high-strength enclosures. The new equation results in significantly lower vent areas for low-strength enclosures as compared to the previous edition of NFPA 68.

A.7.3 The equations used in this guide have been developed based upon venting initially at atmospheric pressure without ducts. They have not been evaluated as to the effect of vent ducts in partial volume applications.

A.7.3.3 See Annex H.

A.7.11.2 Alternate protection measures can be found in Chapter 8 of this document and in NFPA 69, Standard on Explosion Prevention Systems.

A.8.4.3 The curve identified “Dusts with $KSt > 200$ ” in Figure 8.4.3 is based on the data in reference 75 for gasoline vapor deflagrations. The curve identified as “Propane, Dusts with $KSt > 200$ ” in Figure 8.4.3 is obtained by reducing [75] (L/D)

max data for gasoline vapor by 50 percent. Therefore, the committee has exercised engineering judgment in adapting the data for use with dusts as well as gases.

Annex B Guidelines for Measuring Deflagration Indices of Dusts and Gases

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

B.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]. Since gases are not addressed in ASTM E 1226, test procedures are discussed in this annex.

Currently no ASTM standard method is available for use in determining the minimum ignition energies of dusts (as exists for gases). Although several test methods for dusts have been developed by different companies and organizations, the equivalency of such test results is in question. Reference [92] is a review of ignition energy test methods that have been developed for dusts and gases. (See Figure B.1.)

FIGURE B.1 Effect of Test Volume on KG Measured in Spherical Vessels.

B.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.

B.3 Basic Principles.

Figure 6.3.3.6(a) through Figure 6.3.3.6(g) and Figure 7.2.6(a) through Figure 7.2.6(q), presented in this guide, 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 KG or KSt index) needs to be experimentally obtained for use with Figure 6.3.3.6(a) through Figure 6.3.3.6(g) and Figure 7.2.6(a) through Figure 7.2.6(q). 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.

B.3.1 The KG and KSt 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 m³(35 ft³) closed test vessel. The maximum rate of pressure rise found in the 1 m³ (35 ft³) vessel was designated KSt. KSt is not a fundamental material property, but depends on the conditions of the test. The classification work carried out in the 1 m³ (35 ft³) vessel provides the only direct link between small-scale closed vessel tests and the large-scale vented tests on which Figure 6.3.3.6(a) through Figure 6.3.3.6(g) and Figure 7.2.6(a) through Figure 7.2.6(q) are based.

It is possible that the KG index can similarly be determined in a 1 m³ (35 ft³) vessel, but published KG values correspond to tests made in smaller vessels. The variable KG is known to be volume-dependent and should not be considered a constant. Its use is restricted to normalizing data gathered under a fixed set of test conditions.

B.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 m³ (35 ft³) vessel in which the original KSt classifications were made, it is essential to standardize the test conditions that are employed using samples tested either in the 1 m³ (35 ft³) vessel or in a vessel that has been standardized to it. ASTM defines the standardization requirements for dusts. Figure 6.3.3.6(a) through Figure 6.3.3.6(g) identify a series of gas mixtures that were used in the full-scale tests. The actual KG 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 identified in Figure 6.3.3.6(a) through Figure 6.3.3.6(g). If all values are measured under identical conditions in a vessel that meets certain criteria (see Section B.4), the figures can be used by interpolation. To calibrate for dusts, which cannot be identified by composition alone, it is necessary to obtain samples that have established KSt values. (See Section B.5.)

B.3.3 Determination of the KG and KSt Indices. If the maximum rate of pressure rise is measured in a vessel with a volume of other than 1 m³ (35 ft³), Equation B.1 is used to normalize the value obtained to that of a 1 m³ (35 ft³) vessel.

(B.1)

where:

P = pressure (bar)

t = time (sec)

V = volume (m³)

K = normalized KG or KSt 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 m³ (35 ft³) using Equation B.1. 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 KG or KSt index for the test material.

Example: The volume of a spherical test vessel is 26 L (0.026 m³), 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 B.1, the normalized index equals 572 (0.026)^{1/3}, or 169 bar-m/sec.

B.3.4 Effect of Volume on KG and KSt. In the case of many initially quiescent gases, the normalized KG index is found not to be constant but to increase with vessel volume. Figure B.1 shows the variation of KG with vessel volume for methane, propane, and pentane as measured in spherical test vessels [77]. The increase in KG is related to various flame acceleration effects, as described in [44], [78], and [79]. Therefore, KG values that are measured in vessels of different sizes cannot be compared directly, even if all other factors affecting KG are held constant. Any KG measurement should be made in a spherical vessel at least 5 L (0.005 ft³) in volume, and the values obtained should be used only to interpolate between the venting recommendations of gases that are identified in Figure 6.3.3.6(a) through Figure 6.3.3.6(c). (See Section B.4.)

The effect of vessel volume alone on KSt 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 KSt in Equation B.1 is independent of vessel volume. It has been found [47] that KSt values that are obtained in the original 1 m³ (35 ft³) classifying vessel cannot be reproduced in spherical vessels with volumes of less than 16 L (0.016 m³) nor 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 (0.02 ft³) or a squat cylinder of larger volume [such as the 1 m³ (35 ft³) classifying vessel itself]. The principle of KSt standardization in such vessels is to adjust test conditions (particularly initial turbulence) until it can be demonstrated that all dusts yield KSt values that are in agreement with the values that have been established in the 1 m³ (35 ft³) vessel [96]. If vessels of volumes other than 1 m³ (35 ft³) are used, Equation B.1 must be used. Use of vessels with different volumes can lead to errors that are dependent on KSt. The possibility of such errors should be considered where test data are applied to vent design [77].

B.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.

B.4 Gas Testing.

The test vessel used for gas testing should be spherical, with a volume of at least 5 L (0.005 ft³) and a recommended volume of 20 L (0.02 ft³) 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 KG measurements in small vessels.

Standardized gas mixtures, as identified in Figure 6.3.3.6(a) through Figure 6.3.3.6(g), 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 KG value has been determined. A table of KG values is then established for the standardized gases as measured in the test vessel. The table values are not necessarily the same as the KG values determined by using the figures. (See B.3.4.)

To subsequently apply the figures to a test gas, the maximum KG 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 KG values above and below the test value as measured in the test vessel. The vent recommendations are then determined by interpolation of the recommendations for the standardized gases.

A database in which KG values are given for a wide variety of gases that have been tested under the standardized conditions should be established for the test equipment. KG values should not be reported unless the database or, at a minimum, the KG 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 B.6.)

Although Figure 6.3.3.6(a) through Figure 6.3.3.6(g) deal with deflagrations of gases in air, it can be necessary to predict the effect of other oxidants such as chlorine. The KG 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.

B.5 Dust Testing.

Dust samples that have the same chemical composition do not necessarily display similar KSt 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 7.2.6(a) through Figure 7.2.6(q) do not identify the dusts that are involved in large-scale testing, except by their measured KSt values. Although Annex D provides both KSt and dust identities for samples that are tested in a 1 m³ (35 ft³) vessel, it should not be assumed that other samples of the same dusts yield the same KSt 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 KSt and P_{max} characteristics have been established in the standard 1 m³ (35 ft³) vessel [96].

B.5.1 Obtaining Samples for Standardization. Samples should be obtained that have established KSt values in St-1, St-2, and St-3 dusts. At the time this guide 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 m³ (35 ft³) vessel.

B.5.2 Effect of Dust-Testing Variables. The following factors affect the measured K_{St} for a particular spherical test vessel [20 L (0.02 ft³) 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, since 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.

B.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, Annex F.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 [47] in relation to the dust classification work in the 1 m³ (35 ft³) 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.

B.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 B.5.2.2(1) through (5) that have yielded satisfactory results. For example, a 26 L (0.026 m³) test vessel [77] employs a 1 L (100 m³) 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 B.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 B.5.2.2. In addition, the mode of ignition (see B.5.2.3) should not be changed for standardized testing.

B.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 m³ (35 ft³) 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 (0.02 ft³), 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 B.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.

B.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 B.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 μ m). 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 mm), 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 KSt 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 KSt 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 KSt values that can apply to the practical system.

The use of a whipping hose (see B.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.

B.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 (0.02 ft³) 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 ft³) vessel do not propagate flame in a 1 m³ (35 ft³) vessel at the same concentration.

Cashdollar and Chatrathi 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 m³ (35 ft³) 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 m³ (35 ft³)] vessels. The authors further recommend an ignition criterion of an absolute pressure ratio greater than 2 plus a KSt 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 mm). 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.

B.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 resolve. 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 obviate 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 C Fundamental Burning Velocities for Selected Flammable Gases in Air

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

C.1 General.

The values of fundamental burning velocity given in Table C.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 C.1(b).

Table C.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
,tert.obutyl-	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	Hydrogen	312 *
2,3-dimethyl-	52	Isopropyl alcohol	41
2-methyl-	55	Isopropylamine	31
n-Butane	45	Jet fuel, grade JP-1 (average)	40
2-cyclopropyl-	47	Jet fuel, grade JP-4 (average)	41
2,2-dimethyl-	42	Methane	40*
2,3-dimethyl-	43	diphenyl-	35
2-methyl-	43	Methyl alcohol	56
2,2,3-trimethyl-	42	1,2-Pentadiene (ethylallene)	61
Butanone	42	cis-1,3-Pentadiene	55
1-Butene	51	trans-1,3-Pentadiene (piperylene)	54
2-cyclopropyl-	50	2-methyl-(cis or trans)	46
2,3-dimethyl-	46	1,4-Pentadiene	55
2-ethyl-	46	2,3-Pentadiene	60
2-methyl-	46	n-Pentane,	46
3-methyl-	49	2,2-dimethyl-	41
2,3-dimethyl-2-butene	44	2,3-dimethyl-	43
2-Buten 1-yne (vinylacetylene)	89	2,4-dimethyl-	42
1-Butyne	68	2-methyl-	43
3,3-dimethyl-	56	3-methyl-	43
2-Butyne	61	2,2,4-trimethyl-	41
Carbon disulfide	58	1-Pentene	50
Carbon monoxide	46	2-methyl-	47
Cyclobutane	67	4-methyl-	48
ethyl-	53	cis-2-Pentene	51
isopropyl-	46	1-Pentene	63
methyl-	52	4-methyl-	53
methylene	61	2-Pentyne	61
Cyclohexane	46	4-methyl-	54
methyl-	44	Propane	46*
Cyclopentadiene	46	2-cyclopropyl-	50
Cyclopentane	44	1-deutero-	40
methyl-	42	1-deutero-2-methyl-	40
Cyclopropane	56	2-deutero-2-methyl-	40
cis-1,2-dimethyl-	55	2,2-dimethyl-	39
trans-1,2-dimethyl-	55	2-methyl-	41
ethyl-	56	2-cyclopropyl	53
methyl-	58	2-methyl-	44
1,1,2-trimethyl-	52	Propionaldehyde	58
trans-Decalin (decahydronaphthalene)	36	Propylene oxide (1,2-epoxypropane)	82
n-Decane	43	1-Propyne	82
1-Decene	44	Spiropentane	71
Diethyl ether	47	Tetrahydropyran	48
Dimethyl ether	54	Tetralin (tetrahydronaphthalene)	39
Ethane	47	Toluene (methylbenzene)	41
Ethane (ethylene)	80*		

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

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

Gas (in air)	Table C-1(a) (in oxygen)	Andrews and Bradley [84]		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 D Deflagration Characteristics of Selected Flammable Gases

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

D.1 KG Values.

As stated in 6.3.3.8.2 and Annex B, the KG 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 KG for a particular set of test conditions is only one among a continuum of values that vary over the range of test conditions.

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

FIGURE D.1 Reported KG Data. [111]

Table D.1 provides KG values for several gases. The values were determined by tests in a 5 L (0.005 ft³) 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).

Table D.1 Flammability Properties of Gases 5 L (0.005 ft³) sphere; E = 10 J, normal conditions [101]

Flammable Material	P _{max} (bar)	KG (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

aMeasured at elevated temperatures and extrapolated to 25°C (77°F) at normal conditions.

bE = 100 J–200 J.

c200°C (392°F).

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

(D.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 D.1 produces the most accurate values where the two flammable gases have similar values of KG.

D.2 Using New KG Data.

A method for developing KG 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 6, KG data should be adjusted for equivalency with the Bartknecht data as shown in Table D.2. The procedure uses the Bartknecht KG values for methane (55) and propane (100) as points of reference. The following procedure is recommended.

Table D.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 KG = -14.0 + 1.50 K G (as measured).

* Not recommended due to excessive extrapolation.

D.2.1 Develop KG values for propane and methane using the same equipment and method as employed for obtaining data on other gases of interest.

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

(D.2)

(D.3)

where:

WB = W. Bartknecht data

New = New data

D.2.3 The adjusted value of KG that is determined by the new method is calculated as follows:

(D.4)

Annex E Deflagration Characteristics of Selected Combustible Dusts

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

E.1 Introduction.

Table E.1(a) through Table E.1(e) are based on information obtained from Forschungsbericht Staubexplosionen [86].

Table E.1(a) Agricultural Products

Material	Mass Median Diameter (m)	Minimum Flammable Concentration (g/m ³)	Pmax		
(bar)	KSt (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 E.1(b) Carbonaceous Dusts

Material	Mass Median Diameter (m)	Minimum Flammable Concentration (g/m ³)	Pmax		
(bar)	KSt (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 ₂ O	—		125	84.0	67	1
Soot, pine	<10	—		7.9	26	1

Table E.1(c) Chemical Dusts

Material	Mass Median Diameter (m)	Minimum Flammable Concentration (g/m ³) (bar)	KSt (bar-m/sec)	Dust Hazard Class	Pmax
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 E.1(d) Metal Dusts

Material	Mass Median Diameter (m)	Minimum Flammable Concentration (g/m ³) (bar)	KSt (bar-m/sec)	Dust Hazard Class	Pmax
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
Zinc	10	250	6.7	125	1
Zinc	<10	125	7.3	176	1

Table E.1(e) Plastic Dusts

Material	Mass Median Diameter (m)	Minimum Flammable Concentration (g/m ³) (bar)	KSt (bar-m/sec)	Dust Hazard Class	Pmax	
(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	
(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

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 m³ (35 ft³) vessel:

- (1) Minimum explosive concentration
- (2) Maximum pressure developed by the explosion, Pmax
- (3) Maximum rate of pressure rise (dP/dt)max
- (4) KSt value, which is equivalent to (dP/dt)max because of the size of the test vessel
- (5) Dust hazard class as used in Figure 7.2.6(a) through Figure 7.2.6(q)

E.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 KSt values. For example, various calcium stearate dusts have been found to have ranges of KSt 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.

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

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

F.1

The following procedure can be used to assess the impact of the vent panel mass on Pred.

F.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.

F.1.2 The reduced deflagration pressure is first calculated using Equation 7.1, based on low-mass vents. Corrections for vessel L/D and Partial Volume can then be added. Next the correction factors for inertia effects are calculated.

F.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, pvi, higher than the nominal static value, pv, and
 - (2) As a higher reduced pressure, pri, after full vent deployment with respect to the pri0 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, pvi or pri, used as the reduced pressure produced in the vented deflagration.

F.1.3.1 The inertia correction is limited to:

- (1) vent panel density, $v < 200 \text{ kg/m}^2$
- (2) nominal $p_v < 0.5 \text{ bar}$

F.1.4 Both inertia effects are evaluated using two dimensionless parameters, K and $K_{St,v}$. However, one term in the parameters is different, the dust reactivity. In the first case, the deflagration index, KSt, is used to determine KSt and KSt. In the second case, the effective mixture reactivity, K, is used to determine K and K.

F.1.5 The deflagration index, KSt, 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 KSt, but which 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:

(F.1)

where:

$K_{St,v}$ = deflagration index with vent relief pressure correction

KSt = deflagration index (bar-m/sec)

p_v = vent relief pressure (bar abs)

p_0 = initial pressure (bar abs)

The volume correction for Equation F.1 is the following:

(F.2)

where:

K = volume correction to deflagration index

V = enclosure volume (m³)

This volume correction is applied only where the enclosure volume is greater than 10 m³; otherwise, $K = K_{St,v}$.

F.1.6 The shape factor for the vent(s) is:

For square panels, $cs = 1$.

For circular panels, $cs = 0.886$.

For rectangular panels, apply the following equation:

(F.3)

where:

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

F.1.7 Calculate KSt and K using Equations F.4 and F.5.

(F.4)

(F.5)

where:

KSt, K = dimensionless parameter

v = vent panel density (kg/m²)

n = number of equal-sized panels

cs = shape factor

cd = constant = 232.5 m/sec

p0 = initial pressure (Pascal absolute, N/m²)

V = enclosure volume (m³)

KSt = deflagration index (bar-m/sec)

K = effective mixture reactivity (bar-m/sec)

pm = unvented deflagration pressure (bar abs)

F.1.7.1 For hinged vent closures, increase the value of vent panel density, v, by 33 percent.

F.1.8 Calculate KSt and K using Equations F.6 and F.7.

(F.6)

(F.7)

where:

KSt, K = dimensionless parameter

Av = vent area (m²)

F.1.9 Calculate the pressure function, f (Pv), using Equations F8 and F9.

(F.8)

(F.9)

where:

Pv = pressure ratio

pv = vent panel static relief pressure (bar abs)

p0 = initial pressure (bar abs)

pm = unvented deflagration pressure (bar abs)

F.1.10 Calculate the panel inertia parameter, β , using Equation F.10.

(F.10)

where:

β = panel inertia parameter

m = vent gravity coefficient, assisting or slowing vent opening as defined in Table F.1.10

g = gravitational acceleration (m/sec²)

pv = vent panel static relief pressure (Pascal absolute, N/m²)

p0 = initial pressure (Pascal absolute, N/m²)

Table F.1.4.1 Value of Vent Gravity Coefficient

Panel Characteristics	Value of m
Vertical panel, no hinge (translating)	0
Vertical panel, hinged on a side	0
Vertical panel, hinged at the top	1
Vertical panel, hinged at the bottom	-1
Horizontal panel, on top of the vessel	1
Other orientations	0
Horizontal panel, on bottom of the vessel	-1

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

(F.11)

where:

pvi = effective vent relief pressure with inertia (bar abs)

pv = vent panel static relief pressure, pstat+ 1 (bar abs)

pm = unvented deflagration pressure (bar abs)

p0 = initial pressure (bar abs)

F.1.12 The new reduced pressure after full vent deployment can be determined as follows, depending on the value of K:

(F.12)

where:

pri = the reduced pressure developed with inertia (bar abs)

pr0 = the reduced pressure developed with zero low-mass vents, Pred+ 1 (bar abs)

pm = unvented deflagration pressure, Pmax+ 1 (bar abs)

p0 = initial pressure (bar abs)

F.1.13 Compare the results obtained in Equations F.11 and F.12. The larger of the two results, pvi or pri, represents the new maximum reduced deflagration pressure (in bar abs) due to the vent panel inertia effect. The value of pvi or pri must be converted to gauge pressure as Pred to iterate Equation 7.1. If the calculated pressure exceeds the enclosure strength, the user should repeat the calculation with a larger vent area.

F.2

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

(1) V = 100 m³

(2) KSt = 200 bar-m/sec

(3) p0 = 1 bar abs

(4) Pmax = 9 bar abs

(5) v = 24.4 kg/m²

(6) n = 4 (equals square panels vertically mounted, not hinged)

(7) Av = 6 m²

(8) $P_{stat} = 0.05 \text{ bar}$

The first step is to determine the reduced deflagration pressure developed if zero-mass vents were used.
From Equation 7.1, solve for :

The reduced pressure is then calculated by

In order to solve Equation F.3, we must first determine the values of K_{St} , K_{St} , and :

From Equation F.9,

and from Equation F.8,

Now we can solve Equation F.3:

In order to solve Equation F.10, we must first determine the values of K and K .

From Equation F.1,

and from Equation F.2,

Now we can solve Equation F.10:

The new pressure due to panel inertia is the larger of the figures determined in Equations F.3 and F.10. In this example, Equation F.10 produced the larger pressure and therefore the new pressure due to panel inertia is 1.272 bar abs.

Annex G Research Reports and Supporting Documents

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

G.1

The new equations for Chapter 7 have been developed using material based upon the following research conducted by Factory Mutual Research Corporation.

G.1.1 Generalized vent correlation equation:

Tamanini, F., and J. Valiulis 1996. "Improved Guidelines for the Sizing of Vents in Dust Explosions." *Journal of Loss Prevention in the Process Industries*, 9(1):105–118.

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Ural, E. A. 2001. "A Simplified Development of a Unified Dust Explosion Vent Sizing Formula." *Proc. 35th Annual Loss Prevention Symp.*, American Institute of Chemical Engineers, Houston, TX, April 22–26.

Ural, E. A. 1989. "Simplified Analytical Model of Vented Explosions." Published as Appendix C in FMRC Report J. I. 0Q2E2.RK. Large Scale Vented Dust Explosions, Effect of Turbulence on Explosion Severity, Tamanini and Chafee, Factory Mutual Research Corporation.

G.1.2 Effect of vent ducts on vent area:

Tamanini, F. 1995. "An Improved Correlation of Experimental Data on the Effects of Ducts in Vented Dust Explosions." *Proc. 8th Int'l Symp. Loss Prevention & Safety Promotion in the Process Industries*, Vol. 1, Antwerp: June 6–9.

Ural, E. A. 1993. "A Simplified Method for Predicting the Effect of Ducts Connected to Explosion Vents." *J. Loss Prevention in the Process Industries* 6(1):3–10.

G.1.3 Partial volume deflagration:

Tamanini, F. 1996. "Vent Sizing in Partial-Volume Deflagrations and Its Application to the Case of Spray Dryers." *J. Loss Prevention in the Process Industries* 9(5):339–350.

G.1.4 Vent panel inertia effect:

Tamanini, F. 1998. "Disclosure of FMRC Method for Panel Inertia Effects in Dust Explosions." FMRC Research, July 30.

Tamanini, F. 1996. "Modeling of Panel Inertia Effects in Vented Dust Explosions." *Process Safety Progress* 15(4):247–257, Winter.

Annex H Effect of Partial Volumes on Buildings — Example Problem

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

H.1

NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, applies the layer thickness criteria over 5 percent of the floor area. This guide has chosen to apply the layer thickness criteria of $\frac{1}{8}$ inch over 100 percent of the floor area and other surfaces defined in Step 3 to be more conservative.

H.2

Building Example. Thin layers of coal dust are known to form on the floor of a coal-fired powerhouse with a 20 m \times 30 m floor area, and a 4 m ceiling height. Deflagration vents for roof installation are to be designed for a Pred of gauge pressure of 1 psi, and a P_{stat} of gauge pressure of 0.50 psi.

H.3

Four samples from measured 4 ft² (0.37 m²) areas are collected and weighed, with an average mass of 148 g.

H.4

Inspection of the other exposed surfaces in the powerhouse reveals that there are deposits on the top surface of ceiling beams. Two samples taken from measured 4 ft² areas have an average mass of 100 g. The beam top flange surface area is 20 m².

H.5

The mass of coal dust in the coal conveyors is estimated to be 20 kg (1 percent of the total mass of coal). Although there is also a coal bunker in the powerhouse, it is assumed not to contribute to any building deflagration because it is vented through the building roof.

H.6

Testing of the samples resulted in a worst-case P_{max} of gauge pressure of 91.7 psi, a worst-case K_{St} of 80 bar-m/sec, and a worst-case c_w of 500 g/m³.

H.7

Using the P_{red} of gauge pressure of 1 psi and P_{max} of gauge pressure of 91.7 psi, $\beta = 0.011$. Using a vent panel with a P_{stat} of gauge pressure of 0.50 psi = 0.0345 bar:

H.8

H.9

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

I.1

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Annex J Informational References

J.1 Referenced Publications.

The following documents or portions thereof are referenced within this guide for informational purposes only and are thus not part of the recommendations of this document unless also listed in Chapter 2.

J.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 30, Flammable and Combustible Liquids Code, 2000 edition.

NFPA 69, Standard on Explosion Prevention Systems, 1997 edition.

NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, 2000 edition.

Fire Protection Guide to Hazardous Materials, 1997 edition.

J.2 Other Publications.

J.2.1 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts, 1994.

ASTM E 1515, Standard Test Method for Minimum Explosible Concentration of Combustible Dusts, 1998.

J.2.2 NACE Publication. National Association of Corrosion Engineers, 1440 South Creek Drive, Houston, TX 77084-4906.

National Association of Corrosion Engineers Handbook, 2nd edition, 1991.

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J.3 References for Extracts.

The following documents are listed here to provide reference information, including title and edition, for extracts given throughout this guide as indicated by a reference in brackets [] following a section or paragraph. These documents are not a part of the recommendations of this document unless also listed in Chapter 2 for other reasons.

NFPA 69, Standard on Explosion Prevention Systems, 1997 edition.

NFPA 211, Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances, 2000 edition.

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