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NFPA 68
Guide for Venting of Deflagrations
1994 Edition

NFPA

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101

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The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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NFPA 68

Guide for

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1994 Edition

This edition of NFPA 68, *Guide for Venting of Deflagrations*, was prepared by the Technical Committee on Explosion Protection Systems and acted on by the National Fire Protection Association, Inc. at its Fall Meeting held November 15-18, 1993 in Phoenix, AZ. It was issued by the Standards Council on January 14, 1994, with an effective date of February 11, 1994, and supersedes all previous editions.

The 1994 edition of this standard has been approved by the American National Standards Institute.

Origin and Development of NFPA 68

The *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 fundamentals and parameters of explosions; data developed by small-scale tests, interpretation of the results of these tests, and the use of vents and vent closures current at that time. This information was then related to "rules of thumb" vent ratio recommendations that were used for many years. Some of the vents designed using these "rules of thumb" functioned well; perhaps it is well that some others were never put to the test.

Since 1954, extensive experimentation has been done in Great Britain and Germany to add to the information already known. The U.S. Bureau of Mines has also done some work in this area. However, the work was not completed because the group involved was assigned to different programs.

In 1974, NFPA 68 was revised and the work done in Great Britain and Germany was included in hopes 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 added considerable data that was 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 represents a complete rewrite of the document to more effectively communicate the principles of venting deflagrations to users of the document. This effort has produced revisions to each chapter to improve the organization of information within the document without changing the venting methodology presented in the document. The thrust of this revision was to make improvements in the useability and adoptability of the guide. The effect of these changes should clarify this complex technology.

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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.

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.

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NOTICE: Information on referenced publications can be found in Appendix F.

Foreword

This guide is arranged with like subjects grouped together for most uses. However, occasionally cross-referencing between chapters can provide valuable information. The following is a brief summary of topics and their locations. The user is cautioned, however, that each topic is innately connected with the material of the entire guide, and selected use of any specific paragraph is not recommended.

Chapter 1 General

1-1 Scope.

1-1.1 This guide applies to the design, location, installation, and use of devices and systems that will vent the combustion gases and pressures resulting from a deflagration within an enclosure so that structural and mechanical damage is minimized. The deflagration can result from the ignition of a combustible gas, mist, or dust.

This guide is considered 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 objectives for protection. Venting of deflagrations will only minimize the damage resulting from combustion.

1-1.2 This guide does not apply to detonations, bulk autoignition of gases, or unconfined deflagrations, such as open-air or vapor cloud explosions.

1-1.3 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 from other heat sources. (*See NFPA 30, Flammable and Combustible Liquids Code.*)

1-1.4 This guide does not apply to emergency vents for runaway exothermic reactions or self-decomposition reactions.

1-1.5 This guide does not apply to pressure relief devices on equipment such as oil-insulated transformers. It also does not apply to pressure relief devices 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 will not prevent a deflagration; venting can, however, minimize the destructive effects of a deflagration.

1-3 Definitions. For the purpose of this guide, the following terms have the meanings given below.

Burning Velocity. The rate of flame propagation relative to the velocity of the unburned gas ahead of it. See Fundamental Burning Velocity.

Combustible. Capable of undergoing combustion.

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 flames.

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

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

Dust. Any finely divided solid, 420 microns or less in diameter (i.e., material capable of passing through a U.S. No. 40 standard sieve).

Enclosure. A confined or partially confined volume. Some examples are a room, building, vessel, silo, bin, pipe, or duct.

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

Flame Speed. The speed of a flame front relative to a fixed reference point. Flame speed is dependent on turbulence, the equipment geometry, and the fundamental burning velocity.

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

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

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

Fog. See Mist.

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

Gas. The state of matter characterized by complete molecular mobility and unlimited expansion. Used synonymously with the term "vapor."

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

K_G. The measure of explosibility of a gas cloud as defined in Section 2-5.

K_{St}. The measure of explosibility of a dust cloud as defined in Section 2-5.

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

Minimum Ignition Energy. The minimum amount of thermal energy released at a point in a combustible mixture that will cause indefinite flame propagation away from that point, under specified test conditions. The lowest value of the minimum ignition energy is found at a certain optimum mixture. It is this value (at this optimum mixture) that is usually quoted as the minimum ignition energy.

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

Optimum Mixture. A specific mixture of fuel and oxidant that yields the most rapid combustion in terms of a specific measured quantity or that has the lowest value of the minimum ignition energy or that produces the maximum deflagration pressure. The optimum mixture may not be the same for each combustion property measured.

Oxidant. Any gaseous material that can react with a fuel (either gas, dust, or mist) to produce combustion. Oxygen in air is the most common oxidant.

Rate of Pressure Rise (dP/dt). The rate of increase in pressure over the time interval required for that increase to occur. The maximum rate of pressure rise is computed from the slope of the steepest part of the pressure-versus-time curve during deflagration in a closed vessel. (*See Appendix B, Guidelines for Measuring Deflagration Indices of Dusts and Gases.*)

Reduced Pressure (P_{red}). The maximum pressure developed in a vented enclosure during a vented deflagration. It is also used to define the maximum pressure that can be withstood by the weakest structural element of the vented enclosure.

Static Activation Pressure (P_{stat}). Pressure that activates a vent closure with a rate of pressure rise less than 0.1 bar/min.

Stoichiometric Mixture. A mixture of a combustible material and an oxidant in which the oxidant concentration is just sufficient to completely oxidize the fuel.

Ultimate Strength. That pressure that results in the destructive failure of the weakest component.

Vapor. See Gas.

1-4 Conversion Factors. The conversion factors in Table 1-4, to three significant figures, will be useful in understanding the data presented in this guide:

Table 1-4 Conversion Factors

Length	1 m	=	3.28 ft
		=	39.4 in.
	1 in.	=	2.54 cm
	1 ft	=	30.5 cm
	1 μm, micron; micrometer	=	1.00 x 10^{-6} m
Area	1 m^2	=	10.8 ft^2
	1 $in.^2$	=	6.45 cm^2
Volume	1 liter	=	61.0 $in.^3$
	1 ft^3	=	7.48 U.S. gal
	1 m^3	=	35.3 ft^3
		=	264 U.S. gal
	1 gal (U.S.)	=	3.78 liters
		=	231 $in.^3$
		=	0.134 ft^3
Pressure	1 atmosphere	=	760 millimeters Mercury (mm Hg)
		=	101 kiloPascals (kPa)
		=	14.7 psi
		=	1.01 bars
	1 psi	=	6.89 kPa
	1 Newton/m^2	=	1.00 Pascal
	1 bar	=	100 kPa
		=	14.5 psi
		=	0.987 atmosphere
	1 kilogram/cm^2	=	14.2 psi
	1 kilogram/m^2	=	0.205 lb/ft^2 (psf)
Energy	1 J	=	1.00 Watt-second
	1 Btu	=	1055 J
	1 J	=	0.738 ft-lb
K_G and K_{St} Conversion Factors	$\frac{\text{1 bar-meter}}{\text{sec}}$	=	$\frac{\text{47.6 psi-ft}}{\text{sec}}$
	$\frac{\text{1 psi-ft}}{\text{sec}}$	=	$\frac{\text{0.021 bar-meter}}{\text{sec}}$
Concentration	1 oz. Avoir/ft^3	=	1000 g/m^3

1-5 Symbols. For the purpose of this guide, the following symbols have the meanings given below:

A	—	Area, m^2 or ft^2 or $in.^2$
A_s	—	Internal Surface Area of Enclosure, ft^2 or m^2
A_v	—	Vent Area, m^2 or ft^2
C	—	Constants in Correlation Equations for Figures 7-1(d), 7-1(e), and 7-1(f) (*see 7-1.1.2*) or Constant in Venting Equation in Chapter 4
C_g	—	Concentration of Gas in Mixture, percent by volume
dP/dt	—	Rate of Pressure Rise, bar/sec or psi/sec
F_r	—	Reaction Force, lb
K_G	—	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
p	—	Perimeter of Duct Cross-Section, m or ft
P	—	Pressure, bar (gauge) or psig
P_{max}	—	Maximum Pressure Developed in an Unvented Vessel, bar (gauge) or psig
P_{red}	—	Reduced Pressure (i.e., the maximum pressure actually developed during a vented deflagration), bar (gauge) or psig.
P_{stat}	—	Vent Closure Release Pressure, bar (gauge) or psig
ΔP	—	Pressure Differential, bar or psi
S_u	—	Fundamental Burning Velocity, cm/sec
S_f	—	Flame Speed, cm/sec
S_t	—	Transitional Flame Velocity, cm/sec
t_f	—	Duration of Pressure Pulse, sec
UFL	—	Upper Flammable Limit, percent by volume
μm	—	micron; micrometer
V	—	Volume, m^3 or ft^3

NOTE: All pressures are gauge pressure unless otherwise specified.

Chapter 2 Fundamentals of Deflagration

2-1 General.

2-1.1 The following conditions are necessary for a deflagration to occur:

(a) Fuel concentration within flammable limits.

(b) Sufficient oxidant to support combustion.

(c) Ignition source strong enough to initiate combustion.

(d) The fuel and oxidant need to be mixed.

2-1.2 A deflagration results in an increase in the initial pressure-volume (PV) product according to the ideal gas law, Eq. 1, through change in absolute temperature (T) and molar quantity (n) of gas species.

$$PV = nRT \qquad (1)$$

(Where R is the universal gas constant.)

2-1.3 Deflagrations in closed systems (V = constant) that are not strong enough to accommodate the rise in pressure could result in damage to the system. The maximum pressure (P_{max}) typically achieved by deflagration of carbonaceous materials in air initially at ambient temperature and pressure is in the range of 8 to 10 times the initial absolute pressure.

2-1.4 Deflagration venting is one means of controlling damage. By releasing expanding gases through an opening engineered for the purpose, it is possible to maintain a reduced maximum pressure (P_{red}) that is below that which would cause unacceptable damage.

2-1.5 The peak pressure generated and the maximum rate of pressure rise during the combustion process are key factors in the design of deflagration protection systems.

2-2 Fuel.

2-2.1 General. Any material capable of reacting with an oxidizing medium can be classified as a fuel. A fuel can be in the gas, liquid, or solid phase. Liquid and solid fuels pose the same type of deflagration risk when they are dispersed in air as fine mists or dusts. Fuels that are a combination of a combustible gas and a combustible dust or combustible liquid mist and a combustible dust are known as hybrid mixtures.

2-2.2 Fuel Concentration.

2-2.2.1 Combustible Gases. This guide is limited to air-fuel (oxidant) mixtures where the fuel can be comprised of many components.

2-2.2.1.1 Combustible gases have concentrations below and above which they will not burn. These concentrations are called the flammability limits and are respectively the lower flammable limit (LFL) and the upper flammable limit (UFL). Between these concentration limits, ignition is possible and combustion can take place. Ignition of mixtures outside these composition limits fails because insufficient energy is given off to heat the adjacent unburned gases to their ignition temperature. Lower and upper flammability limits are determined by test and are apparatus dependent. Numerous fuels have published flammability limits that can be used to determine whether a system can deflagrate.

2-2.2.1.2 The mixture compositions that are observed to support the maximum pressure and the fastest propagation of a deflagration front are typically on the fuel-rich side of the stoichiometric mixture. Note that the concentration for the maximum rate of pressure rise and the concentration for P_{max} can be slightly different.

2-2.2.2 Combustible Dusts.

2-2.2.2.1 Solid particulates smaller than about 420 μm (passing through a 40 mesh screen) are classified as dusts. Dusts of combustible materials, when dispersed in air, can propagate a flame. The predominant means of flame propagation in dust clouds is through the fuel gas that forms around decomposing or pyrolyzing particles as they become heated by radiant and thermal heat transfer from the approaching flame front.

2-2.2.2.2 As with gaseous mixtures, there is a lower dust cloud concentration known as the lower flammable limit (LFL) that will support flame propagation.

2-2.2.2.3 The LFL of a dust is dependent on its particle size distribution. Large particles participate inefficiently in the deflagration process. The LFL is usually above the theoretical stoichiometric composition for dusts. The composition that produces the fastest rate of pressure rise in a closed vessel is typically in the range of 300 to 1000 g/m^3 (0.3 to 1.0 oz/ft^3) for fine carbonaceous dusts.

2-2.2.2.4 Dust clouds seldom exhibit an upper flammable limit that is practical for use in deflagration control.

2-2.2.2.5 Combustible dust flammability data should be used with caution. Dust clouds with concentrations below the lower flammable limits can create hazardous conditions because of the tendency for dust to fall out of suspension and settle on surfaces. Such deposits can be thrown into suspension and form a dust cloud having an ignitible concentration.

2-2.2.3 Hybrid Mixtures.

2-2.2.3.1 The presence of a combustible gas component in a mixture reduces the apparent lower flammability limit and ignition energy for a dust/air mixture. The effect can be considerable and can occur even though the gas is below its lower flammable limit and the dust is below its minimum flammable concentration. Careful evaluation of the ignition and deflagration characteristics of the specific mixtures is required.

2-2.2.3.2 It has been shown that the introduction of a combustible gas into a cloud of dust that would normally be a minimal deflagration hazard can result in a vigorous combustion of the hybrid mixture. An example of this phenomenon is the combustion of unplasticized polyvinyl chloride dust in an air/methane atmosphere.

2-2.2.3.3 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.

2-2.2.4 Mists. Mists of combustible liquid droplets have lower and upper flammable limits. The determination of these limits is complicated by droplet dispersion and settling. The lower flammable limit (LFL) for dispersed liquid hydrocarbon mists varies from about 50 g/m^3 (0.05 oz/ft^3) to about 10 g/m^3 (0.01 oz/ft^3) as the droplet diameter increases from about 10 to 100 μm (Reference 58 and Figure 8 of Reference 61). Fifty g/m^3 (0.05 oz/ft^3) is roughly equal to the LFL for combustible hydrocarbon gases in air at room temperature.

2-3 Oxidant.

2-3.1 The oxidant for a deflagration is normally the oxygen in air. Oxygen concentrations greater than 21 percent tend to increase the fundamental burning velocity and increase the probability of transition to detonation. Conversely, concentrations less than 21 percent tend to decrease the rate of combustion. There is for most fuels a limiting oxygen concentration below which combustion will not occur. (*See NFPA 69, Standard on Explosion Prevention Systems.*)

2-3.2 Other oxidants, such as the halogens and oxides of nitrogen, should be considered.

2-4 Ignition Source.

2-4.1 General.

2-4.1.1* One measure of the ignition sensitivity of a gas, dust, or hybrid mixture is its minimum ignition energy. The minimum ignition energy is typically less than 1 mJ for gases and 100 mJ for dusts. Minimum ignition energies (MIE) are reported for some gases and dust clouds (References 7 through 13, 86, and 88). These minimum ignition energies can be much less than common ignition sources in commercial and industrial systems from electric arcs, electrostatic discharge, and sparks. The technical guidelines in this document are based on tests involving ignition sources much larger than the MIE, and up to 10 kJ. Stronger ignition sources, such as flame jet ignitions, deserve special consideration.

2-4.1.2 Ignition energy requirements can decrease with increasing temperatures and pressures of the system. There also exists a minimum ignition temperature that is related to contact with hot surfaces. This temperature is called autoignition temperature when dealing with gases. For dusts, the ignition temperature is reported as either a cloud or a layer depending on the method of test. See NFPA 497M, *Manual for Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations,* for information.

2-4.1.3 An ignition source such as a spark or a flame can travel from one piece of equipment to another. A spark generated in a grinding operation can travel through a duct to a dust collector and can ignite the dust anywhere along the way. Similarly, a flame produced by an ignition source in one enclosure can become a much larger ignition source if it enters another enclosure.

2-4.1.4 In vessels smaller than 1 m^3, an increase in the energy of the ignition source increases both the maximum pressure and the maximum rate of pressure rise developed during a deflagration. In larger vessels, these increases only occur with powerful sources of ignition, such as jet flames. Thus, the energy released by a point source of ignition in a relatively large vessel will have little effect on the course of the deflagration. This is because the effect of the turbulence induced at the flame front will outweigh any effects of the ignition source.

2-4.1.5 The location of the ignition source within an enclosure can affect the rate of pressure rise. Ignition at the geometric center of an enclosure will usually result in the largest rate of pressure rise.

2-4.1.6 Simultaneous multiple ignition sources can produce turbulence in the fuel/oxidant mixture that will intensify deflagration.

2-4.2 Mists and Foams.

2-4.2.1 Mists can ignite not only at initial temperatures above the flash point, but also well below the flash point. In the extreme case, a cloud of frozen droplets can deflagrate in the same manner as a dust cloud. Ease of ignition of liquid mists is related principally to the representative droplet diameter. As the droplet diameter increases, the ignition energy required increases (Reference 86).

2-4.2.2 Foams of combustible liquids burn readily and, as a source of finely dispersed mist, they can exhibit a low MIE. Oxygen is more soluble than nitrogen in most combustible liquids and, if a foam is produced by a degassing process, the oxidant concentration may be enriched. This guide does not address mitigation of deflagration events involving foams.

2-4.3 Combustible Dusts. Minimum ignition energy is extremely dependent on particle size (Reference 1). See Figure 2-4.3 for an illustration of this effect.

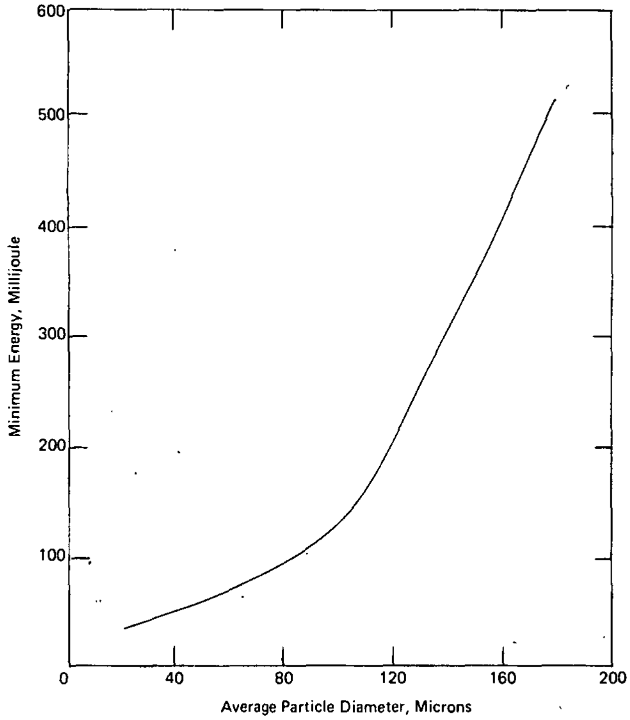


Figure 2-4.3 Effect of average particle diameter of a typical agricultural dust on the minimum ignition energy. (Unpublished data courtesy of U.S. Mine Safety and Health Administration.)

2-4.4 Hybrid Mixtures. As illustrated in Figure 2-4.4, small amounts of combustible gas can lower the minimum ignition energy of a hybrid mixture.

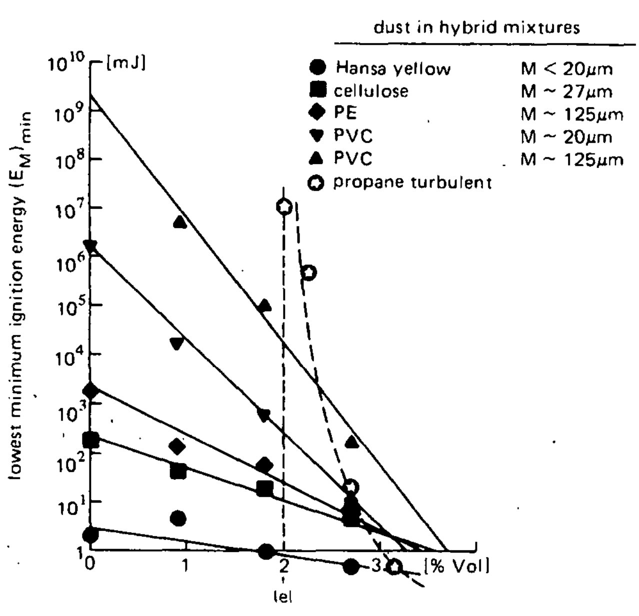


Figure 2-4.4 Lowest minimum ignition energy of hybrid mixtures versus propane content (Reference 3).

2-5 Maximum Pressure and Maximum Rate of Pressure Rise.

2-5.1 General.

2-5.1.1 Deflagration in closed vessels results in a rapid rise in pressure. The key characteristics of closed-vessel deflagrations are the maximum pressure attained, P_{max}, and the maximum rate of pressure rise, $[(dP/dt)_{max}]$, developed during the event. One measure of the explosibility of a combustible dust is computed from the maximum rate of pressure rise attained by combustion in a closed vessel. The index of explosibility is defined as:

$$K = (dP/dt)_{max} V^{1/3} \quad (2)$$

where V is the volume of the test vessel. The value of $(dP/dt)_{max}$ will be a maximum for a particular fuel concentration, referred to as the "optimum" concentration, and is characteristic of the particular combustible.

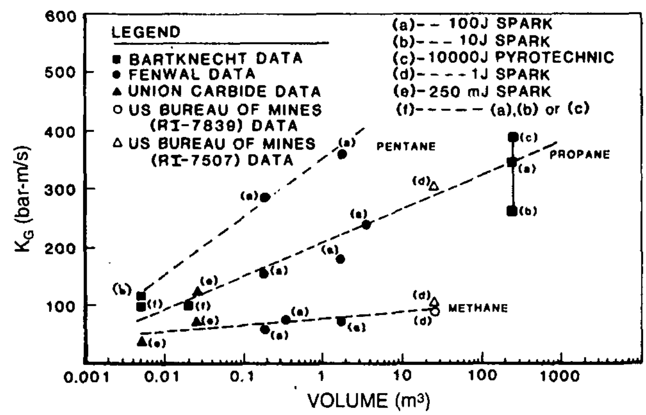


Figure 2-5.1 Effect of test volume on K_G measured in spherical vessels.

2-5.1.2 The maximum rate of pressure rise is determined by test. Refer to Appendix B, Guidelines for Measuring Deflagration Indices of Dusts and Gases.

2-5.2 Combustible Dusts. Experiments with combustible dusts show that the maximum pressure and K_{St} increase with a decrease in the dust particle size. See Figure 2-5.2.

2-5.3 Hybrid Mixtures. The maximum rate of pressure rise and the maximum pressure depends on the concentration of the flammable gas in the hybrid mixture. See Figure 2-5.3.

2-6 Other Factors.

2-6.1 Burning Velocity and Flame Speed.

2-6.1.1 The burning velocity is the rate of flame propagation relative to the velocity of the unburned gas ahead of it. The fundamental burning velocity, S_u, is the burning velocity for laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas.

2-6.1.2 Values of S_u have been measured and published for many gases. The burning velocity for a dust cloud can be estimated from closed-vessel deflagration tests. Values of S_u for a number of gases in air are given in Appendix B. Values of burning velocity reported for clouds of combustible dusts are typically an order of magnitude lower than for gases.

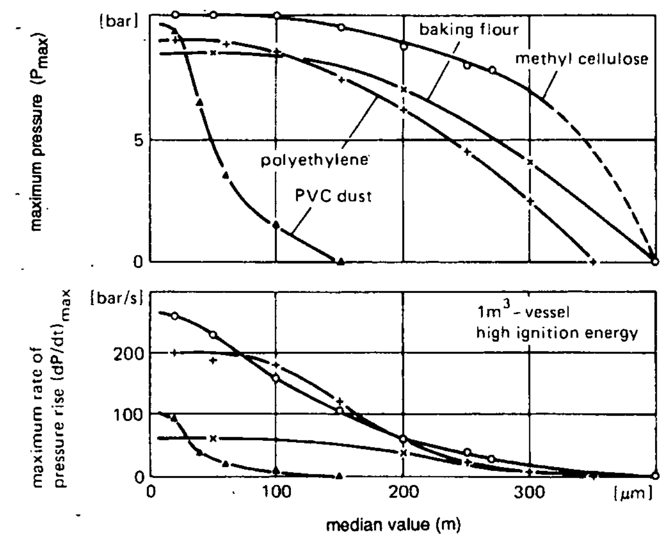


Figure 2-5.2 Effect of average particle diameter of dusts on the maximum pressure and the maximum rate of pressure rise developed by a deflagration in a 1-m³ vessel (Reference 3).

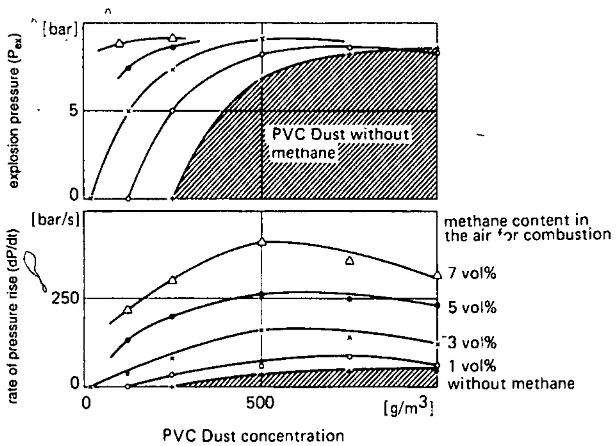


Figure 2-5.3 Combustion data for polyvinyl chloride/methane/air mixtures (1-m³ vessel; chemical detonator with an ignition energy of 10,000 J) (Reference 4).

2-6.1.3 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 that of the burned gas.

$$S_f = Su\left(\frac{\sigma_u}{\sigma_B}\right) \tag{3}$$

σ_u means density of unburned gas.
σ_B means density of burned gas.

2-6.2 Initial Temperature and Pressure. Any change in the initial absolute pressure of the fuel/oxidant mixture at a given initial temperature will produce 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 will produce an inverse change in the maximum pressure attained. (*See Figure 2-6.2.*) However, an increase in temperature usually results in an increase in the maximum rate of pressure rise.

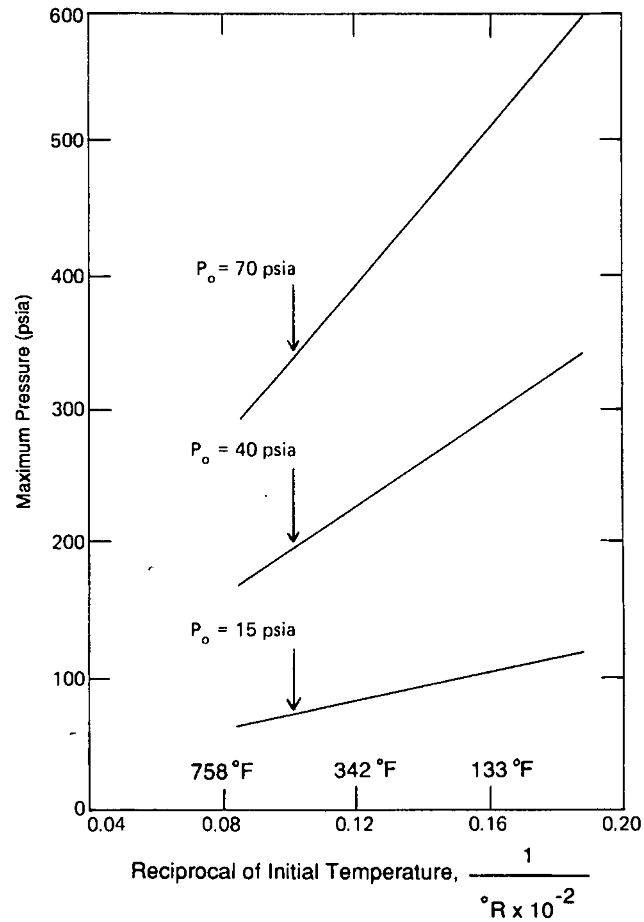


Figure 2-6.2 Effect of initial temperature on the maximum pressure developed in a closed vessel for deflagrations of 9.9 percent methane/air mixtures at several initial pressures (Reference 15).

2-6.3 Turbulence.

2-6.3.1 Flame speeds are greatly enhanced by turbulence. Turbulence can be increased in a system by normal fluid flow or particularly by flow past obstacles. Turbulence causes flames to become stretched, which increases the net flame surface area exposed to unburned materials. In elongated enclosures, such as ducts, turbulence generation is enhanced and flame speeds can increase to very high values and transition from deflagration to detonation conditions is possible.

2-6.3.2 Initial turbulence in closed vessels results in higher rates of pressure rise, and greater maximum pressures than would be obtained if the fuel/oxidant mixture were at initially quiescent conditions. This is shown in Figure 2-6.3.

2-6.3.3 Turbulence is also created during venting as gases and dusts move by obstacles within the enclosure; this turbulence also leads to higher maximum pressures and higher maximum rates of pressure rise.

2-6.4 Presence of Moisture.

2-6.4.1 Moisture in the air (humidity) surrounding a dust particle has no significant effect on a deflagration once ignition has occurred.

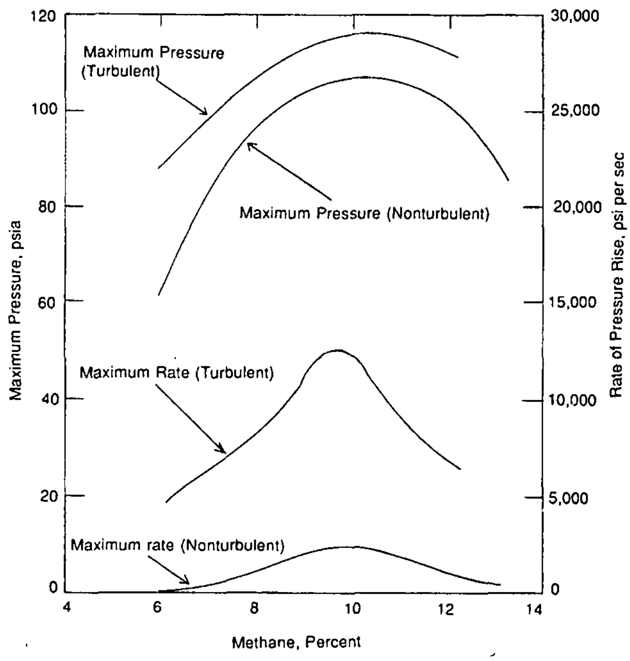


Figure 2-6.3 Maximum pressure and rate of pressure rise for turbulent and nonturbulent methane/air mixtures in a 1-ft³ closed vessel (Reference 16).

2-6.4.2 Moisture in the dust will usually raise the ignition temperature of the dust because of the energy absorbed in vaporizing the moisture. In many cases, there are direct relationships between moisture content of the dust and the minimum energy required for ignition, the minimum flammable concentration, the maximum pressure developed during a deflagration, and the maximum rate of pressure rise. For example, the minimum ignition temperature of cornstarch dust can increase by as much as 50°C (122°F) when the moisture content increases from 1.6 to 12.5 percent by weight.

2-6.4.3 As a practical matter, moisture cannot be considered an effective means of preventing a deflagration since most ignition sources will provide more than enough energy to vaporize the moisture and to ignite the dust. For moisture to prevent ignition of a dust by most common sources, such as hot pieces of slag from cutting operations or hot bearing surfaces, the dust would have to be so damp that a cloud would not readily form. Material containing this much moisture usually will cause processing difficulties.

2-6.5 Presence of Inert Material.

2-6.5.1 Inert Gases. Inert gases can be used to reduce the oxidant concentration. The reduction in oxidant concentration can reduce the rate of combustion of the gas or dust mixture. At some minimum oxidant concentration, the mixture becomes incapable of deflagration. Gases such as nitrogen or carbon dioxide are often used to prevent ignition. The use of inert gases is discussed in NFPA 69, *Standard on Explosion Prevention Systems.*

2-6.5.2 Inert Powder. Inert powder can reduce the combustibility of a dust by the absorption of heat. Unfortunately, the amount of inert powder necessary to prevent a deflagration is large, with concentrations of 40 to 80 percent. Some inert powders such as silica can be harmful because they increase the dispersibility of the combustible dust.

Addition of inert powder to a combustible dust/oxidant mixture will reduce the maximum rate of pressure rise and will increase the minimum concentration of combustible dust necessary for ignition. Rock-dusting of coal mines is one practical application of the use of inert dust to prevent a deflagration. However, enough rock dust is usually added to provide a concentration of at least 65 percent inert dust. See Figure 2-6.5 for an example of the effect of admixed inert powder.

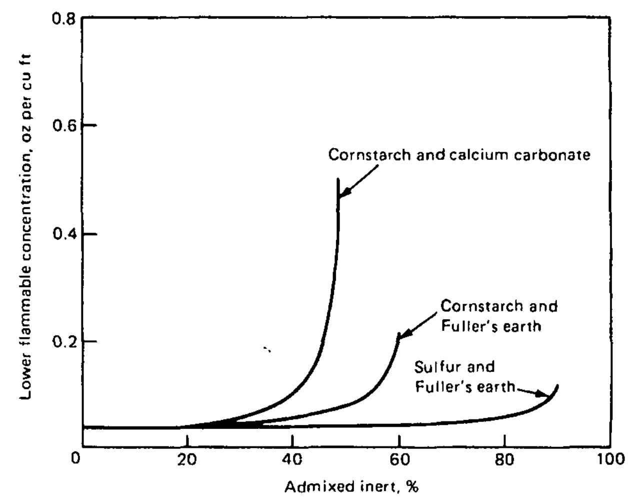


Figure 2-6.5 Effect of admixed inert powder on the minimum explosive concentration of several dusts (Reference 17).

Chapter 3 Fundamentals of Venting of Deflagrations

3-1 Fundamentals of Venting.

3-1.1 A deflagration vent is an opening in an enclosure through which burned and unburned material expands and flows. If no venting is provided, the maximum pressures developed during a deflagration of an optimum fuel/air mixture typically will be between 8 and 10 times the initial absolute pressure. In many cases it is impractical and economically prohibitive to construct an enclosure that will withstand or contain such pressures. In some cases, however, it is possible to design for containment of a deflagration. (*See NFPA 69, Standard on Explosion Prevention Systems.*)

3-1.2 Nothing in this guide is meant to prohibit a totally relieving enclosure, as long as the potential damage is recognized.

3-1.3 The vent area can be reduced from that indicated in Chapters 4 through 7 if suitable large-scale tests show that the resulting damage is acceptable to the user and authorities having jurisdiction.

3-1.4 The proper design of deflagration vents depends on many variables, only some of which have been investigated in depth. The simplest techniques use one or more empirical factors that allow a simplified expression for vent area to be adjusted so as to envelope available test data. These data are the result of analyses of actual explosion incidents and experimental tests.

3-1.5 Tests and analyses conducted have allowed certain generalizations to be made. The calculation techniques presented in this guide are based on these generalizations and, therefore, should be recognized as approximate only. The user of this guide is urged to give special attention to all precautionary statements.

3-1.6 Vents can be provided in the enclosure to limit the pressure developed to an acceptable level. This allowable pressure (P_{red}) is determined by the user. It may be at a level where there is no damage to the enclosure, or where permanent deformation of some degree is acceptable.

3-1.7 For a given opening pressure, the larger the vent area provided, the lower will be the pressure developed. Open vents are more effective than covered vents. Vents with lightweight covers are more effective than those with heavy covers. The required vent area will depend 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.

3-2 Consequences of a Deflagration.

3-2.1 Damage can result should a deflagration occur in any enclosure that is too weak to withstand the pressure from a deflagration. For example, an ordinary masonry wall [8-in. (20-cm) brick or concrete block, 10 ft (3 m) high] cannot withstand internal pressure of much more than 0.5 psig (0.3 bar gauge). Unless an enclosure is designed to withstand the maximum expected pressure from a deflagration, venting should be considered to minimize damage. The area of the vent must be large enough to limit the deflagration pressure (P_{red}) to some predetermined safe level. In addition to the deflagration pressure, there is a thermal hazard associated with the flame. This thermal hazard exists both within the enclosure and in the path of the vented flame.

3-2.2 Limited data are available on the actual forces experienced by the structural elements of an enclosure during a deflagration. Designs should be based on the specifics of each enclosure (vessel, equipment, room, building), its material of construction, its resistance to mechanical shock, the effects of vents (including consequential thrust forces), and the level and duration of pressure. Changes in structural strength over time due to weather, building movement, corrosion, internal loading, or external damage should be considered. In practice, the enclosure design should be based on withstanding the maximum pressure attained during venting (P_{red}) of the deflagration.

3-2.3 The rate of pressure rise is an important parameter in the venting of a deflagration. A rapid rate of rise means that only a short period of time is available for successful venting. Conversely, a slower rate of rise permits the venting to proceed more slowly, yet still be effective. In terms of required vent area, the more rapid the rate of rise, the greater the area needed for venting to be effective, all other factors being equal.

3-2.4 The effect of a deflagration depends on the maximum pressure attained, the maximum rate of pressure rise, and the duration of the peak pressure. The total impulse imparted to the enclosure (i.e., the integral of the pressure vs. time curve) is reduced as the vent area increases. (*See Figure 3-2.4.*) However, total impulse is not a useful design basis. The stress developed on the enclosure is calculated on the basis of the equivalent static load. (*See 4-5.2 and Chapter 5.*)

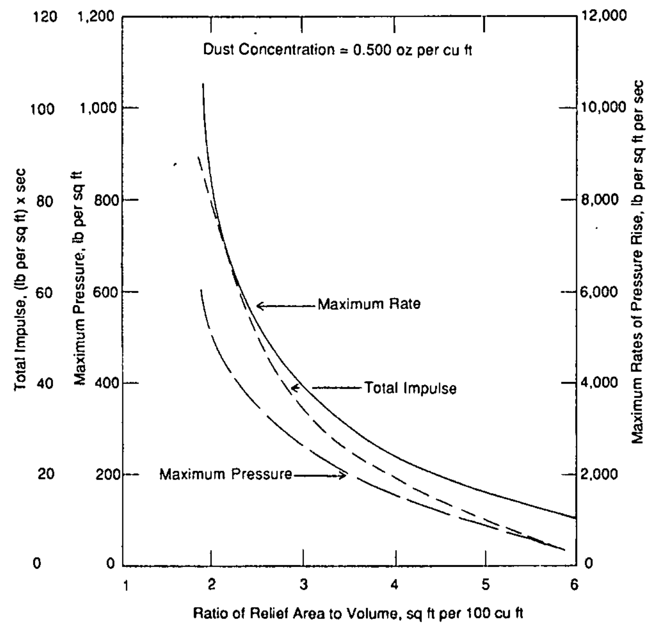


Figure 3-2.4 Variation of pressures, rates, and impulses with vent ratios in magnesium deflagrations in a vented vessel (Reference 18).

3-2.5 The force exerted on an enclosure by a deflagration is dynamic. However, work by Howard and Karabinis (Reference 26) indicates that the enclosure may be assumed to respond as if the peak deflagration pressure is applied as a static load, provided some inelastic deformation (but not catastrophic failure) can be accepted.

3-2.6 When a gas or dust deflagration is vented, a tongue of flame of brief duration issues from the vent. Unburned dust will be ignited as it flows out the vent and can produce a large fireball that can extend not only outward and upward, but also downward from the vent. This has been shown in numerous tests conducted with full-scale equipment.

3-3 Enclosure Strength.

3-3.1 The term P_{red} is defined as the maximum internal pressure that can be resisted by the weakest structural element. (*See Section 3-2.*)

3-3.2 In designing an enclosure to prevent catastrophic failure while still allowing some inelastic deformation, the normal dead and live loads should not be relied on to provide adequate restraint. Walls should be designed to support the total load.

3-3.3 Usual designs allow P_{red} to be selected up to two-thirds the ultimate strength for equipment, provided deformation of the equipment can be tolerated.

3-3.4 Ductile design practices 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.

3-3.5 P_{red} should always exceed P_{stat} by at least 0.35 psig (0.02 bar gauge) for low strength enclosures and by at least 0.72 psig (0.5 bar gauge) for high strength enclosures.

3-4 Vent Variables.

3-4.1 Vent Location, Size, and Shape. The maximum pressure developed in a vented enclosure decreases as the available vent area increases. If the enclosure is relatively small and symmetrical, one large vent can be just as effective as several small vents of equal combined area. Location of multiple vents to achieve uniform coverage of the enclosure surface to the greatest extent practicable is recommended. Rectangular vents are almost as effective as square or circular vents of equal area; thus, vent shape has minimal effect on the successful application of venting.

3-4.2 Inertia of Vent Closure. The free area of a vent does not become fully effective in relieving the deflagration pressure until the vent closure moves completely out of the way of the vent opening. Until this occurs, the closure obstructs the combustion gases issuing from the vent.

3-4.3 The greater the mass of the closure, the longer the closure takes to completely clear the vent opening for a given vent opening pressure. Conversely, closures of low mass move away from the vent opening more quickly, and venting is more effective.

3-4.4 The addition of a vent discharge duct can substantially increase the pressure developed in a vented enclosure. See Section 5-4.

3-5 Vent Operation.

3-5.1 Vents should function dependably. Closures should not be hindered by deposits of snow, ice, paint, corrosion, or debris, or by buildup of deposits on their inside surfaces. Adequate clear space must be maintained on both sides of the vent to enable operation without restriction and without impeding the free flow through the vent.

3-5.2 Vent closures should be maintained in accordance with Chapter 10 and manufacturers' recommendations.

3-5.3 Closures should not be bonded to the enclosure by accumulations of paint. Materials used should be suitable to minimize corrosion.

3-6 Basic Recommendations for Venting.

3-6.1 Since venting of deflagrations is a complex subject of many variables on which information is limited, the following provides only general guidelines. Chapters 4 through 8 of this guide provide guidance on design of vents. Chapter 4 addresses low strength enclosures [P_{red} less than 1.5 psig (0.1 bar gauge)]. Higher strength structures are addressed by the nomographs of Chapters 5, 6, and 7, with added conditions for elongated shapes, and ducted vents in Chapters 5, 7, and 8.

3-6.2 Variables for the required vent area will include but not be limited to the size, geometry, internal obstructions, and strength of the enclosure; the maximum rate of pressure rise; the maximum pressure developed for the fuel/oxidant mixture in question; and the design of the vent itself, including the presence or absence of a closure device. Methods are presented in later chapters to determine the required vent area.

3-6.3 The vent opening should be free and clear and not impeded. If the vent discharges into a congested area, the pressure inside the vented enclosure will increase. The major blast pressure could be caused by ignition of unburned gases or dusts outside the enclosure.

3-6.3.1 The vented material discharged from an enclosure during a deflagration should be directed to a safe location to avoid injury to personnel and to minimize property damage. (*See Section 5-5.*)

3-6.3.2 It will be necessary in some cases to provide restraining devices to keep vent panels or closures from becoming fragment hazards. An alternative means of protection is to provide a barrier close enough to the vent to intercept any fragments, but far enough from the vent so as not to impede its operation. (*See Chapter 9 for recommended restraint techniques.*)

3-6.4 Appropriate signs should be posted to provide warning as to the location of the vent.

3-6.5 If vents are fitted with closure devices that do not remain open after activation, it should be recognized that a vacuum could be created when gases in the enclosure cool.

3-6.6 Interconnections between separate pieces of equipment present a special hazard. Where such interconnections are necessary, deflagration isolation devices should be considered, or the interconnections should be vented. (*See 3-6.9 of this guide and NFPA 69, Standard on Explosion Prevention Systems, for information on isolation devices.*) Without successful isolation or venting of the interconnection, vent areas calculated on the design bases herein might be inadequate because of creation of high rates of pressure rise.

3-6.7 The adverse effects due to venting can be minimized by locating vented equipment outside buildings away from normally occupied areas.

3-6.8 Reaction forces resulting from venting should also be considered in the design of the equipment and its supports. (*See 5-2.9.*)

3-6.9 Ducts used to direct vented gases from the vent to the outside of a building should be noncombustible and strong enough to withstand the maximum expected deflagration pressure. Ducts should be as short as possible and preferably should not have any bends. See Section 5-4, 5-4.3, and 5-4.4 for further information.

3-6.10 Situations can occur in which it is not possible to provide adequate deflagration venting as described in Chapters 4 through 7 of this guide. This is not justification for providing no venting at all. It is suggested that the "maximum practical" amount of venting be provided, since some venting may reduce the resulting damage to a limited degree. In addition, consideration should be given to other protection and prevention methods. (*See NFPA 69, Standard on Explosion Prevention Systems.*)

3-6.11* Enclosure Wall Effects. The reduced pressure (P_{red}) in a vented gas deflagration can be significantly reduced 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 responsible for high flame speeds and amplified pressure oscillations in deflagrations of initially quiescent gas-air mixtures in unobstructed enclosures.

Chapter 4 Venting of Deflagrations in Low Strength Enclosures

4-1 Introduction. It is intended that this chapter be used along with the information contained in the rest of this guide. In particular, Chapters 3, 9, and 10 should be reviewed before applying the information in the chapter.

4-1.1 This chapter is applicable to the design of deflagration vents for low strength enclosures capable of withstanding pressures of not more than 1.5 psig (0.1 bar gauge). Chapters 5, 6, and 7 of this guide provide recommendations for enclosures of higher strengths. Typically, this chapter will apply to buildings, ovens, dust collectors, and other similar equipment.

4-2 General.

4-2.1 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 could be exposed to the effects of flame, heat, or pressure.

4-2.2 The venting should be sufficient to prevent the maximum pressure developed within the enclosure (P_{red}) from causing unacceptable structural damage.

4-2.2.1 Doors, windows, ducts, or other openings in walls intended to be pressure resistant should also be designed to withstand P_{red}.

4-2.3 Care should be taken to ensure that the weakest structural element is identified, as well as any equipment or other devices that might be supported by structural elements. All structural elements and supports should be considered. For example, floors and roofs are not usually designed for loading from beneath. However, a lightweight roof might be considered sacrificial, as long as its movement can be tolerated.

4-2.4 Reaction thrust forces for supported enclosures are discussed in 4-2.5. Examples of these types of enclosures include dust collectors and vapor collection ducts for incinerators.

4-2.5 The vent area should be distributed as symmetrically and as evenly as possible.

4-3 Calculating the Vent Area.

4-3.1* The recommended venting equation for low strength structures is as follows:

$$A_v = \frac{C\,(A_s)}{(P_{red})^{1/2}} \qquad (4)$$

where

A_v = vent area (ft² or m²)
C = venting equation constant (see Table 4-3)
A_s = internal surface area of enclosure (ft² or m²)
P_{red} = maximum internal pressure that can be withstood by the weakest structural element not intended to fail (in psi or bars, not to exceed 1.5 psi or 0.1 bar).

4-3.2 The form of the venting equation is such that there are no dimensional constraints to the shape of the room provided the vent area is not applied solely to one end of an elongated enclosure. (Other general vent considerations are given in Section 3-5.) 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 circular or square, the effective diameter can be taken as the hydraulic diameter, given 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 is constrained as follows:

$$L_3 \le 12\,(A / p) \qquad (5)$$

where

L_3 = longest dimension of the enclosure (ft or m)
A = cross-sectional area (ft² or m²)
p = perimeter of cross section (ft or m).

4-3.2.1 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:

$$L_3 \le 8\,(A / p)\ \text{(ft or m)} \qquad (6)$$

4-3.2.2 Where these dimensional constraints on the enclosure are not met, the alternate methods as described in Chapters 6 through 8 should be considered for possible solutions.

4-3.3 Venting Equation Constant. The value of C in the venting equation in 4-3.1 characterizes the fuel and clears the dimensional units. Table 4-3 gives some recommended values of C. These values of C are calculated for air mixtures.

4-3.3.1 The values of C in Table 4-3 were determined by enveloping data. If suitable large-scale tests are conducted for a specific application, an alternate value of C can be determined.

Table 4-3 Fuel Characteristic Constant for Venting Equation

Fuel	$C(psi)^{1/2}$	$C(bar)^{1/2}$
Anhydrous ammonia	0.05	0.013
Methane	0.14	0.037
Gases with fundamental burning velocity less than 1.3 times that of propane*	0.17	0.045
St-1 dusts	0.10	0.026
St-2 dusts	0.12	0.030
St-3 dusts	0.20	0.051

*NOTE: Includes hydrocarbon mists and organic flammable liquids.

4-3.3.2 The database includes References 24 and 26 through 41. Most data are for aliphatic gases. It is believed that liquid mists can be treated the same as aliphatic gases provided that the fundamental burning velocity of the vapor is less than 1.3 times that of propane. No recommendations can presently be given for fast-burning gases such as hydrogen, certain alkenes, alkynes, dienes, and epoxides. This is because the recommended method allows for initial turbulence and turbulence-generating objects, and no venting data have been generated to address such conditions for fast-burning gases. Expert opinion should be sought in such cases.

4-3.3.3 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 4-7.2 and 9-3.4.*) Even if detonation does not occur, it might be impossible to successfully vent fast deflagrations in some cases.

4-4 Calculation of Internal Surface Area.

4-4.1 The area (A_s) is the total area that constitutes the perimeter surfaces of the enclosure 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 (A_s) in the venting equation 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 A_s for the basic geometry of the major structure. The internal surface of any adjoining rooms should be included. This includes adjoining rooms separated by a partition incapable of withstanding the expected pressure.

4-4.2 The surface area of equipment and contained structures should be neglected.

4-5 Enclosure Strength. The user is referred to Section 3-3 for specific remarks relating to enclosure strength.

4-6 Methods to Reduce Vent Areas. In some circumstances the vent area calculated by the formula in 4-3.1 will exceed the area available for installation of vents. When such situations arise, it is recommended that one of the techniques indicated in the following paragraphs be used to obtain the needed protection.

4-6.1 The calculated vent area (A_v) can be reduced by increasing the strength of the enclosure (value of P_{red}). This can be accomplished by reinforcing the enclosure. The value of P_{red} should not be increased above 1.5 psig (0.1 bar gauge) for design under this chapter. If P_{red} is increased above 1.5 psig (0.1 bar gauge), the methods of Chapters 5, 6, or 7 should be followed.

4-6.2 The calculated vent area (A_v) can be reduced by installation of a suitable wall to confine the deflagration hazard area to a geometric configuration with a smaller internal surface area (A_s). The new wall would be designed in accordance with Section 3-3.

4-6.3 The calculated vent area (A_v) can be reduced if suitable large-scale tests demonstrate that the flammable material has a smaller constant (C) than indicated in Table 4-3. (*See 4-3.3.1.*)

4-6.4 The need for deflagration vents can be eliminated by the application of explosion prevention techniques described in NFPA 69, *Standard on Explosion Prevention Systems*.

4-6.5 The vent area can be reduced for gas deflagrations in relatively unobstructed enclosures by the installation of noncombustible, acoustically absorbing wall linings provided that large-scale test data confirm the reduction. These tests should be conducted with the highest anticipated turbulence levels and with the proposed wall lining material and thickness.

4-7 Vent Design. (*See also Section 3-4, Vent Variables.*)

4-7.1 Where inclement weather, environmental contamination, or loss of material is not a consideration, open vents can be used and are recommended. In most cases, vents will be covered by some type of vent closure. The closure should be designed, constructed, installed, and maintained so that it will release readily and move out of the path of the combustion gases. The closure should also not become a hazard when it operates.

4-7.2 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. The vent closure weight should not exceed 2.5 lb/ft^2 (12.2 kg/m^2).

4-7.3 The material of construction of the closure should be suitable for the environment to which it will be exposed. Brittle materials will fragment, producing missiles. Some closures, upon activation, are blown away from their mounting points. 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 will discharge burning dusts or gases, posing a personnel hazard.

4-7.4 Deflagration vent closures should release at as low an internal pressure as practical, yet remain in place when subjected to external wind forces producing negative pressures, to prevent vents from being pulled off. In most cases, a closure release pressure of 20 lb/ft^2 is acceptable. In areas subject to severe windstorms, release pressures up to 30 lb/ft^2 are used. In any case, locating vents at building corners and eavelines should be avoided due to the higher uplift pressures in these areas. In hurricane areas, local building codes often require higher resistance to wind uplift. In these situations the limitations of 3-3.5 should be recognized, and strengthened internal structural elements should be provided.

4-7.5 If an enclosure itself 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).

4-7.6 The vent closure(s) should cover only the required vent area for the compartment being protected.

4-7.7 Each closure should be designed and installed to move freely without interference by obstructions such as ductwork, piping, etc. This ensures that the flow of combustion gases is not impeded by an obstructed closure. (*See 3-5.1.*)

4-7.8 A vent closure could open if personnel fall or lean on it. If injury could result from this event, guarding should be provided to prevent personnel from falling against vent closures.

4-7.9 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.

4-8 Sample Calculations.

4-8.1 Consider a 20 × 30 × 20 ft (6.1 × 9.2 × 6.1 m) (LWH) dispensing room for Class I flammable liquids. Anticipated flammable liquids have fundamental burning velocities less than 1.3 times that of propane (*see Table C-1*). The room is located against an outside wall and, in anticipation of deflagration venting requirements, the three inside walls are designed to withstand 100 psf (0.69 psi). Design of the venting would proceed as follows. For the anticipated flammable liquids, Table 4-3 gives a venting equation constant C of 0.17.

Internal surface area of the room = 3200 sq ft (297 m^2)

$$\text{vent area } A_v = \frac{(0.17)\,(3200)}{(0.69)^{1/2}} = 655 \text{ sq ft } (61 \text{ m}^2) \qquad (7)$$

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

If the wall strength were increased to 150 lb/ft^2, a vent area of 533 sq ft (50 m^2) would be required. This wall strength can usually be achieved, and is recommended over the common 100-lb/ft^2 specification.

4-8.2 Consider the building illustrated in Figure 4-8(a) for which deflagration venting is required. The building is to be protected against a deflagration of a hydrocarbon vapor having the burning characteristics of propane. The maximum internal overpressure that this building can withstand has been determined by structural analysis to be 0.5 psi (3.45 kPa).

4-8.3 Divide the building into sensible geometric parts (Parts 1 and 2) shown in Figure 4-8(b).

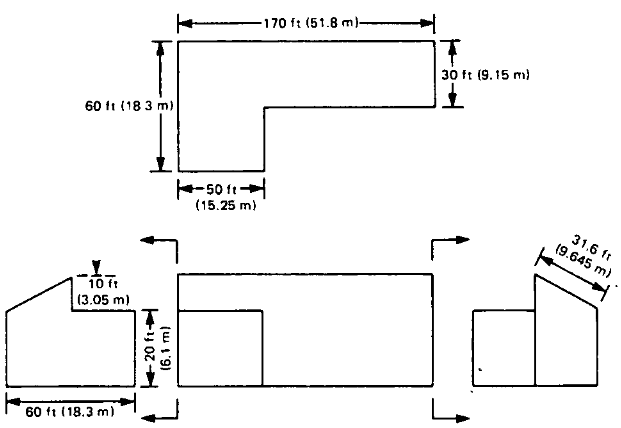


Figure 4-8(a) Building used in sample calculation (not to scale).

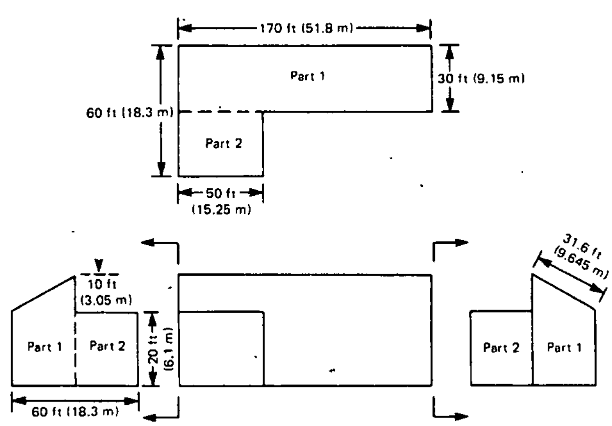


Figure 4-8(b) Building used in sample calculation (not to scale).

4-8.4 Calculate the total internal surface area of each part of the building.

Part 1 Surface Area

Floor	=	170 × 30 = 5100 ft^2 (474 m^2)
Roof	=	170 × 31.6 = 5372 ft^2 (499 m^2)
Rear Wall	=	170 × 20 = 3400 ft^2 (316 m^2)
Front Wall	=	120 × 30 + 50 × 10 = 4100 ft^2 (381 m^2)
Side Walls (Rectangular Part)	=	2 × 30 × 20 = 1200 ft^2 (111 m^2)
Side Walls (Triangular Part)	=	30 × 10 = 300 ft^2 (28 m^2)
Total internal surface area of Part 1 (A_{s1})	=	19,472 ft^2 (1809 m^2)

Part 2 Surface Area

Floor	=	50 × 30 = 1500 ft^2 (139 m^2)
Roof	=	50 × 30 = 1500 ft^2 (139 m^2)
Front Wall	=	50 × 20 = 1000 ft^2 (93 m^2)
Side Walls	=	2 × 30 × 20 = 1200 ft^2 (111 m^2)
Total internal surface of Part 2 (A_{s2})	=	5200 ft^2 (483 m^2).

Thus, the total internal surface area for the whole building, A_s, is given by:

$$A_s = 19{,}472 + 5200 = 24{,}672 \text{ ft}^2 \ (2292 \text{ m}^2)$$

4-8.5 Calculate the total vent area requirement using:

$$A_v = \frac{C\,(A_s)}{(P_{red})^{1/2}} \qquad (8)$$

Where

A_s = 24,672 ft^2 (2290 m^2)
P_{red} = 0.5 psi (3.45 kPa)
C = 0.17 (psig)$^{1/2}$ (from Table 4-3).

Substituting,

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

The total vent area requirements of 5932 ft^2 (550 m^2) should be divided evenly over the outer surface of the building and should be apportioned between the parts in the same ratio as their surface area. Thus,

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

$$\text{Part II } A_{v2} = A_v\left(\frac{A_{s2}}{A_s}\right) = (5932)\left(\frac{5{,}200}{24{,}672}\right) = 1250 \text{ ft}^2 \ (116 \text{ m}^2)$$

4-8.6 Check to determine whether sufficient external surface area on the building is available for venting.

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

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

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

4-8.7 An irregularly shaped building can be squared off to approximate a building of regular geometry whose internal surface area can be easily calculated. This is particularly applicable to buildings with "saw-toothed" roofs or other such architectural features.

4-8.8 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 placement 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 matched to the vent area required. The minimum pressure requirement for the weakest structural member is obtained by substituting into the equation the available area, the internal surface area, and the appropriate C value, 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."

4-8.9 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 the equation can be validly applied. *(See 4-3.2.)*

Chapter 5 Venting of Deflagrations in High Strength Enclosures — General

5-1 Introduction. It is intended that this chapter be used along with the information contained in the rest of this guide. In particular, Chapters 3, 9, and 10 should be reviewed before applying the information in this chapter.

5-1.1 This chapter and Chapters 6 and 7 apply to enclosures such as vessels, silos, etc., capable of withstanding pressures of more than 1.5 psig (0.1 bar gauge).

5-1.2 Deflagration vent requirements are dependent on many variables, only some of which have been fully investigated. The technology of calculating the required vent area in an enclosure subject to deflagration is based on a limited number of tests and the analyses of actual explosion incidents. The testing and analyses conducted to date have allowed certain generalizations to be made; the recommended calculation methods presented in this guide are based on these generalizations. The calculation methods should, therefore, be regarded as approximate only. The user of this guide is urged to give special attention to all precautionary statements.

5-1.3 It is not possible to successfully vent a detonation.

5-1.4 The maximum pressure that will be reached during venting, P_{red}, will always exceed the pressure at which the vent device releases; in some cases it will be much higher. This maximum pressure is affected by a number of factors. These should be considered when designing the enclosure that will be protected. This chapter and Chapters 6 and 7 give guidelines for determining this maximum pressure.

5-2 Basic Principles. Certain basic principles are common to the venting of deflagrations of gases, mists, and dusts. These include but are not limited to the following:

5-2.1 The vent design should be adequate to prevent the deflagration pressure inside the vented enclosure from exceeding two-thirds of the ultimate strength of the weakest part of the enclosure, which should not fail. This criterion anticipates that the enclosure could bulge or otherwise deform.

5-2.2 Vent closures should open dependably. Their proper operation should not be hindered by deposits of snow, ice, paint, sticky materials, polymers, etc. Their operation should not be prevented by corrosion or by objects that obstruct the opening of the vent closure, e.g., piping, air conditioning ducts, or structural steel.

5-2.3 Vent closures should have a low mass per unit area to minimize inertia in order to reduce opening time. The total mass of the closure divided by the area of the vent opening should not normally exceed 2.5 lb/ft^2 (12.2 kg/m^2). For gases such as methane and ammonia (where there are no internal turbulence inducers) and St-1 dusts, a mass per unit area should not exceed 8 lb/ft^2 (39 kg/m^2). Greater mass per unit area results in higher maximum pressure during venting. The vent closure should have no counterweights; counterweights add more inertia.

5-2.4 Vent closures should not become missile hazards as a result of their operation.

5-2.5 Vent closures should withstand exposure to the materials and process conditions within the enclosure being protected. They should also withstand ambient conditions on the nonprocess side.

5-2.6 Vent closures should release at pressures reasonably close to their design release pressures.

5-2.7 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 could be subjected.

5-2.8 Vent closures should be inspected and properly maintained in order to ensure dependable operation. In some cases, this could mean replacing the vent closure at suitable time intervals. *(See Chapter 10.)*

5-2.9* The supporting structure for the enclosure should be strong enough to withstand any reaction forces developed as a result of operation of the vent. The equation for these reaction forces has been established from test results (Reference 42). The following equation is only applicable for enclosures without vent ducts:

$$F_r = 1.2\,(A_v)\,(P_{red}) \qquad (9)$$

Where

F_r = reaction force resulting from combustion, lb
A_v = vent area, in.^{2}
P_{red} = maximum pressure developed during venting, psig.

5-2.9.1 The total thrust force can be considered equivalent to a force applied at the geometric center of the vent. 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 enclosure restraints for resisting thrust forces.

5-2.9.2 Reference 42 contains a general equation that approximates the duration of the thrust force of a dust deflagration. It only applies to enclosures without vent ducts. Knowing this duration can aid in the design of certain support structures for enclosures with deflagration vents. The duration calculated by the following equation will be quite conservative:

$$t_f = \frac{(0.01)\,(\text{sec}^2)\,(K_{St})\,(V^{1/3})}{(P_{red})\,(A_v)} \qquad (10)$$

Where

t_f = duration of pressure pulse, sec
K_{St} = deflagration index for dust (*see Chapter* 7)
V = vessel volume, m^3
P_{red} = maximum pressure developed during venting, bar gauge
A_v = area of vent (without vent duct), m^2.

5-2.9.3 The equivalent static force that a structure supporting a vented enclosure will experience during deflagration venting is given by the following equation:

$$F_S = 0.62\,(A_v)(P_{red}) \qquad (11)$$

Where

F_S = equivalent static force experienced by supporting structure, lb
A_v = vent area, $in.^2$
P_{red} = maximum pressure developed during venting, psig.

5-3 Correlating Parameters for Deflagration Venting.

5-3.1 The technical literature reports extensive experimental work on venting of deflagrations in enclosures up to 250 m^3 in volume (References 3 and 43 through 48). From this experimental work, Bartknecht and Donat have developed a series of nomographs, Figures 6-2(a) through (d) in Chapter 6 and Figures 7-1(a) through (f) and 7-2(a) and 7-2(b) in Chapter 7, that can be used for determining the necessary vent areas for enclosures.

5-3.2 The nomographs supersede techniques 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.

5-3.3 The selection of the proper nomograph to use is discussed in detail in Chapters 6 and 7.

5-3.4 The nomographs do not exactly predict the vent area required for different volumes of enclosures. Certain data (Reference 40) indicate that the gas venting nomographs are not conservative in every case. For the present, however, the use of the venting nomographs is recommended on the basis of successful industrial experience. Also, tests involving extreme levels of turbulence/congestion demonstrate that pressures exceeding those indicated by the nomographs can occur. (References 38 and 83).

5-3.5 The nomographs apply only to enclosures where the length-to-diameter ratio is less than 5. For long pipes or process ducts or enclosures whose L/D ratio is 5 or greater, the deflagration vent design should be based on the information given in Chapter 8. (*See also 7-4.1.*)

5-3.6 The nomographs for deflagration venting of gases (Chapter 6) and for deflagration venting of dusts (Chapter 7) are based on experimental data. The nomographs for gases cannot be used for dusts, and vice versa.

5-3.7 The venting nomographs are based on deflagrations in which the oxidant is air.

5-4 Effects of Vent Discharge Ducts.

5-4.1 The vented material discharged from an enclosure during a deflagration should be directed to a safe location to avoid injury to personnel and to minimize property damage. (*See Section 5-5.*)

5-4.2 If it is necessary to locate enclosures that require deflagration venting inside buildings, the vents must not discharge within the building. Flames and pressure waves discharging 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.

5-4.3 If a vented enclosure is located within buildings, it should be placed close to exterior walls so that the vent ducts will be as short as possible, preferably not more than 3 m (10 ft) long.

5-4.4 Vent ducts will significantly increase the pressure developed in the enclosure during venting. The vent ducts should have a cross section at least as great as that of the vent itself. The increase in pressure due to the use of vent ducts as a function of duct length is shown in Figures 5-4(a) for gases and 5-4(b) for dusts. Other methods of predicting the effects of vent ducts are addressed in Reference 89.

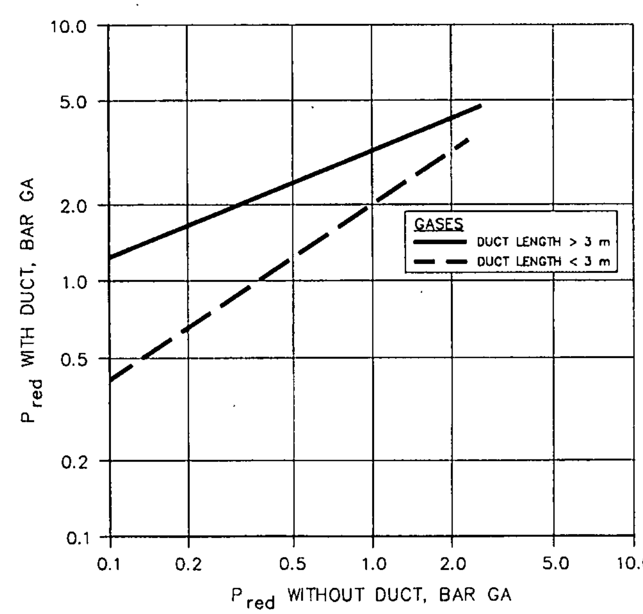


Figure 5-4(a) Maximum pressure developed during venting of gases, with and without vent ducts (Reference 49).

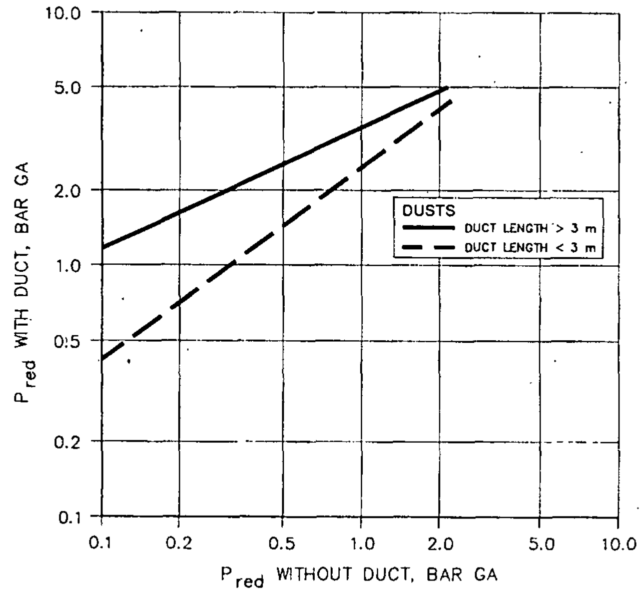


Figure 5-4(b) Maximum pressure developed during venting of dusts, with and without vent ducts (Reference 62).

5-4.5 The use of vent ducts of larger cross section than the vent might result in a smaller increase in the pressure developed during venting (P_{red}) than when using vent ducts of equivalent cross section (Reference 89), but this effect is difficult to quantify because of limited test data.

5-4.6 Vent ducts should be as straight as possible. Any bends will cause increases in the pressure developed during venting. If bends are unavoidable, they should be as shallow-angled (i.e., have as long a radius) as practical.

5-5 Exposure from the Venting Process. Flames and pressure waves emerging from an enclosure during the venting process can injure personnel, ignite other combustibles in the vicinity, cause ensuing fires or secondary explosions, and cause pressure damage to adjacent buildings or equipment. For a given quantity of combustible mixture, the amount that will be expelled from the vent, and the thermal and pressure damage that occurs outside of the enclosure, will depend on the volume of the enclosure, the vent opening pressure, and the magnitude of P_{red}. For a given enclosure volume and a given quantity of combustible mixture, a lower vent opening pressure will result in more unburned material being discharged through the vent, creating a larger fireball outside the enclosure. A higher vent opening pressure will result in more combustion taking place inside the enclosure prior to the vent opening and higher velocity through the vent.

5-6 Location of Deflagration Vents Relative to Air Intakes. Deflagration vents should not be located in such positions that the vented material can be picked up by air intakes.

Chapter 6 Venting of Deflagrations of Gas Mixtures and Mists in High Strength Enclosures

6-1 General. This chapter applies to enclosures capable of withstanding more than 1.5 psig (0.1 bar gauge). It is intended that this chapter be used along with the information contained in the rest of this guide. In particular, Chapters 3, 5, 9, and 10 should be reviewed before applying the information in this chapter.

6-1.1 Nomographs for Deflagration Venting. The nomographs in Figures 6-2(a) through 6-2(d) (Reference 3) can be used for determining the necessary vent area for venting methane, propane, coke gas, or hydrogen during a deflagration. It is important to note that these nomographs were developed for initial conditions of:

(a) No initial turbulence in the enclosure at the time of ignition,

(b) No turbulence-producing internal appurtenances,

(c) An ignition energy of 10 J or less, and

(d) Atmospheric pressure.

See later sections of this chapter for the effects of changes in these variables.

6-1.1.1* As an alternative to Figures 6-2(a) through 6-2(d), the following equation can be used to determine the necessary vent area for methane, propane, coke gas, or hydrogen deflagrations. The equation was developed to reproduce the values obtained from the nomographs and is presented here as a convenience for the user of this guide (Reference 50). The equation is:

$$A_v = a(V)^b \bullet e^{c(P_{stat})} \bullet (P_{red})^d \qquad (12)$$

Where

A_v = vent area, m^2
V = enclosure volume, m^3
e = 2.718 (base of natural logarithm)
P_{red} = maximum pressure developed during venting, bar gauge
P_{stat} = vent closure release pressure, bar gauge

and for:

	a =	b =	c =	d =
Methane	0.105	0.770	1.230	-0.823
Propane	0.148	0.703	0.942	-0.671
Hydrogen	0.279	0.680	0.755	-0.393
Coke gas	0.150	0.695	1.380	-0.707

NOTE: Since this equation is derived from the nomographs, it is no more accurate than the nomographs themselves and should not be extrapolated beyond the limits of 6-6.4. The equation is subject to the same limitations as the nomographs and therefore should not be used for indiscriminate extrapolation. Serious errors in the value of A_v can occur if this is done.

6-1.2 The nomographs apply only to cases where the enclosure length-to-diameter ratio (L/D) is five or less. For venting an enclosure having an L/D greater than 5, refer to Chapter 8.

6-2 Deflagration Venting of Gases Other than Those Specified on the Nomographs. The nomographs in Figures 6-2(a) through 6-2(d) can be used to establish the deflagration vent requirements for gases other than methane, propane, coke gas, and hydrogen. Three approaches that can be used for other gases are described below.

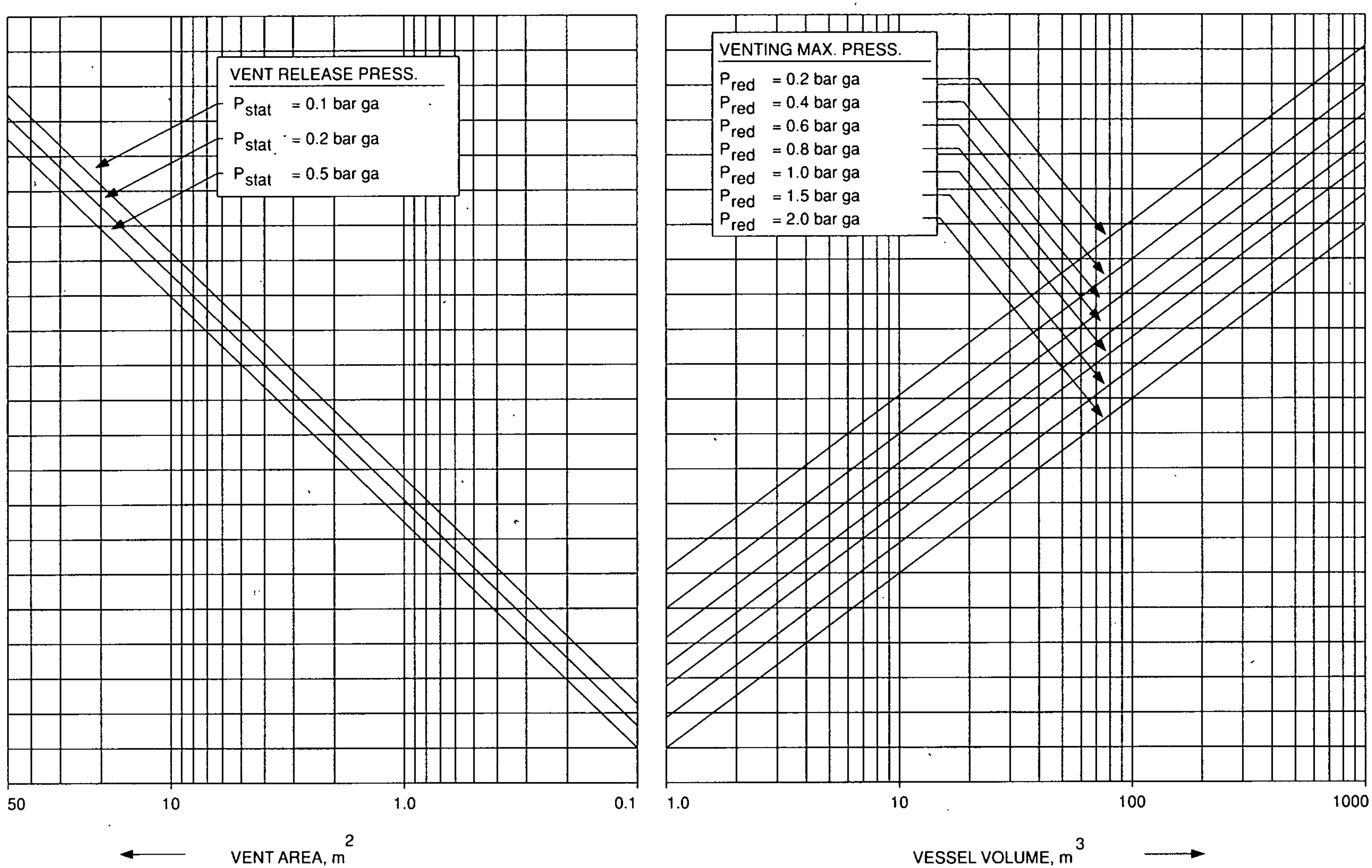


Figure 6-2(a) Venting nomograph for quiescent methane.

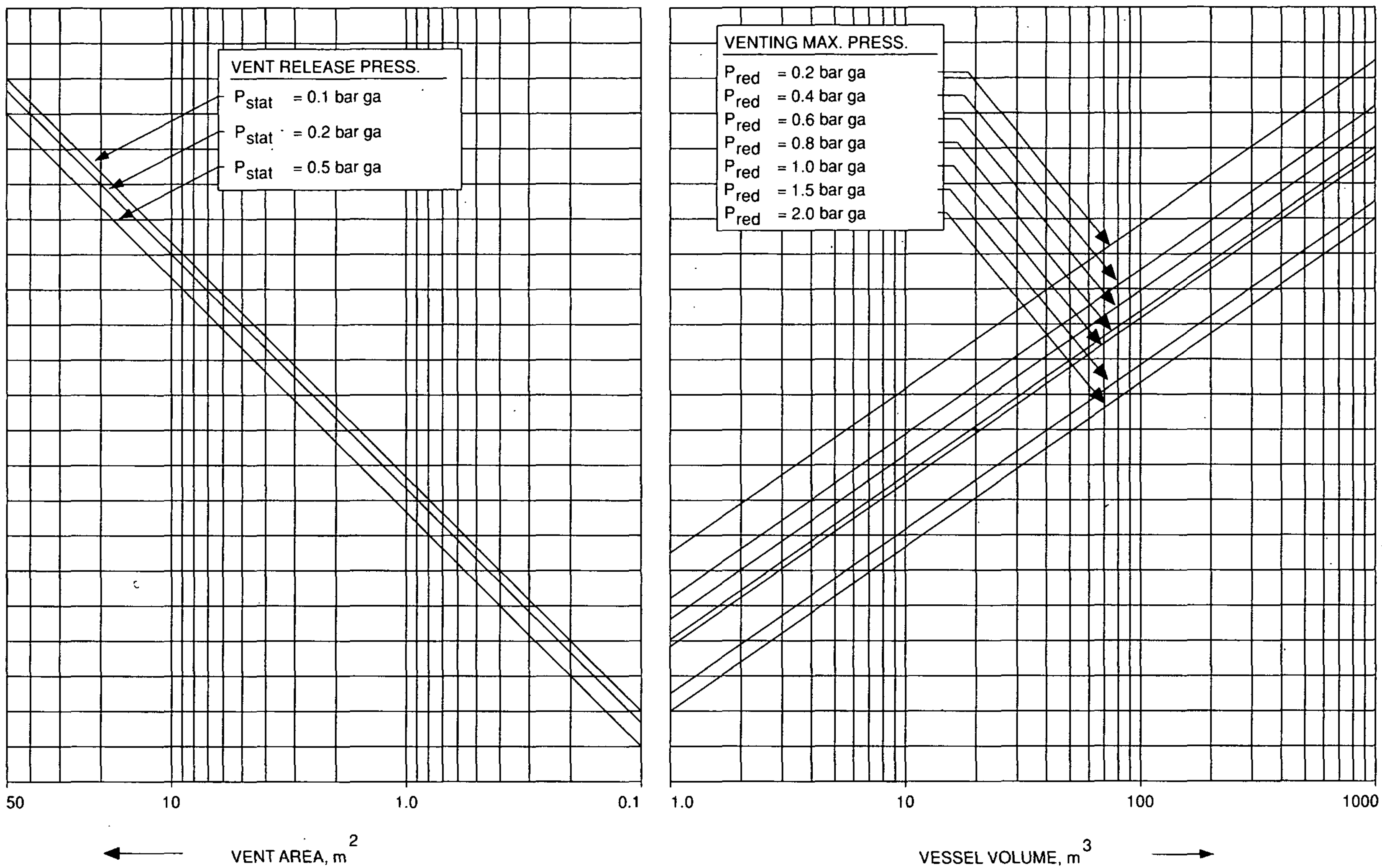


Figure 6-2(b) Venting nomograph for quiescent propane.

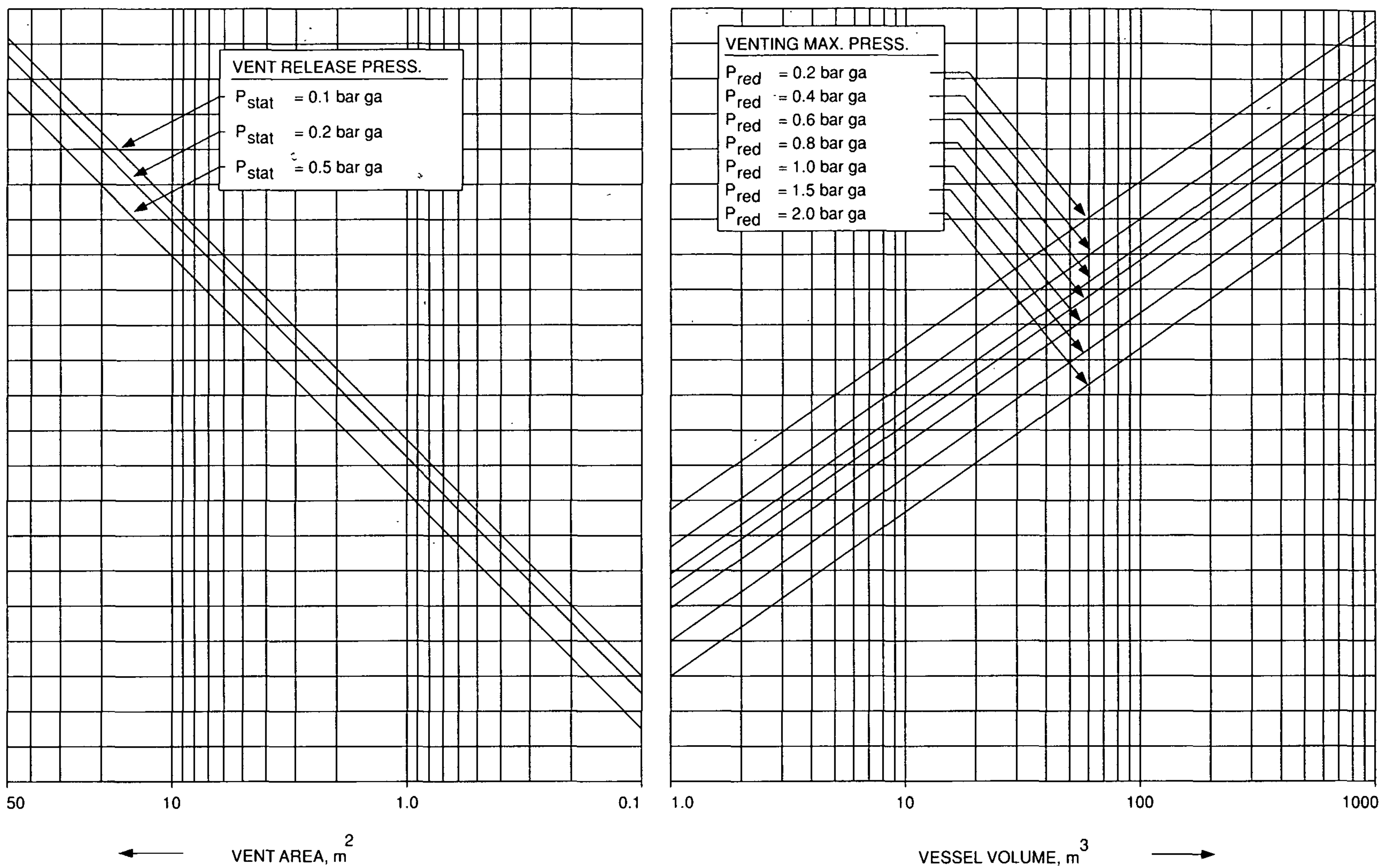


Figure 6-2(c) Venting nomograph for quiescent coke oven gas.

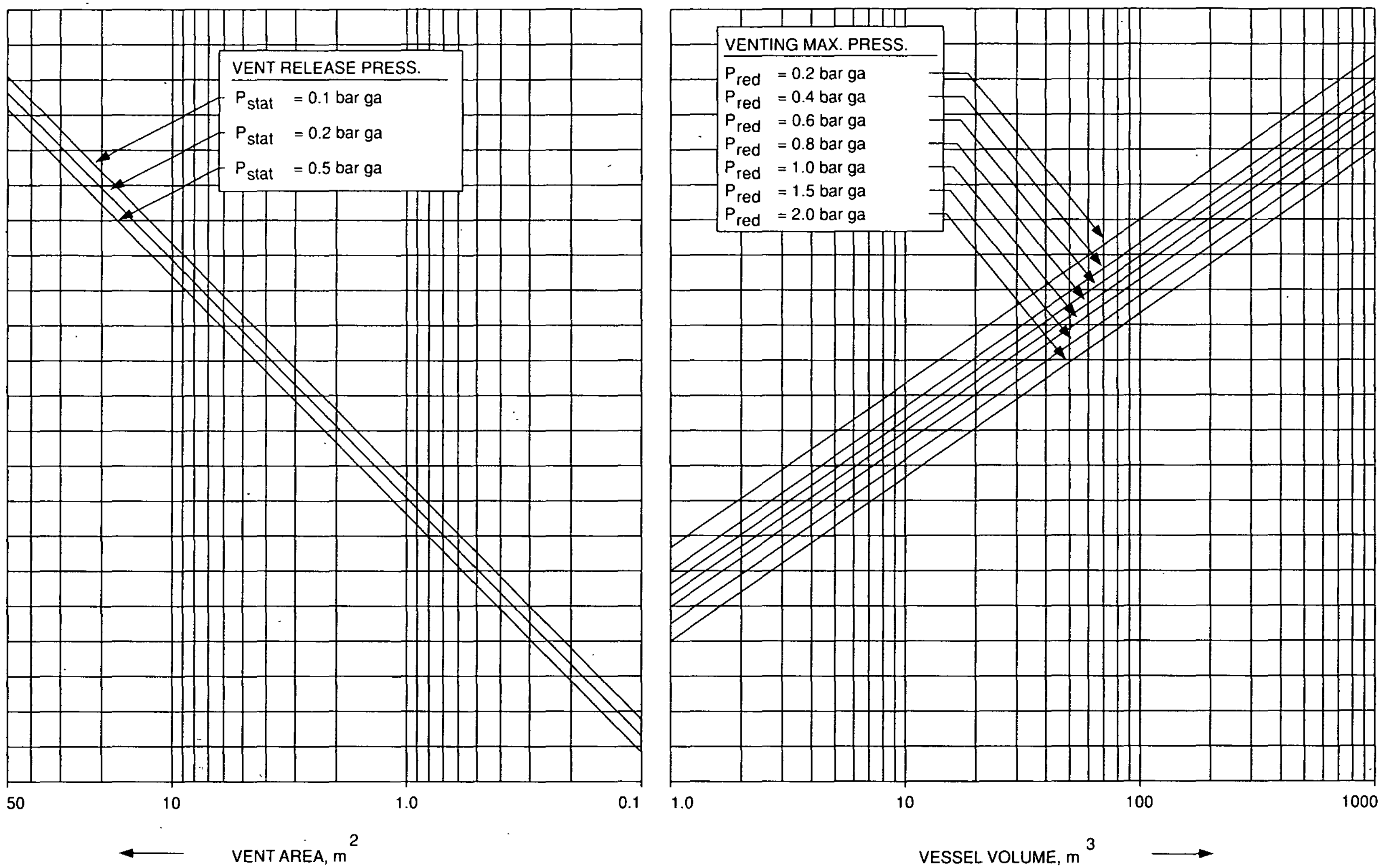


Figure 6-2(d) Venting nomograph for quiescent hydrogen.

6-2.1 Use of Deflagration Testing to Interpolate Between Nomographs. Deflagration testing, as described in Appendix B, can be used to characterize a specific gas for interpolation between the nomographs. The basis for this interpolation is that, if two gases yield the same maximum rate of pressure rise, $(dP/dt)_{max}$, when they are ignited in the same closed test enclosure, it can be assumed that they will both require the same vent area to provide protection for any size of enclosure.

The maximum rate of pressure rise of a gas varies with the volume and shape of the test enclosure and with the ignition energy. Thus, if this technique is to be used for interpolation, the values of the maximum rate of pressure rise for the specific gas, and for the gases used in the nomographs, should be determined. These determinations should be performed in the same test enclosure, using the same ignition energy. For further details of the test procedure, see Appendix B. See 6-2.4 for an example of interpolation between the nomographs of the "standard" gases having higher and lower maximum rates of pressure rise than the gas in question.

6-2.2 Classification of Gases by Fundamental Burning Velocity. With less dependability, the deflagration venting requirements of certain gases can be determined by comparing their fundamental burning velocities, S_u, with that of propane. Table C-1 in Appendix C gives values of S_u for many common gases. It should be noted that the values of S_u in this table have been derived from a single source, as explained in the appendix. These values may not be consistent with those from other sources.

If the fundamental burning velocity given in Appendix C for a specific gas is less than 60 cm/sec (about 1.3 times that of propane), then the propane nomograph [Figure 6-2(b)] can be used. If the fundamental burning velocity exceeds 60 cm/sec, then the hydrogen nomograph [Figure 6-2(d)] can be used.

6-2.3 Use of Nomographs Without Testing. If test data of the type described in 6-2.1 are unavailable, the hydrogen nomograph, Figure 6-2(d), can be used to estimate the vent requirements. Although this approach is conservative in many cases, the additional vent area resulting from its use will normally be small.

6-2.4 Example of Determining the Required Deflagration Vent Area by Interpolation. Given a 10 m^3 enclosure, which should be provided with deflagration venting for a gas that is not specifically covered by a nomograph, calculate the required vent area for the following conditions:

Maximum allowable value of P_{red}	= 0.8 bar gauge
P_{stat}	= 0.2 bar gauge
Maximum rate of pressure rise for gas in question in a particular test vessel	= 730 bar/sec.

Using the propane and hydrogen nomographs [Figures 6-2(b) and (d)], the required vent area to protect the enclosure specified will be 1.01 m^2 and 1.10 m^2, respectively. The maximum rates of pressure rise for propane and hydrogen are 369 and 2029 bar/sec, respectively, in the same test enclosure. By linear interpolation, the required vent area for this enclosure and this specific gas is:

$$1.01 + \left(\frac{730\text{-}369}{2029\text{-}369}\right) \times (1.10 - 1.01) = 1.03 \text{ m}^2 \quad (13)$$

6-2.5 K_G Values. The maximum rate of pressure rise can be normalized to give the K_G value. (*See Equation 27 in Appendix B.*) It should, however, be noted that the K_G value is not constant and will vary depending on test conditions. In particular, increasing the volume of the test enclosure and increasing the ignition energy can result in increased K_G values. Although the K_G value provides a means of comparing the maximum rates of pressure rise of known and unknown gases, it should be used only as a basis for deflagration vent sizing if the tests for both materials are performed in enclosures of approximately the same shape, size, and with the same kind of igniter having consistent ignition energy. (*See Appendix D for examples of K_G values.*)

6-3 Effects of Initial Turbulence and Internal Appurtenances for Enclosures with Initial Pressure Near Atmospheric.

6-3.1 Initial Turbulence. In many industrial enclosures, the gas phase is present in a turbulent condition. An example is the continuous feed of a combustible 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.

If the gas system is initially turbulent, the rate of deflagration is increased (References 3 and 31). In this case, the nomographs do not apply directly. It has been found that initially turbulent methane and propane exhibit $(dP/dt)_{max}$ values similar to that of initially quiescent hydrogen. For this reason, the hydrogen nomograph should be used for venting initially turbulent gases that have $(dP/dt)_{max}$ values, in the quiescent state, that are similar to or less than that of propane.

The susceptibility of a turbulent system to detonation increases with increasing values of the quiescent $(dP/dt)_{max}$. In particular, compounds that have $(dP/dt)_{max}$ values close to that of hydrogen are highly susceptible to detonation when ignited under turbulent conditions. It should be noted that venting will tend to inhibit transition from deflagration to detonation, but is not an effective method of protecting against the effects of a detonation once the transition has occurred.

6-3.2 Enclosure Appurtenances. The presence of internal appurtenances within a vented enclosure can cause turbulence, which can result in transition from deflagration to detonation. When the enclosure contains internal appurtenances, an expert should be consulted to determine if the potential exists for a detonation to occur. (Reference 51.)

6-4 Use of the Nomographs with Hydrogen. The user is cautioned that hydrogen/air deflagrations can readily undergo transition to detonations. It is therefore recommended that, before using the nomograph for hydrogen [Figure 6-2(d)], consideration should be given to the potential for a detonation to occur. This could require test work and consultation with an expert on the subject.

6-5 Effect of High Ignition Energy.

6-5.1 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 large.

6-5.2 A typical case is that of two enclosures connected by a pipe. Ignition in one enclosure will cause two effects in the second enclosure. Pressure development in the first enclosure will force gas through the connecting pipe into the second enclosure, resulting in an increase in both pressure and turbulence. The flame front will also be forced through the pipe into the second enclosure, where it will become a very large ignition source. The overall effect will depend on the relative sizes of the enclosures and the pipe, as well as on the length of the pipe. This has been investigated by Bartknecht, who found the effects can be large (Reference 52). Pressures developed in the pipeline itself can also be quite high, especially if the deflagration changes to detonation. When such conditions prevail in equipment design, the reader should refer to Reference 52 and 62, or should consult a specialist.

6-6 Extrapolation of Nomographs.

6-6.1 The lowest P_{stat} value on the nomographs is 0.1 bar gauge; the lowest P_{red} value is 0.2 bar gauge. It is sometimes desirable to vent enclosures at lower pressures, with resulting lower maximum pressure developed during venting (P_{red}). Determining the necessary vent area requires extrapolation of the nomographs. A graphical approach is shown in Figure 6-6. Such a graph will need to be constructed for each enclosure size.

6-6.2 In Figure 6-6, the vent areas for a 10-m^3 enclosure were taken from the four gas nomographs at constant P_{red}, but for different values of P_{stat}. Similar graphs can be constructed for various values of P_{red}. This graph allows interpolation and extrapolation, thus extending the utility of the basic nomographs.

6-6.3 Some papers have proposed calculation of vent areas for gases on the basis of fundamental flame and gas flow properties and experimentally determined constants (References 22, 74, and 75). These calculation procedures have not yet been fully tested against the venting nomographs. The venting nomographs are to be taken as the final authority within their applicable ranges of P_{stat} and P_{red}.

6-6.4 The user is cautioned not to extrapolate the nomographs below 0.05 bar gauge for P_{stat} nor below 0.1 bar gauge for P_{red}. For values below these, refer to Chapter 4. P_{red} should also not be extrapolated above 2.0 bar gauge, the upper limit in the nomographs. P_{stat} can be extrapolated upward, but it should always be less than P_{red} by at least 0.05 bar gauge.

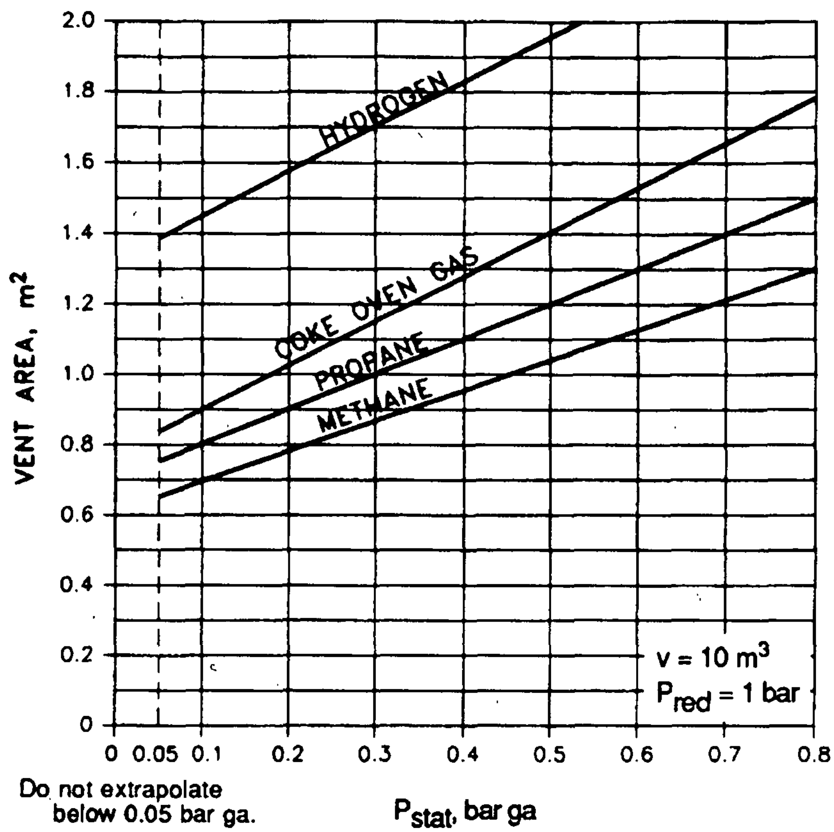


Figure 6-6 Extrapolation of Nomographs (Reference 54).

6-7 Effect of Initial Elevated Pressure.

6-7.1 The venting nomographs and equations in Chapter 6 can be used directly to establish the required vent area for an enclosure containing a gas mixture at an initial pressure, before ignition, no higher than 0.2 bar gauge. If the initial pressure, before ignition, is between 0.2 and 3.0 bar gauge, the correlation in this section can be used.

6-7.2* For a given vent size, the maximum pressure developed during the venting of a deflagration will vary as a function of the initial absolute pressure raised to an exponential power. Data from Reference 55 constitute the basis for this correlation. For this calculation, the ratio of the absolute pressure of vent closure opening to the absolute pressure at time of ignition is assumed to be constant. For propane, and for gases having K_G values no higher than 1.3 times that of propane, the recommended exponent is 1.5; for hydrogen, 1.2. The exponent of 1.5 for propane is confirmed by References 57 and 75. By interpolation, the recommended constant for ethylene is 1.4.

6-7.3 The calculation involves the following steps:

(a) Calculate the ratio of the elevated absolute pressure at which the vent closure opens to the elevated absolute pressure before ignition, e.g., operating pressure. This ratio is numerically equal to a P_{stat} in absolute pressure units that will be used in the nomographs, after conversion to gauge pressure.

(b) Establish the available area of vent opening.

(c) Using the nomographs [Figures 6-2(a) through 6-2(d)] or the equation in 6-1.1.1, and the value of P_{stat} from step A, the vent opening area, and the enclosure volume, determine the P_{red}.

(d) Calculate the maximum pressure developed during the venting from the initially elevated pressure by using the following equation:

$$P_{red,\,2} = (P_{red,\,1})\left(\frac{P_2}{P_1}\right)^{\gamma} \tag{14}$$

where:

P_1 = atmospheric pressure = 1.0 bar abs

P_2 = elevated initial pressure before ignition, bar abs

(and see NOTES, below).

$P_{red,1}$ = maximum pressure as determined from the nomographs and converted to bar absolute, developed by the deflagration in a vented enclosure [when the initial pressure, before ignition, is 1 bar absolute = 0 bar gauge (from c, above)].

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

γ = 1.5 for propane or a fuel gas having K_G below 1.3 times that for propane

= 1.4 for ethylene

= 1.2 for hydrogen

NOTE 1: The value to be used for P_2 should be carefully chosen to represent the likely maximum pressure at which a flammable atmosphere can exist in the enclosure at the time of ignition. It may be the normal operating pressure. On the other hand, if there can be pressure excursions during operation, it may be the maximum pressure excursion, or the pressure at relief valve fully open position.

NOTE 2: Venting from vessels at initially elevated pressures will result in severe discharge conditions. The user should consider locating the enclosure to take into account the blast wave associated with the venting process.

(e) P_{red} should be checked against the strength of the enclosure.

6-7.4 As in any vent calculation procedure, any one of the variables (e.g., vent area, P_{stat}, P_{red}) can be determined, provided the others are held constant. Thus, the exact sequence of steps depends on the variable to be determined. The following procedure and example assume that actual P_{stat} and the vent area 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 given here.

Example problem: Determine maximum pressure during venting for the following conditions:

Enclosure volume	= 2.0 m^3
Vent area	= 0.6 m^2
Maximum operating pressure at time of ignition	= 2.125 bar gauge
Vent closure opening pressure	= 2.75 bar gauge
Material in enclosure	= propane/air.

1. Perform the calculation described in 6-7.3(a):

$$\left(\frac{2.75 + 1}{2.125 + 1}\right) = 1.2 \text{ bar abs} \tag{15}$$

= 0.2 bar gauge

= P_{stat} to use for propane nomograph.

2. Determine the area for venting [6-7.3(b)]:

In this example, this is given as 0.6 m^2.

3. Determine P_{red}, as described in 6-7.3(c):

Establish $P_{red,1}$ using the nomograph, Figure 6-2(b), for the following conditions:

Enclosure volume	= 2.0 m^3
Vent area	= 0.6 m^2
P_{stat}	= 0.2 bar gauge
From the nomograph, P_{red}	= 0.35 bar gauge
$P_{red,1}$	= 1 + 0.35 bar abs
	= 1.35 bar abs.

4. Perform the calculation described in 6-7.3(d):

Calculate $P_{red,2}$ using the equation:

$$P_{red,\,2} = (0.35 + 1)\left(\frac{2.125 + 1}{1}\right)^{1.5} \tag{16}$$

= 7.5 bar abs

= 6.5 bar gauge.

6-8 Effect of Initial Temperature. The effect of initial temperature is discussed in this guide in Chapter 2. In most cases; an increase in initial temperature will result in an increase in maximum rate of pressure rise and a decrease in the pressure generated by combustion in an unvented enclosure. It is therefore believed that no adjustment in the estimated pressure developed during venting needs to be made for an increase in initial temperature (Reference 56). The same is probably true for initial temperatures below ambient.

6-9 Effects of Combinations of Variables. There are insufficient data to determine precisely how combinations of variables affect the maximum pressure developed during venting (P_{red}).

6-10 Deflagration of Mists of Combustible Liquids. Combustible mists will ignite not only at temperatures above the flash point temperature of the liquid, but also at temperatures below the flash point temperature (References 58 through 61). In this sense, mists are similar to dispersed dusts, which can also be ignited at any initial temperature. The design of deflagration venting for many combustible mists can be based on the propane venting nomograph. For more detail on combustible mists, see Chapter 2.

6-11 Deflagration of Foams of Combustible Liquids. Foams of combustible liquids can burn. If the foam is produced by bubbling air through the liquid, the bubbles will contain air for burning. Combustion characteristics will depend on a number of properties such as the specific liquid, size of bubble, and thickness of bubble film. There is, however, a more hazardous case. If a combustible liquid is saturated with air under pressure, and if the liquid phase is then released from pressure with the formation of a foam, the gas phase in the bubbles can be preferentially enriched in oxygen. This is because the solubility of oxygen in combustible liquids is higher than that of nitrogen. The increased oxygen concentration will result in intensified combustion. It is therefore recommended that combustible foams be carefully tested relative to design for deflagration venting.

6-12 Venting Deflagrations of Combustible 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 might be the case in a fluidized bed dryer, a "hybrid" mixture results. See also Section 7-8 for more detail.

6-13 Effects of Vent Discharge Ducts. The effects of vent discharge ducts are discussed in Section 5-4.

6-14 Venting of Deflagrations in Conveying and Ventilating Ducts. Most deflagrations of combustible gas mixtures inside ducts occur at initial internal pressures of nearly atmospheric. The venting of deflagrations in such ducts is discussed in Chapter 8.

Chapter 7 Venting of Deflagrations of Dust Mixtures in High Strength Enclosures

7-1 Introduction. This chapter applies to enclosures capable of withstanding pressures greater than 1.5 psig (0.1 bar gauge). It is intended that this chapter be used along with the information contained in the rest of this guide. In particular, Chapters 3, 5, 9, and 10 should be reviewed before applying the information in this chapter.

7-1.1 The most comprehensive design bases for venting of dust deflagrations are contained in VDI Richtlinie 3673, published in Germany (Reference 62). This work is based on data obtained from an extensive test program involving four dusts and four enclosure sizes: 1, 10, 30, and 60 m^3. The nomographs developed from the test data are reproduced here as Figures 7-1(a) through 7-1(f). The nomographs apply to enclosures having L/D ratio of not over 5.

7-1.1.1 As an alternative to Figures 7-1(a), 7-1(b), and 7-1(c), the following equation could be used to determine the necessary vent area. This equation was developed to reproduce the values obtained from the nomographs and is presented here as a convenience for the user of this guide (Reference 50). The equation is:

$$A_v = (a)\,[V^{2/3}]\,[K_{St}]^b\,[P_{red}]^c \qquad (17)$$

where:

$a = 0.000571\ e^{(2\ P_{stat})}$

$b = 0.978\ e^{(-0.105\ P_{stat})}$

$c = -0.687\ e^{(0.226\ P_{stat})}$

and

A_v = vent area, m^2

V = enclosure volume, m^3

e = 2.718 (base of natural logarithm)

P_{red} = maximum pressure developed during venting, bar gauge

P_{stat} = vent closure release pressure, bar gauge

K_{St} = deflagration index for dust, $\frac{(bar)\ (m)}{sec}$

NOTE: Since this equation is derived from the nomographs, it is no more accurate than the nomographs themselves and should not be extrapolated beyond the limits of Section 7-3.2. The equation is subject to the same limitations as the nomographs and, therefore, should not be used for indiscriminate extrapolation. Serious errors in the value of A_v will occur if this is done. For an illustration of a solution of this type of equation, see A-6-1.1.1.

7-1.1.2 As an alternative to Figures 7-1(d), 7-1(e), and 7-1(f), the following equations could be used to determine the necessary vent area. These equations were developed to reproduce the values obtained from the nomographs and are presented here as a convenience for the user of this guide (Reference 63). The equations are:

For Figure 7-1(d), (P_{stat} = 0.1 bar gauge)

$$\text{Log } A_v + C = 0.67005\ (\text{Log } V) + \frac{0.96027}{(P_{red})^{0.2119}} \qquad (18)$$

where:

A_v = vent area, m^2

V = enclosure volume, m^3

P_{red} = maximum pressure developed during venting, bar gauge

C = 1.88854 for St-1 dusts
= 1.69846 for St-2 dusts
= 1.50821 for St-3 dusts.

For Figure 7-1(e), (P_{stat} = 0.2 bar gauge)

$$\text{Log } A_v + C = 0.67191\,(\text{Log } V) + \frac{1.03112}{(P_{red})^{0.3}} \quad (19)$$

where:

A_v = vent area, m^2
V = enclosure volume, m^3
P_{red} = maximum pressure developed during venting, bar gauge
C = 1.93133 for St-1 dusts
= 1.71583 for St-2 dusts
= 1.50115 for St-3 dusts.

For Figure 7-1(f), (P_{stat} = 0.5 bar gauge)

$$\text{Log } A_v + C = 0.65925\,(\text{Log } V) + \frac{1.20083}{(P_{red})^{0.3916}} \quad (20)$$

where:

A_v = vent area, m^2
V = enclosure volume, m^3
P_{red} = maximum pressure developed during venting, bar gauge
C = 1.94357 for St-1 dusts
= 1.69627 for St-2 dusts
= 1.50473 for St-3 dusts.

NOTE: Since these equations are derived from the nomographs, they are no more accurate than the nomographs themselves and should not be extrapolated beyond the limits of 7-3.2. They are subject to the same limitations as the nomographs and, therefore, should not be used for indiscriminate extrapolation. Serious errors in the value of A_v will occur if this is done.

7-1.2 Figures 7-1(a), (b), and (c) are based on the K_{St} values for the individual dusts, as determined by test procedures described in Appendix B. Figures 7-1(d), (e), and (f) are based on the dust classes St-1, St-2, and St-3, respectively. These dust classes represent a range of K_{St} values, as shown in Table 7-1.

For the procedure to be used in calculating K_{St} from experimental data, see B-2-3.

Table 7-1 Hazard Classes of Dust Deflagrations [1, 2]

Hazard Class	K_{St},[3] bar m/sec	P_{max},[3] bar gauge
St-1	≤200	≤10
St-2	201-300	≤10
St-3	>300	≤12

[1]The application of the nomographs is limited to an upper K_{St} value of 600.
[2]See Appendix E for examples of K_{St} values.
[3]K_{St} and P_{max} were determined in approximately spherical calibrated test vessels of at least 20-L capacity as per ASTM E-1226-1988.

7-1.3 K_{St} values of dusts of the same chemical composition vary with the physical properties such as size and shape of dust particle and moisture content. See Appendix B for more information on this subject.

7-2 Use of Dust Nomographs.

7-2.1 The necessary vent area for a dust can be determined from the nomographs as a function of the K_{St} value or the dust hazard class, the enclosure volume, the relieving pressure of the vent closure (P_{stat}), and the maximum pressure developed during venting (P_{red}).

7-2.2 The vent areas predicted by the two sets of nomographs described in 7-1.2 may not completely agree. The agreement is, however, sufficiently close for practical applications. Where experimental values of K_{St} are available, Figures 7-1(a) through 7-1(c) are preferable for establishing the minimum vent area required.

7-2.3 Dusts of the same hazard class that have maximum deflagration pressures not greater than 9 bar gauge require less vent area than those that have a maximum deflagration pressure greater than 9 bar gauge. The nomographs in Figures 7-2(a) and 7-2(b), based on test work reported in Reference 84, are limited to dusts whose maximum deflagration pressure in closed enclosure tests (*see Appendix B*) is not greater than 9 bar gauge and only for vent opening pressures not exceeding 0.1 bar gauge. The limitations stated in 7-2.2 apply to these nomographs as well. Also, none of the equations in 7-1.1.1 or 7-1.1.2 are applicable to these two nomographs.

7-2.3.1 For Class St-1 dusts, the following equation can be used as an alternate to Figure 7-2(a).

$$\text{Log } A_v = 0.77957 \text{ Log } V - 0.42945 \text{ Log } P_{red} - 1.24669 \quad (21)$$

7-2.3.2 For Class St-2 dusts, the following equations can be used as an alternate to Figure 7-2(b).

For V = 1 to 10 m^3

$$\text{Log } A_v = 0.64256 \text{ Log } V - 0.46527 \text{ Log } P_{red} - 0.99461 \quad (22)$$

For V = 10 to 1000 m^3

$$\text{Log } A_v = 0.74461 \text{ Log } V - 0.50017 \text{ Log } (P_{red} + 0.18522) - 1.02406 \quad (23)$$

7-3 Extrapolation and Interpolation of Nomographs.

7-3.1 The dust nomographs can be extrapolated and interpolated using the graphical techniques described in Section 6-6.

7-3.2 Extrapolation of Nomographs.

7-3.2.1 The user is cautioned not to extrapolate the nomographs below 0.05 bar gauge for P_{stat} nor below 0.1 bar gauge for P_{red}. For values below these, use the calculation procedure in Chapter 4. Furthermore, P_{red} should not be extrapolated above 2.0 bar gauge, the upper limit in the nomographs. Although P_{stat} can be extrapolated upward, it should always be less than P_{red} by at least 0.05 bar gauge. The venting nomographs are to be taken as the final authority within their applicable ranges of P_{stat} and P_{red}.

7-3.2.2 The user is cautioned when extrapolating below K_{St} < 50 bar m/sec because of the difficulty in precisely determining these low K_{St} values.

7-3.3 The dust nomographs were developed for essentially atmospheric initial pressure, before ignition, and they apply to initial pressures up to 0.2 bar gauge. No guidance is available at present for systems operating at higher initial pressures.

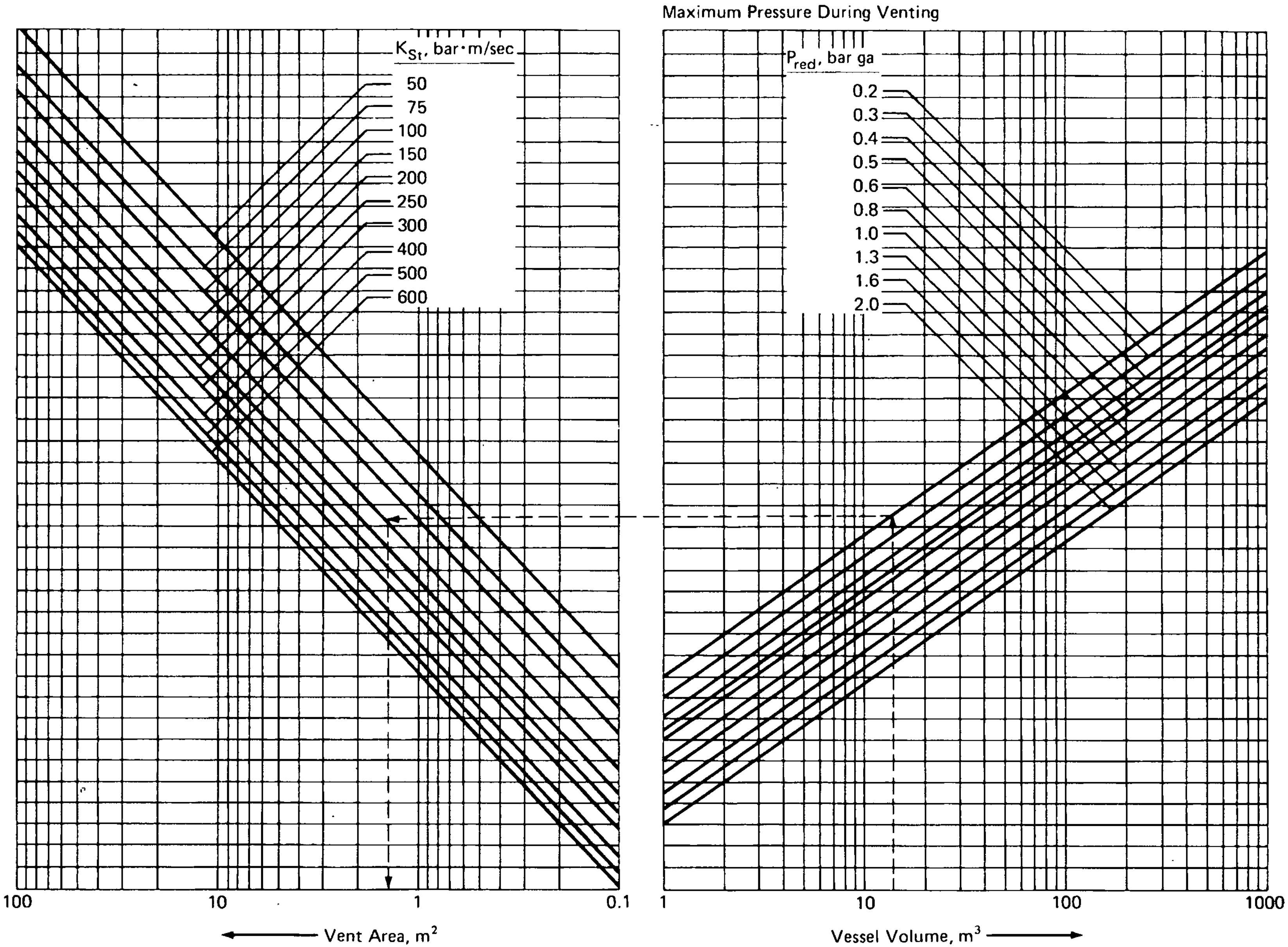


Figure 7-1(a) Venting nomograph for dusts (P_{stat} = 0.1 bar gauge).

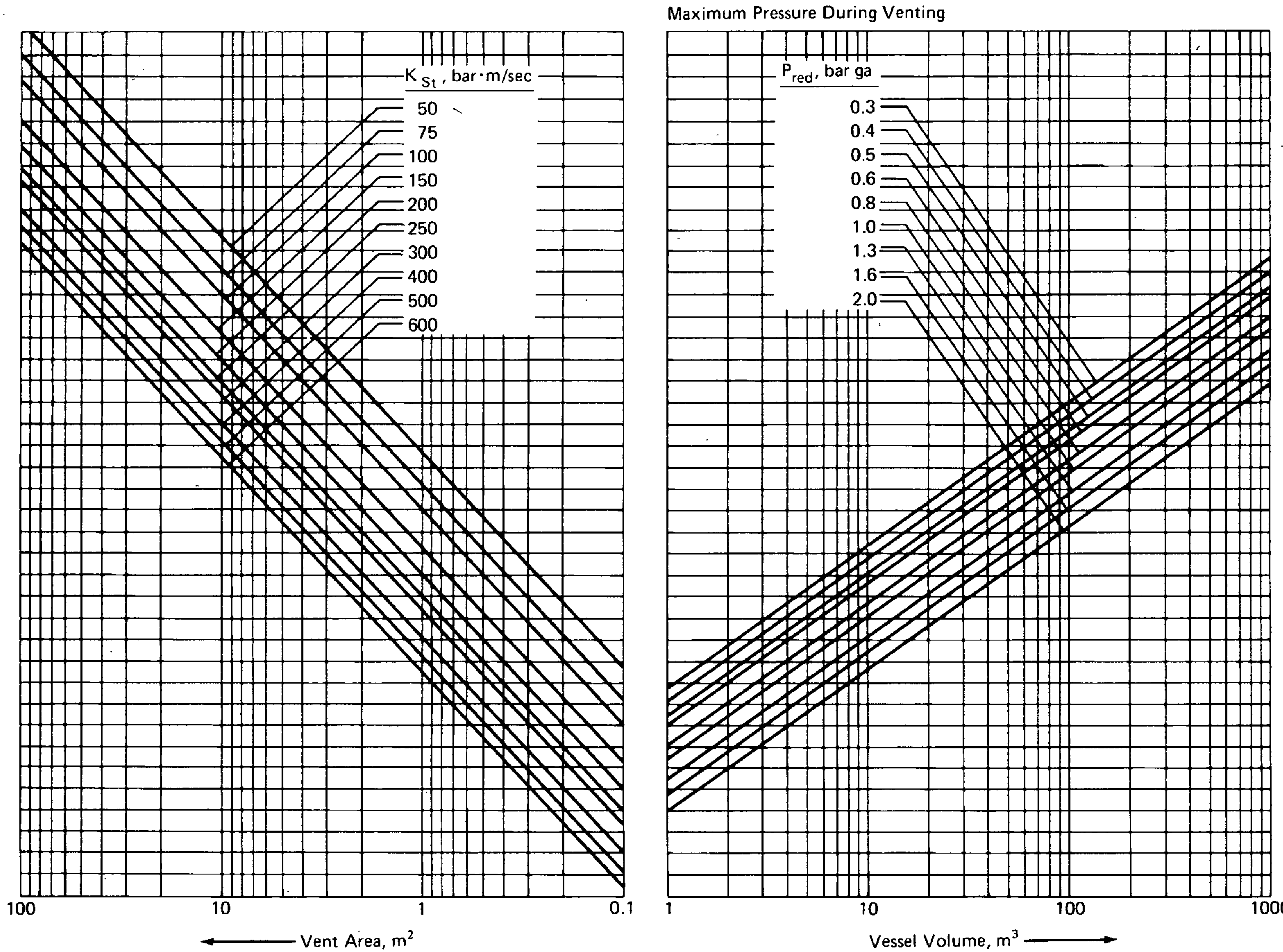


Figure 7-1(b) Venting nomograph for dusts (P_{stat} = 0.2 bar gauge).

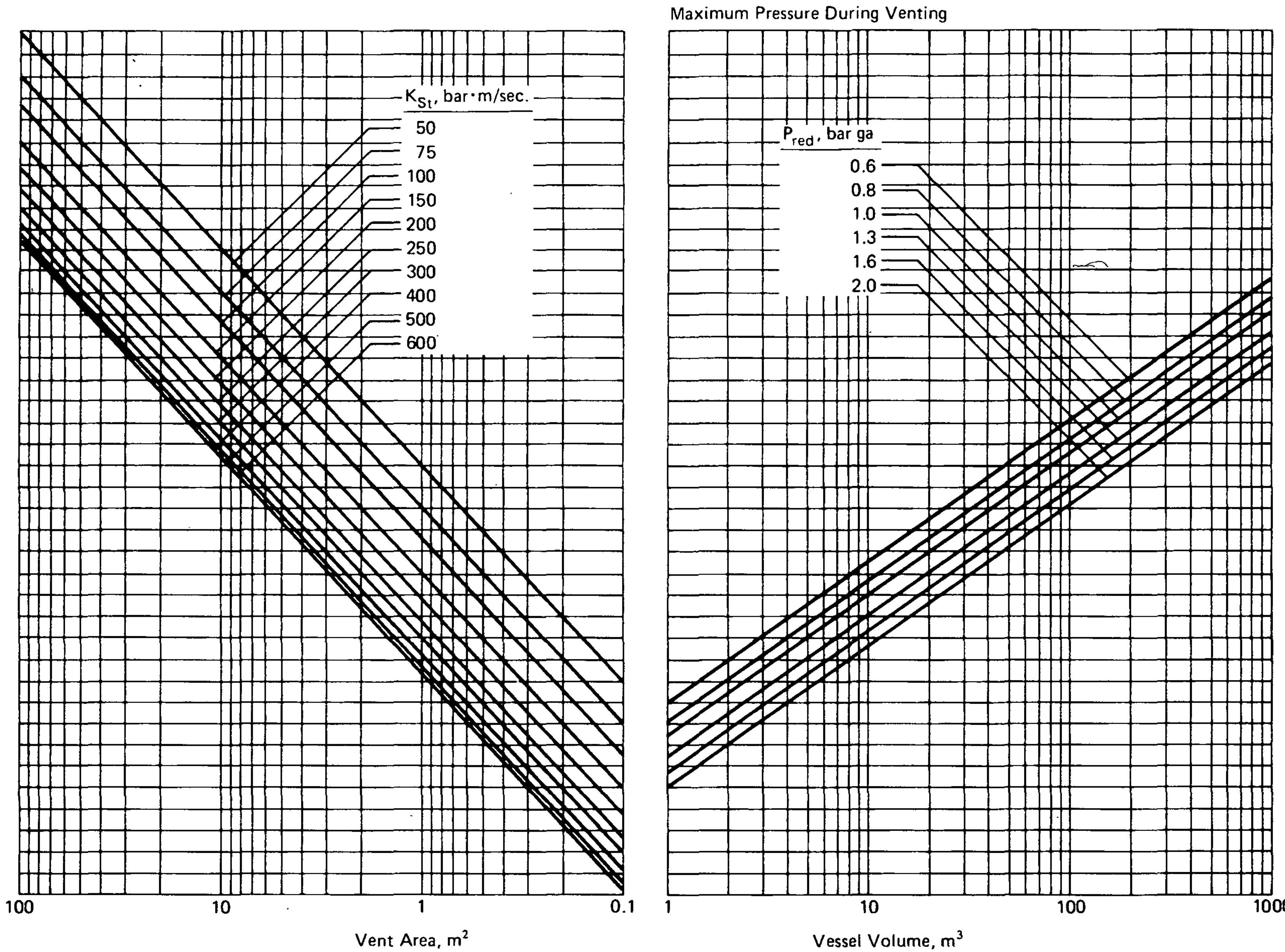


Figure 7-1(c) Venting nomograph for dusts (P_{stat} = 0.5 bar gauge).

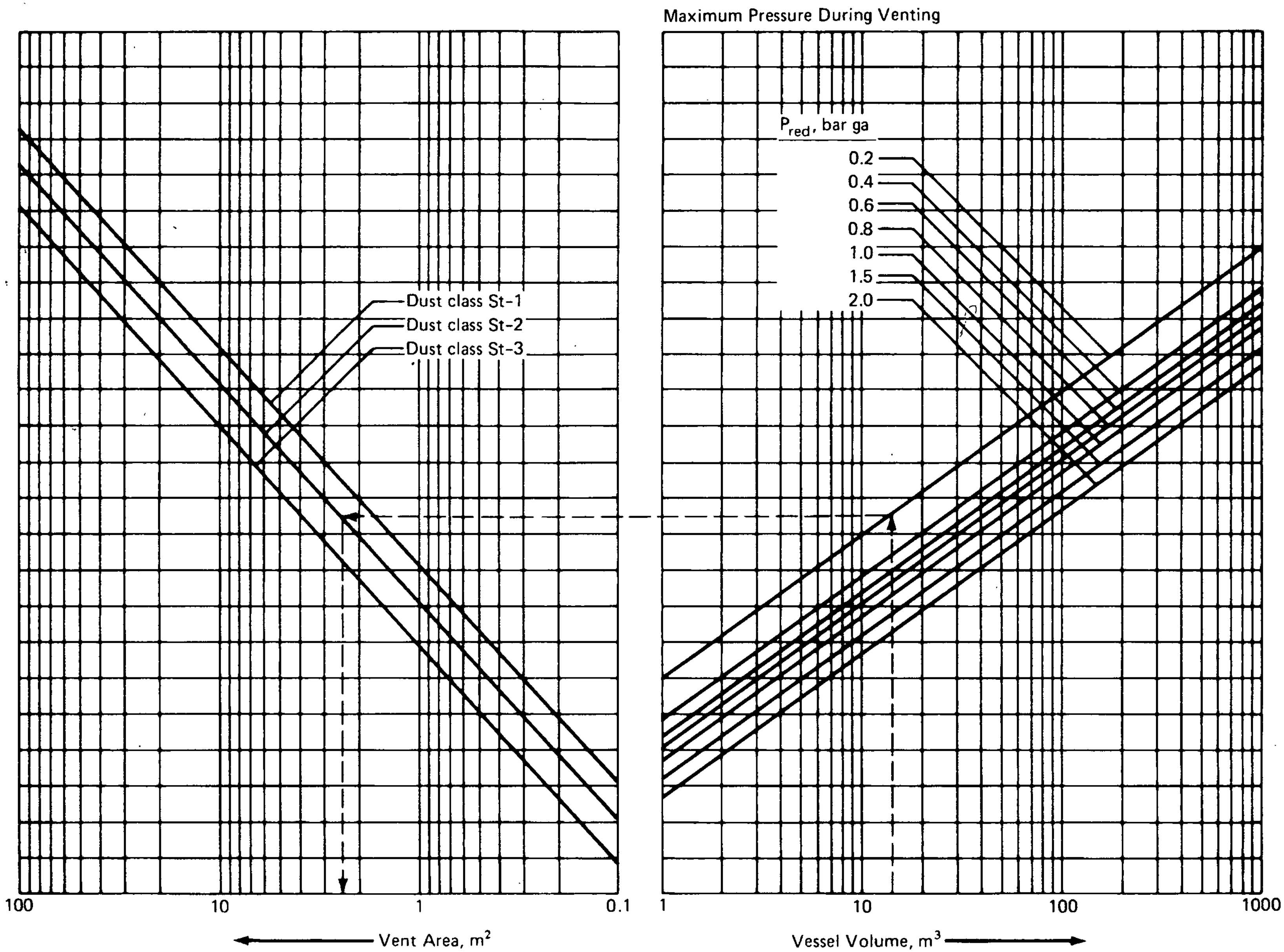


Figure 7-1(d) Venting nomograph for classes of dusts (P_{stat} = 0.1 bar gauge).

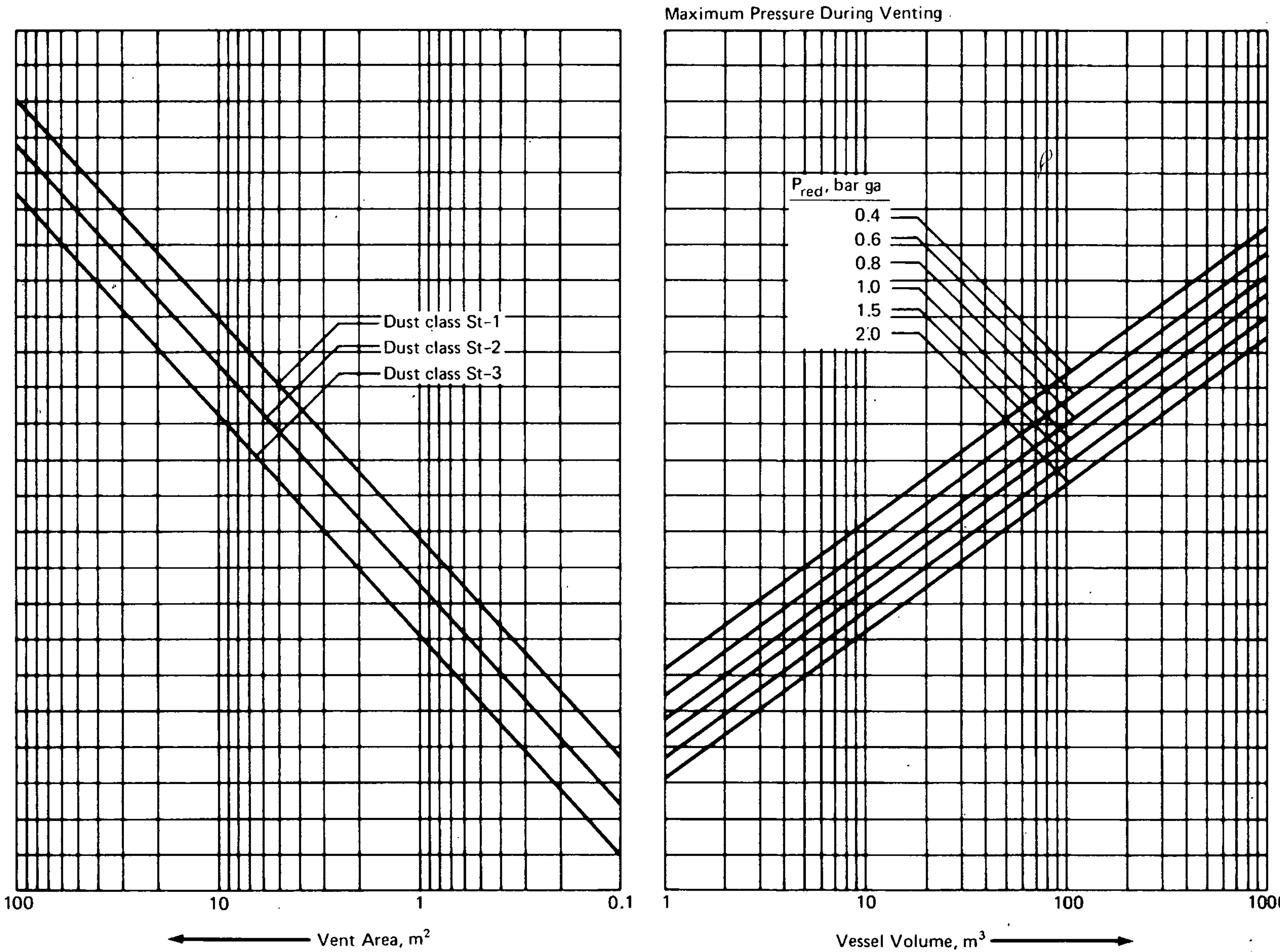


Figure 7-1(e) Venting nomograph for classes of dusts (P_{stat} = 0.2 bar gauge).

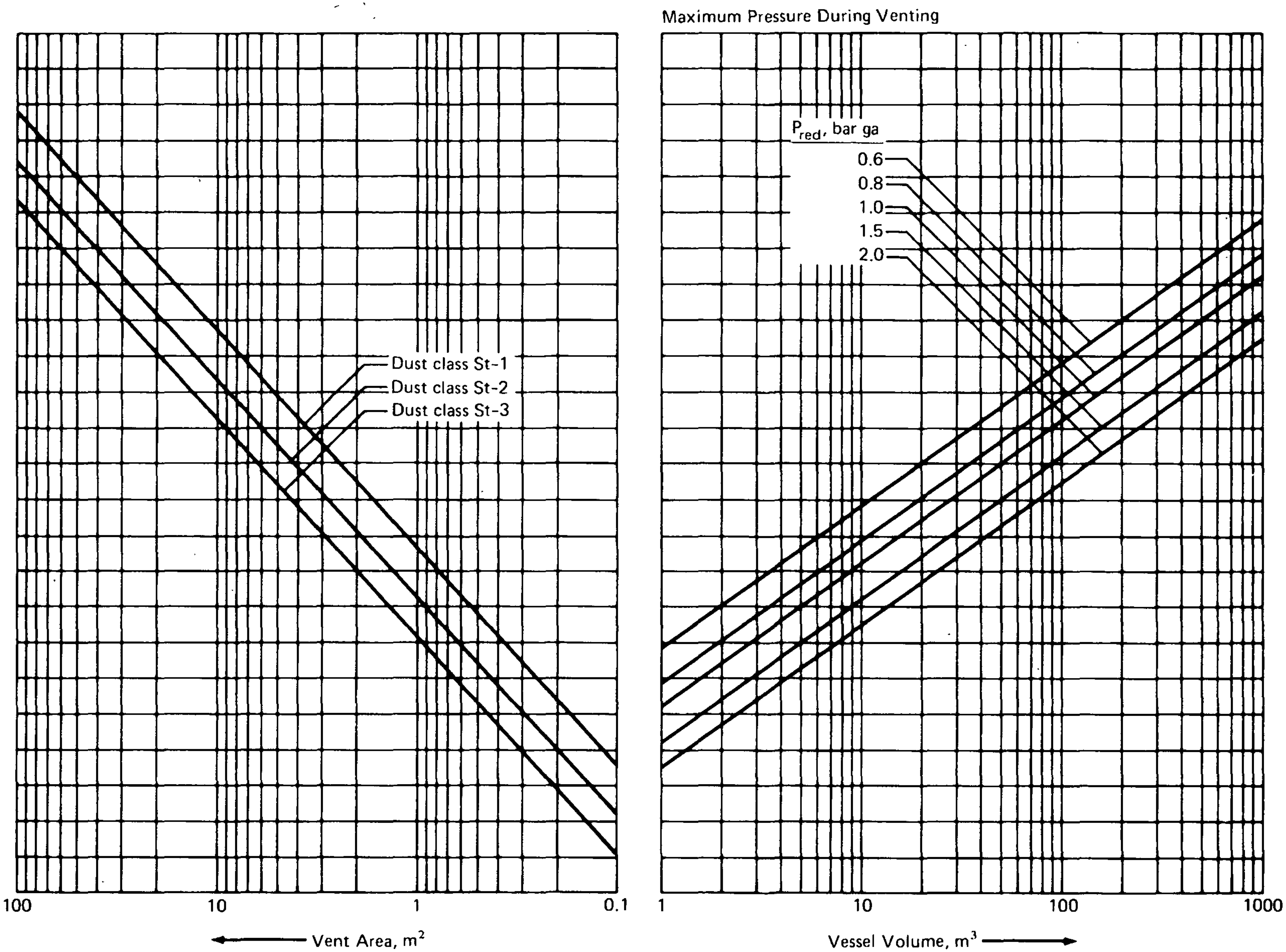


Figure 7-1(f) Venting nomograph for classes of dusts (P_{stat} = 0.5 bar gauge).

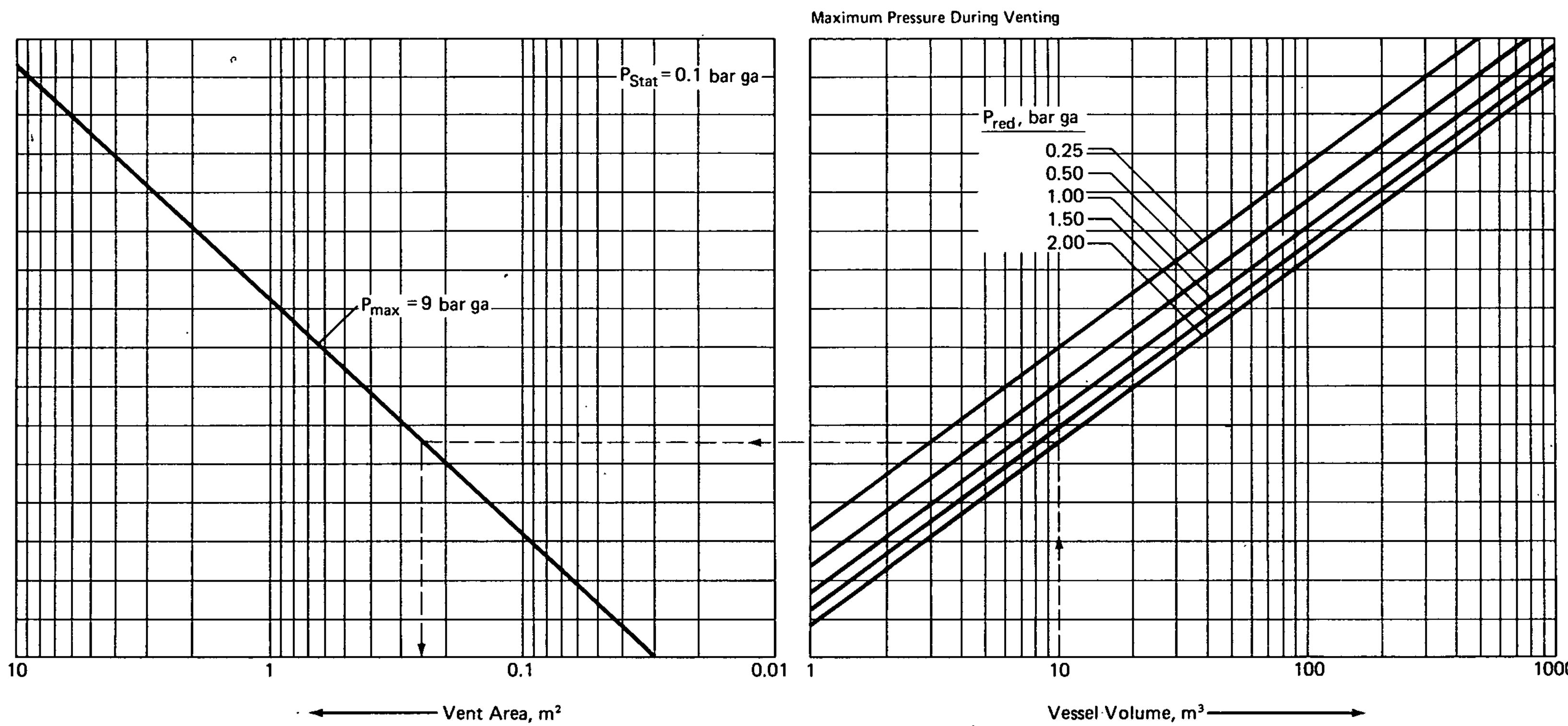


Figure 7-2(a) Alternate venting nomograph for dusts of Class St-1 whose maximum deflagration pressure does not exceed 9 bar gauge.

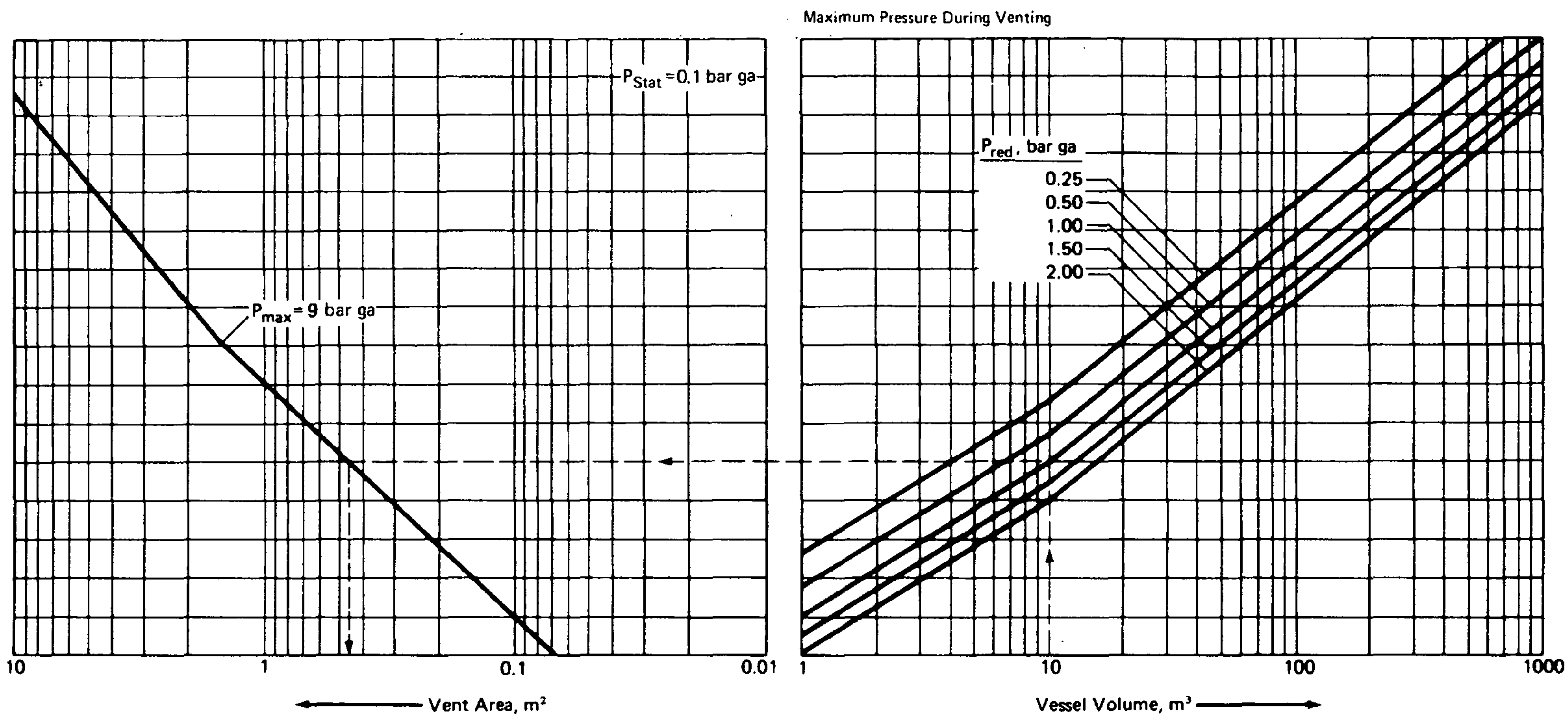


Figure 7-2(b) Alternate venting nomograph for dusts of Class St-2 whose maximum deflagration pressure does not exceed 9 bar gauge.

7-4 Bins, Hoppers, and Silos.

7-4.1 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 Sections 5-5 and 7-7.*) In some instances, the required vent area could be as large as the enclosure cross section. In these cases, the entire enclosure top can be made to vent. Space should be available above the top to allow it to open sufficiently. The top should be as lightweight as possible. (*See Table 9-3.4 for effects of vent mass.*) Large-diameter tops of this type cannot be made self-supporting and will require internal supports. Panels that make up the top should not be welded or otherwise attached to the internal roof supports. As an alternative, individual vent closures could be located on the top or the side (above the maximum level of solids). Where vent closures are located on the side and top of the enclosure, the maximum useful area for venting will correspond to the cross-sectional area of the enclosure.

7-4.2 If the required vent area is greater than the cross-sectional area of the enclosure, the enclosure should be strengthened to withstand a pressure consistent with that developed with a vent area equal to the cross-sectional area. In all cases, the total volume of the enclosure should be assumed to contain a suspension of the combustible dust in question. That is, no credit should be taken for the enclosure being partly full of settled material.

7-4.3 Deflagration venting is sometimes accomplished by means of vent panels distributed around the wall of the enclosure just beneath the top. In such cases, care should be taken not to fill the enclosure above the bottoms of the vent panels. Otherwise, large amounts of dust could be blown out into the atmosphere, be ignited, and form a large fireball. Furthermore, dust piled above the bottoms of vent panels can hinder vent panel opening and can also result in P_{stat} values that are higher than design.

7-5 Effects of Vent Discharge Ducts. The effects of vent discharge ducts are discussed in Section 5-4.

7-6 Venting of Enclosed Bag Dust Collectors. It is desirable to design bag filter vent panels in such a way as to minimize the potential for bags and cages to interfere with the venting process. The filter medium may not adequately segregate the clean and dirty sides of the collector during the deflagration. Therefore, the entire volume of each side should be used when calculating the vent area. In multi-section dust collectors, venting should be provided for each section. (*See also Reference 37.*)

7-7 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. Hence, a very large and long fireball of burning dust develops, which can extend downward as well as upward. The size of the fireball depends on many factors. Personnel enveloped by such a fireball would likely not survive. The potentially large size of the fireball extending from the dust deflagration vent should be considered when locating vents and vent ducts so as to avoid hazards to adjacent equipment and personnel.

7-7.1 In the case of dust deflagration venting, the distance (D) that the fireball can extend outwards from the vent can be 6 times the cube root of the volume (V) of the enclosure vented. If the vented material exits from the vent horizontally, this would be an anticipated horizontal length of the fireball. The height of the fireball (H) could be the same dimension, with half the height below the center of the vent and half the height above. It is extremely important to note that the fireball can in fact extend downward as well as upward. (Reference 87.) In some deflagrations, buoyancy effects can allow the fireball to rise to elevations well above these distances.

$$D = 6\,(V^{1/3}) = H \qquad (24)$$

7-8 Hybrid Mixtures.

7-8.1 Hybrid mixtures of combustible gases or combustible dusts could be ignitable even if both constituents are below their respective lower flammable limits. The properties of hybrid mixtures are extensively discussed by Bartknecht (Reference 3). Certain dusts that do not form combustible mixtures by themselves could do so if a combustible gas is added, even if the latter is at a concentration below its lower flammable limit. The minimum ignition energy of a hybrid mixture is less than that of the dust alone. (*See 2-2.2.3.*)

7-8.2 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. This, in turn, leads to an increase in the required vent area. For hybrid mixtures, use the nomograph for the component that requires the greater vent area (this is usually the gas). An alternative approach is to use tests to determine the equivalent K_{St} using worst-case conditions and apply the appropriate dust nomograph.

Chapter 8 Venting of Deflagrations from Pipes, Ducts, and Elongated Vessels Operating At or Near Atmospheric Pressure

8-1 Scope. This chapter applies to systems operating at pressures up to 3 psig (0.2 bar gauge). This chapter does not apply to vent discharge ducts.

8-2 General.

8-2.1 Several factors make the design of deflagration vents for pipes, ducts, and elongated vessels (length-to-diameter ratios of 5 or greater) a different problem from the design of deflagration vents for ordinary vessels and enclosures. These include:

(a) The geometry of large L/D ratios promotes rapid acceleration of flames. Acceleration to very high flame speeds, or even detonations, can occur.

(b) Turbulence-producing devices such as valves, elbows, and other fittings or obstacles are frequently present. The turbulence produced can generate sudden flame acceleration and a consequent rapid increase in pressure. An obstacle is any appurtenance that blocks more than 5 percent of the pipe or duct.

(c) Ignition of a combustible mixture in a vessel to which a pipe or duct is attached results in a flame front that generates considerable turbulence ahead of itself and precompresses the gas in the pipe or duct. When the flame front reaches the entrance to the pipe or duct, it is fully developed and turbulent. The result is a flame front that propagates into the pipe or duct with much greater initial violence than that which would result from spark ignition in the pipe or duct itself.

(d) Pipes, ducts, and elongated enclosures that transfer combustible material can be subject to deflagration due to ignition within the pipe, duct, or enclosure. Venting of such structures can minimize pressure effects along the structures and, by venting unburned material to a safe area, might reduce the effect of the moving flame front.

8-2.2 The design of adequate deflagration venting for pipes, ducts, and elongated vessels is further complicated by the fact that there has been relatively little systematic test work published on this subject. The guidelines in this chapter are based on information contained in References 3 and 64 through 71 and are thought to provide reasonable protection, but their use should be tempered by sound engineering judgment for specific applications. Any deviation from these guidelines should be in the direction of more, rather than less, vent area.

8-2.3 Wherever it is not possible to provide adequate vents as called for in this chapter, two alternative approaches can be employed:

(a) Provide explosion prevention measures as described in NFPA 69, *Standard on Explosion Prevention Systems*, or

(b) Design the piping or ducts to withstand detonation pressures and provide isolation devices or detonation containment to protect interconnected vessels.

Exception: Class St-1 dusts do not present a detonation potential. Systems designed to withstand pressures up to 10 bar gauge will be adequate for Class St-1 dusts.

8-3 Design Guidelines.

8-3.1 For pipes, ducts, or elongated vessels having cross sections other than circular, the hydraulic diameter should be used in the correlations that follow. The hydraulic diameter is equal to 4 A/p, where A is the area of the cross section and p is the perimeter of the cross section.

8-3.2 The total vent area at each vent location should be at least equal to the cross-sectional area of the duct or pipe. The required vent area can be accomplished by using either one or more than one vent at each location.

8-3.2.1 For an individual vent, any vent area exceeding the cross-sectional area of the pipe, duct, or vessel will not be effective in further reducing the deflagration pressure. The cross-sectional area is the maximum effective vent area obtainable.

8-3.3 Pipes or ducts connected to a vessel in which a deflagration can occur will also require deflagration venting. A vent whose area is equal to the cross-sectional area of the pipe or duct should be provided at a location on the pipe or duct that is no more than 2 diameters distant from the point of connection to the vessel.

8-3.4 Deflagration vents should be located close to possible ignition sources, where these sources can be identified.

8-3.5 For systems handling gases, unless appropriate tests indicate otherwise, pipes and ducts containing turbulence-producing devices should be provided with deflagration vents on each side of the device at distances of 3 diameters.

8-3.6 The weight of deflagration vent closures should not exceed 2.5 lb/sq ft (12.2 kg/m^2) of free vent area.

8-3.7 The release pressure of vents should be as much below the design value of P_{red} as possible, consistent with operating conditions, but should not exceed one-half of the design value for P_{red}. Covers can be held by magnets or springs.

8-3.8 Deflagration vents should discharge to a location that will not endanger personnel.

8-3.9 Consideration should be given to reaction forces that develop during venting. (*See 5-2.9.*)

8-4 Determination of P_{red} for Pipes, Ducts, or Elongated Vessels that Are Vented at One End Only.

8-4.1 The curves in Figure 8-4(a) 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.

8-4.2 Initial Velocity 2 m/sec or Less — Gases. The curves in Figure 8-4(b) should be used to estimate the pressure developed in a pipe, duct, or vessel that is vented at one end only when the pressure results from deflagration of a gas/air mixture initially flowing at a velocity of 2 m/sec or less. This applies to gas mixtures having properties similar to those of propane. For diameters other than those shown, the curves should be interpolated. If the pressure developed can exceed the strength of the container, additional vents should be provided as outlined in Section 8-5.

8-4.3 Initial Velocity 2 m/sec or Less — Dusts. The curves in Figure 8-4(c) should be used to estimate the deflagration pressure developed in a pipe, duct, or elongated vessel that is closed on one end and vented on the other, with no additional vents, when dust/air mixtures initially flowing at 2 m/sec or less are ignited. If the pressure developed exceeds the burst strength of the container, then additional vents should be provided as outlined in Section 8-5.

8-4.4 Initial Velocity Greater than 2 m/sec. As flame acceleration and peak pressures can be greatly enhanced when the flammable mixture is initially flowing at velocities greater than 2 m/sec, it is not possible to provide adequate venting with a single vent. See Section 8-5.

8-5 Explosion Vent Requirements Where More than One Vent Can Be Provided.

8-5.1 Maximum Distance Between Vents. The curves shown in Figure 8-4(a) should be used to determine the maximum allowable distance between vents.

8-5.2 Initial Velocity 2 m/sec or Less. Figure 8-5(a) can be used to determine the increase in pressure caused by a deflagration in a pipe or duct where more than one vent can be provided. This figure applies to gases with fundamental burning velocities no more than 1.3 times that of propane and to dusts for which $K_{St} \leq 300$.

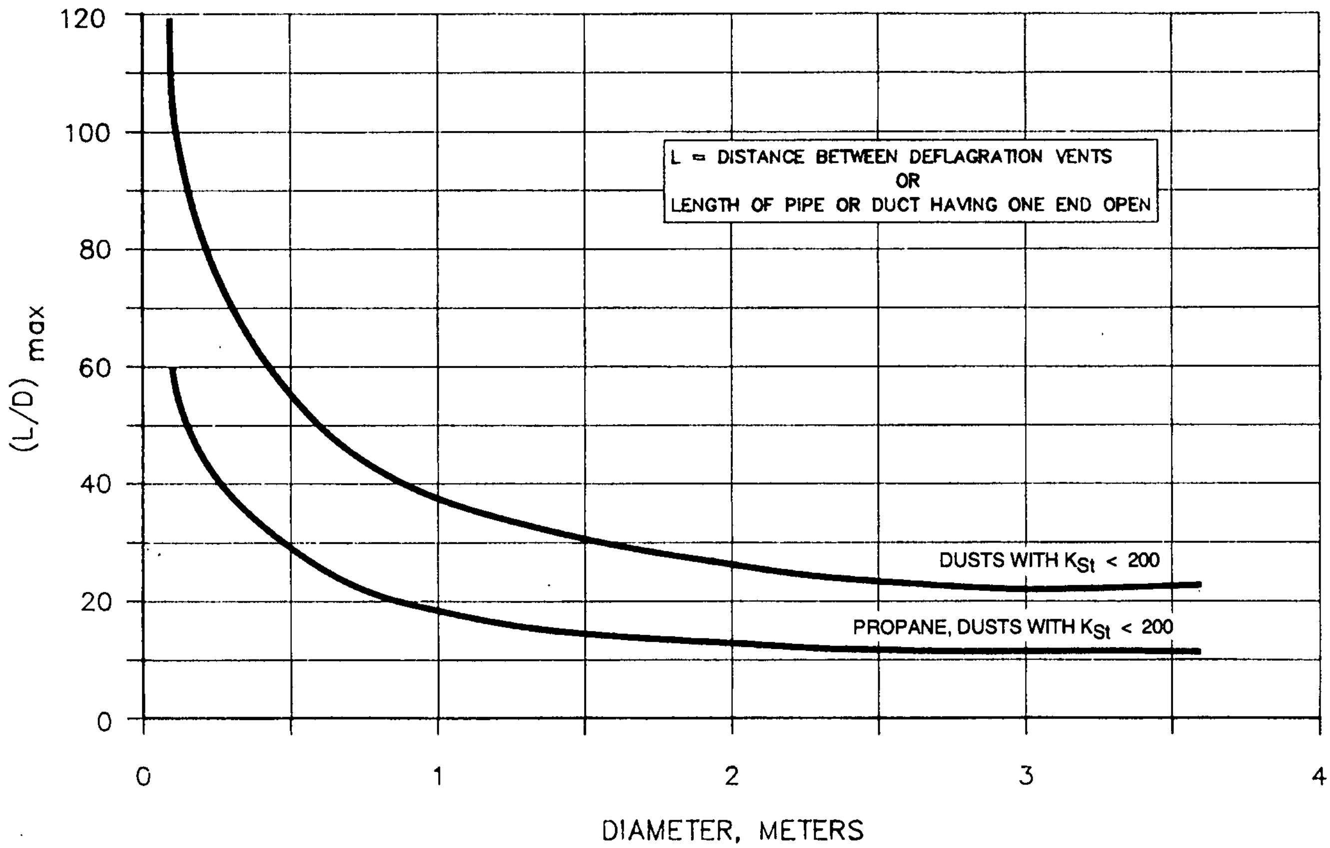


Figure 8-4(a) Maximum allowable distance, expressed as length-to-diameter ratio, for a smooth, straight pipe or duct (Reference 71).

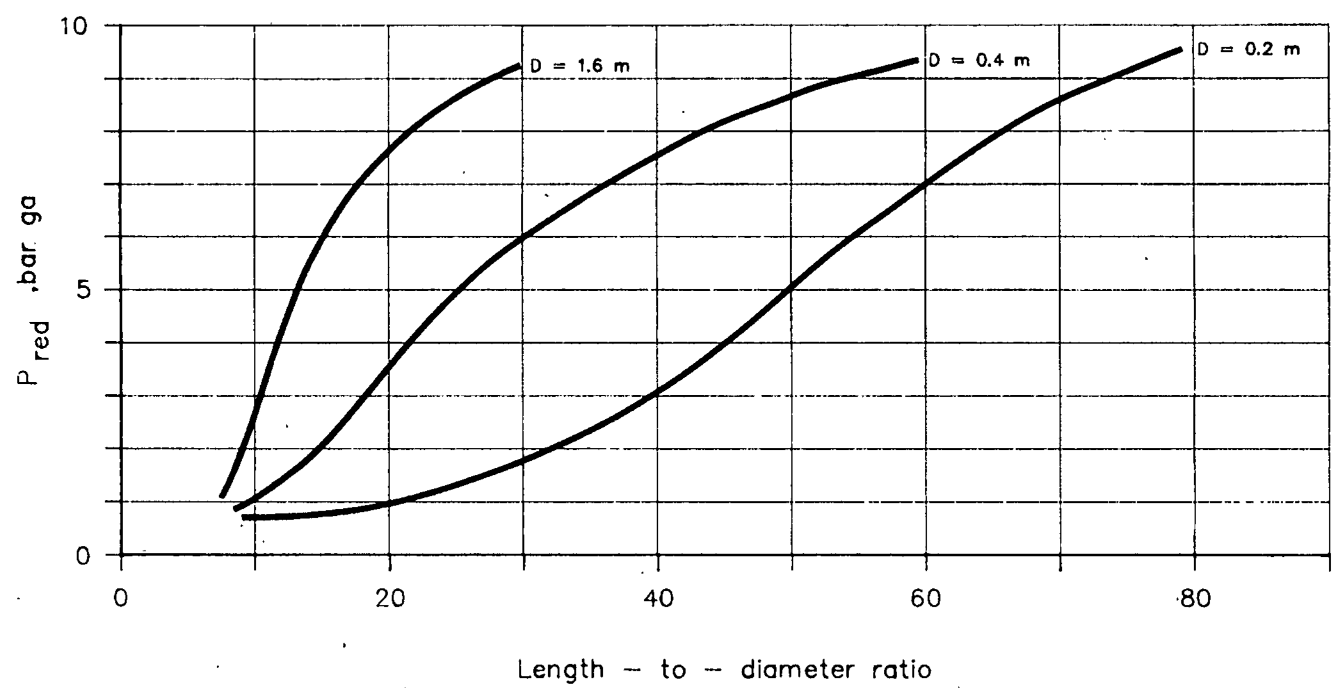


Figure 8-4(b) Maximum pressure developed during deflagration of propane/air mixtures flowing at 2 m/sec or less in a smooth, straight pipe closed at one end.

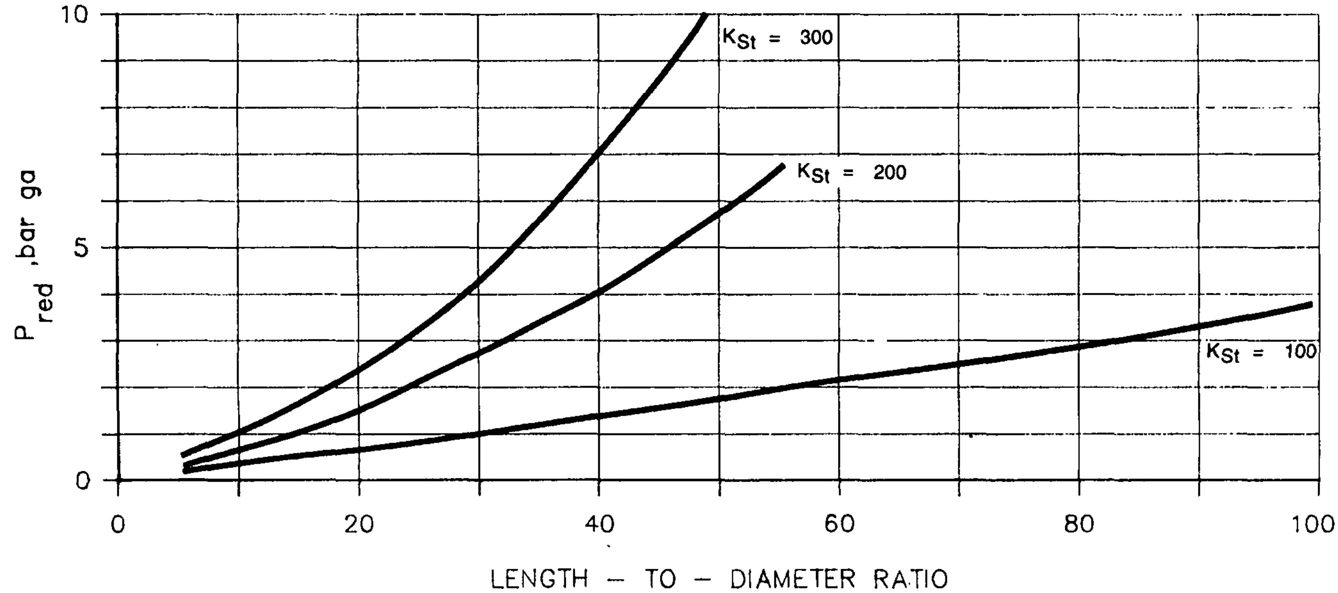


Figure 8-4(c) Maximum pressure developed during deflagration of dust/air mixtures flowing at 2 m/sec or less in a smooth, straight pipe closed at one end.

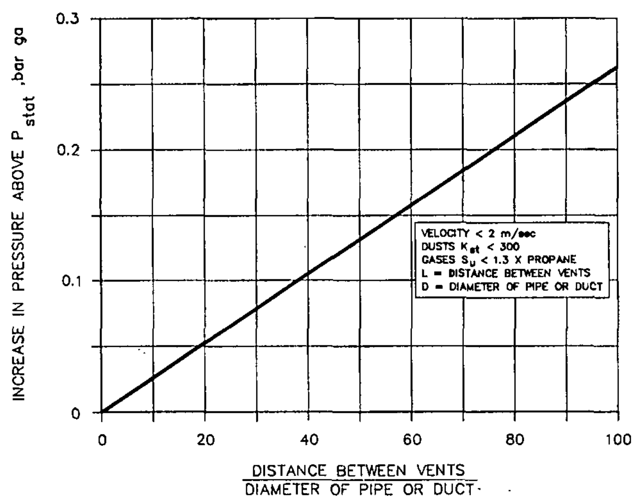


Figure 8-5(a) Maximum pressure developed during deflagration of gases or dusts in a pipe or duct where more than one vent is provided.

8-5.3 Initial Velocity Between 2 m/sec and 20 m/sec. To limit P_{red} to 2.5 psig (0.17 bar gauge) or less, the distance between vents can be determined from Figure 8-5(b). This figure applies to gases with fundamental burning velocities no more than 1.3 times that of propane and to dusts for which $K_{St} \leq 300$.

8-5.4 For Other Gases. The results contained in the preceding paragraphs can be used for gases other than propane, provided the fundamental burning velocity does not exceed 1.3 times that of propane. Conversion of the data is accomplished by use of one of the following equations:

$$P_x = \left(\frac{(S_u)}{(S_p)} \right)^2 (P_p) \tag{25}$$

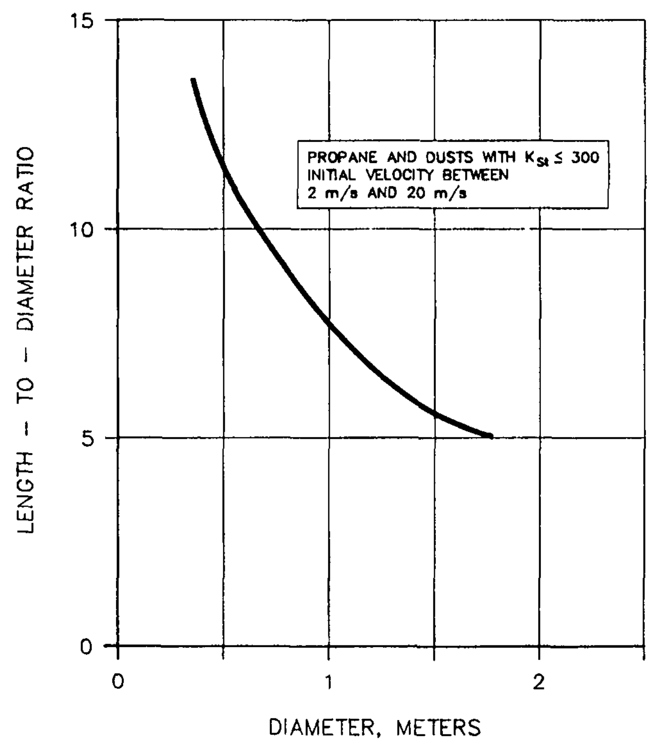


Figure 8-5(b) Vent spacing required to keep P_{red} from exceeding 0.2 bar gauge.

where:

P_x = pressure predicted for gas
P_p = pressure predicted for propane
S_u = fundamental burning velocity of gas
S_p = fundamental burning velocity of propane.

$$L_x = \left(\frac{(S_p)}{(S_u)}\right)^2 (L_p) \qquad (26)$$

where:

L_p = distance between vents for propane
L_x = distance between vents for gas
S_u = fundamental burning velocity of gas
S_p = fundamental burning velocity of propane.

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 to 2 m apart.

8-5.6 Turbulence-Producing Devices. For ducts or pipes containing turbulence-producing devices as previously described, vents should be placed as specified in 8-3.5. Additional vents, as specified elsewhere in Section 8-5, can also be required.

8-6 Examples.

8-6.1 A dryer handling a dust whose K_{St} is 190 is 2 m in diameter and 20 m long and is designed with a single vent. What pressure can occur during a vented explosion?

(a) Check maximum allowable length: According to Figure 8-4(a), an L/D of about 25 is allowable. The dryer has an L/D of 10, so this is acceptable.

(b) Maximum pressure: According to Figure 8-4(c), a pressure of approximately 0.5 bar gauge will be developed in this equipment by the deflagration of this dust. Hence, the equipment should have a design pressure of at least this value.

8-6.2 A flare stack is 0.4 m in diameter by 40 m tall 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 having properties similar to those of propane?

(a) Check maximum allowable length: From Figure 8-4(a), 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.

8-6.3 A straight duct 1 m in diameter and 100 m long is to be protected by deflagration vents. It contains a hydrocarbon/air mixture having properties similar to those of propane. What vent spacing is required to limit the deflagration pressure to 2.5 psig (0.17 bar gauge) if (a) the velocity is less than 2 m/sec, or (b) the velocity is less than 20 m/sec? In both cases, the vents are designed to open at 0.05 bar gauge.

(a) From Figure 8-5(a), the spacing should be about 45 diameters (45 m) in order to limit the increase to 0.12 bar gauge above P_{stat}. However, this violates the maximum allowable spacing of about 18 diameters, as indicated in Figure 8-4(a). Hence, the vent spacing should not exceed 18 m for this case. It is recommended that 7 vents be provided, including 1 at each end.

(b) From Figure 8-5(b), the vents should be placed no more than 7.6 m apart. In order to meet this requirement, it is recommended that a vent be placed at each end and that 13 additional vents be evenly spaced along the duct.

8-6.4 Provide deflagration vents for the ducts in the system shown in Figure 8-6.4. The gas flow through the system is 100 m^3/min, and all ducts are 0.6 m diameter. The maximum allowable working pressure for the ducts and equipment is 0.2 bar gauge and the maximum operating pressure in the system is 0.05 bar gauge. The system handles a Class St-2 dust. It is further assumed that the dryer and dust collector are equipped with adequate deflagration vents.

As required by 8-3.3 and 8-3.5, A and B should be located, respectively, within 2 diameters of the dryer outlet and no more than 3 diameters upstream of the first elbow.

- C located 3 diameters distance.
- F located at a position approximately 2 diameters upstream of the dust collector inlet based on 8-3.3.

Additional venting is required for the 20-m section. The flow of 100 m^3/min corresponds to a velocity of 6 m/sec. Hence, Figure 8-5(b) should be used. According to this figure, the vents should be placed at intervals no greater than 11 diameters, or approximately 6.5 m apart. The distance between vents C and F is 17.2 m; therefore, 2 additional vents (D and E) at approximately equal spacing would meet the requirement.

The total vent area at each vent location should be at least equal to the cross-sectional area of the duct. This will result in a value of 0.2 bar gauge for P_{red}. According to 8-3.7, the vent release pressure should not exceed half P_{red} and therefore must not exceed 0.1 bar gauge.

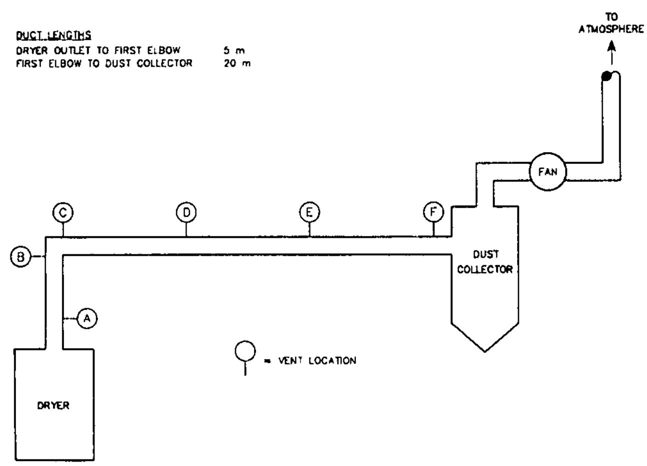


Figure 8-6.4 Diagram for example in 8-6.4.

Chapter 9 Description of Deflagration Vents and Vent Closures

9-1 General.

9-1.1 The deflagration vents and vent closures described in this chapter have been designed to relieve the pressure that results from a deflagration within an enclosure.

9-1.2 Some types of vent 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 suitable vent and vent closure assemblies.

9-2 Normally Open Vents.

9-2.1 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 passing through the vent and increases the pressure drop across the vent. These factors should be considered when choosing louvered vents.

9-2.3 Hangar-type Doors. Large hangar-type or overhead doors can be installed in the side walls of rooms or buildings that contain a deflagration hazard. The doors can be opened to provide sizeable unobstructed vents during operation of the process or equipment in which there is an inherent deflagration hazard. It should be recognized that the opening is a vent only when the door is not in place. Strict supervisory and systems control is essential.

9-3 Normally Closed Vents.

9-3.1 In most cases, a vent closure is fitted over the vent opening to protect against weather, conserve heat, prevent unauthorized entry, preclude release of material, or prevent contamination.

9-3.2 Static release pressure, P_{stat}, is the pressure at which the vent closure releases under static (low rate of pressure rise) conditions.

9-3.2.1 It is the responsibility of the vent closure manufacturer to specify and certify the mean value and tolerance of the P_{stat} of a vent closure when installed according to the manufacturer's recommendations in the intended application.

9-3.2.2 Testing should be carried out to establish the P_{stat} for any given closure release mechanism, and preferably for the closure mechanism installed on the vent closure and tested as a complete assembly. This applies to all types of closure mechanisms including pull-through fasteners, shear bolts, spring magnetic or friction latches, and rupturable membranes.

9-3.2.3 The vent closure should be designed to release at as low a pressure as practical and should be suitable for the service conditions to which it will be exposed. The static release pressure, P_{stat}, should be identified, ideally by test.

9-3.2.4 Temperature Effects on P_{stat}. If the vent enclosure will be exposed to temperatures that can affect the release pressure, this should be taken into consideration in determining P_{stat}.

9-3.3 Vent Closure Identification. The vent closure should be identified as an explosion pressure relieving device and should be suitably marked and the release pressure documented.

9-3.4 The vent closure should be designed to function as rapidly as is practical. Thus, the mass of the closure should be as low as possible to reduce the effects of inertia. The total weight of the movable part of the vent closure assembly should not exceed 2.5 lb/ft^2 (12.2 kg/m^2). Counterweights should not be used because they add to the inertia of the closure. The closure should also be designed to withstand natural forces such as wind or snow loads, operating conditions such as internal pressure fluctuations and internal temperature, and effects of corrosion.

Table 9-3.4 Reduced Pressure (P_{red}) Developed During Deflagration Venting Influenced by Mass of Vent Closure

5% propane in air, 2.6 m^3 enclosure (see reference 91.)

Vent Closure Mass (lb/ft^2)	Static Opening Pressure (P_{stat}) (millibar gauge)	Vent Closure Response Time (millisec)	Reduced (P_{red}) (millibar gauge)
0.073	103	14.5	156
0.68	96	31.0	199
2.29	100	42.6	235
4.26	100	54.0	314

(Test series reported = #17, #1, #3 and #4)
(A_v = 64.8 ft^2; A_s = 11.1 m^2)
(A_v = 64.8 ft^2; A_s = 11.1 m^2)

9-4 Types of Building or Room Vent Closures. The following types of vent closures are intended for use primarily with relatively large, relatively low strength enclosures such as those covered by Chapter 4.

9-4.1 Hinged Doors, Windows, and Panels Closures. These closures are designed to swing outward and normally have latches or similar hardware that automatically release when influenced by 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 will fail under relatively low mechanical stress to release a vent closure are commercially available and many have been tested by listing or approval agencies. Shear and pull-through fasteners are suitable for applications where the vent design calls for very large vent areas, such as the entire side 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 may require higher forces for operation under dynamic condition than under the static conditions at which they are usually tested. These higher forces may not be compatible with the design requirements of the vent system.

9-4.3 Friction-Held Closures. Some commercially available vent and vent closure assemblies use a flexible diaphragm held around its edges in a restraining frame. When a deflagration occurs, the pressure deforms the diaphragm, pushing it from its frame. [*See Figures 9-4.3(a) and (b).*] This type of vent and 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 operating at or close to atmospheric pressure.

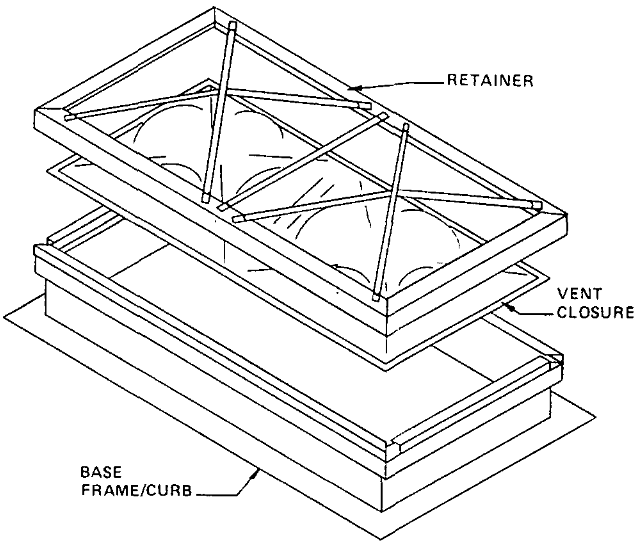


Figure 9-4.3(a) Exploded view of manufactured vent closure.

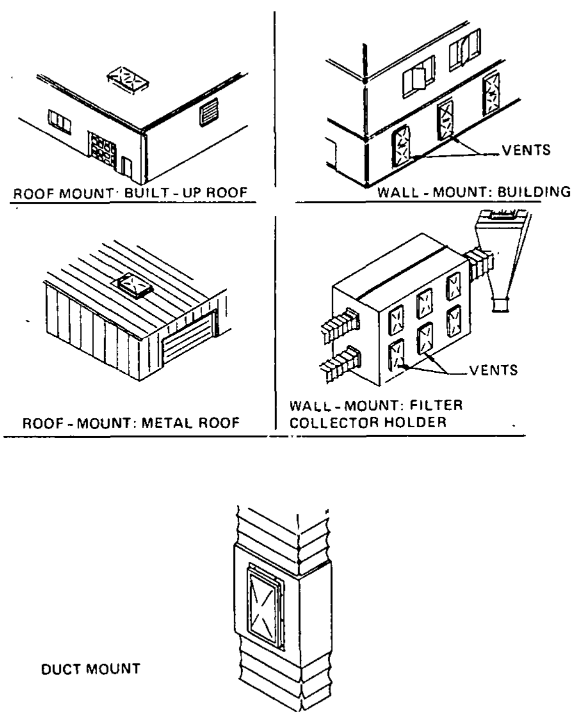


Figure 9-4.3(b) Typical applications for manufactured vent closures.

9-4.3.1 In locations where personnel or equipment might be struck by flying vent closures, tethering of the vent closure or other safety measures is recommended.

9-4.4 "Weak" Roof or Wall Construction. All or a portion of a roof or wall can be designed to fail under slight pressure. In this type of vent closure, suitable lightweight panels can be used.

9-4.5 Large Area Panels. Large area panels may be single layer or multiple layers (insulated sandwich panel). The following text and figures (Section 9-5) refer to tests carried out on metal-faced panels (Reference 26). Alternate methods for other types of panels will require careful engineering design and, preferably, testing of a complete assembly.

9-5 Restraints for Large Area Panels.

9-5.1 Where large, lightweight panels are used as vent closures (usually over entire wall areas), it is usually necessary to tether the vent closures so 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 features of the system include a 2-in. (5-cm) wide, 10-gauge bar washer. The length of the bar is equal to the panel width, less 2 in. (5 cm) and less any overlap between panels. The bar washer/vent panel assembly is secured to the building structural frame using at least three 3/8-in. (10-mm) diameter through-bolts.

9-5.1.1 Precautionary Measures for Aluminum Vent Panels. In tests of 21 gauge corrugated aluminum panels, a tendency for the panels to tear out in the vicinity of the through-bolts (*see Figure 9-5.1*) has been observed. This can be controlled by maintaining at least 3 in. (7.6 cm) distance between the edge of the panel and the bar washer and by hinging the panels to the lowest building structural member. This limits the amount of rotation that can occur, thus reducing the chance of tear-out.

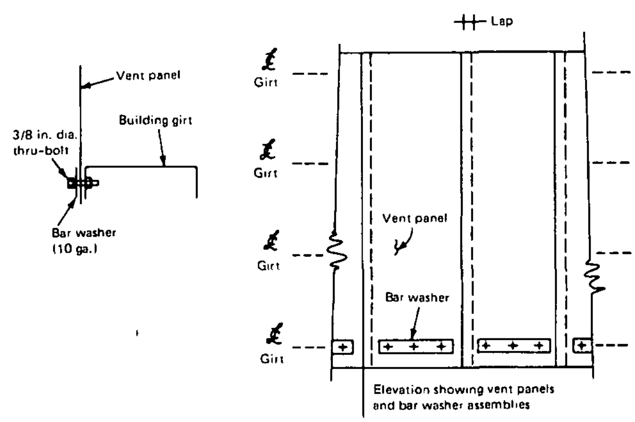


Figure 9-5.1 An example of a restraint system for single-wall metal vent panels.

9-5.2 When the vent closure panel is a double-wall type (such as insulated sandwich panels), the restraint system shown in 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 will occur more slowly, and rotation of the panel can be incomplete. Both factors will tend to delay or impede venting during a deflagration.

The restraint system shown in Figure 9-5.2 is recommended for double-wall panels. For successful functioning, the panel area is limited to 33 ft^2 (3.1 m^2) and its mass to 2.5 lb/ft^2 (12.2 kg/m^2).

9-5.2.1 Tests employing fewer than 3 rope clips have in some instances resulted in slippage of the tether through the rope clips, thus permitting the panel to become a free projectile.

9-5.2.2 Forged eyebolts are necessary. Alternatively, a 0.5-in. (1.3-cm) "U" bolt can be substituted for the forged eyebolt.

9-5.2.3 A "shock absorber" device with a fail-safe tether is provided. The shock absorber is a 4-in. (10-cm) wide, $^{3}/_{16}$-in. (0.48-cm) thick, L-shaped piece of steel plate to which the tether is attached. During venting, the shock absorber will form 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 this leg provides additional distance and time over which the panel is decelerated while simultaneously dissipating some of the panel's kinetic energy.

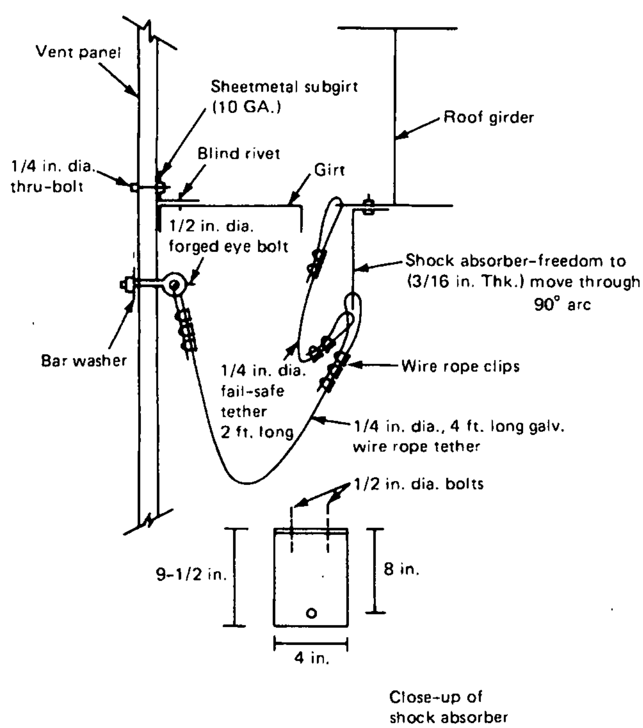


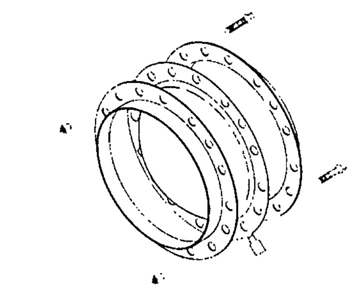
Figure 9-5.2 Example of a restraint system for double-wall insulated metal vent panel.

9-6 Equipment Vent Closures.

9-6.1 Hinged Devices. 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 held shut with spring, magnetic, or friction latches are most frequently used for this form of protection. 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.

9-6.2 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.*)



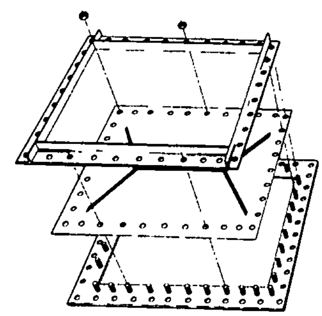


Figure 9-6.2 Typical rupture diaphragm.

9-6.2.2 Opening Characteristics. Some materials 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 having high rates of pressure rise can cause extensive damage to equipment. For these reasons, only rupture diaphragms with controlled opening patterns that ensure full opening on initial rupture should be utilized.

Chapter 10 Inspection and Maintenance

10-1 General.

10-1.1 This chapter covers the inspection and maintenance procedures necessary to ensure 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.

10-1.3 Inspection and maintenance should only be performed by persons experienced and knowledgeable in the installation and operation of the vent closure used.

10-2 Definitions. For the purpose of this chapter, the following terms have the meanings shown.

Inspection. Visual verification that the vent closure is in place and able to function as intended. This is done by ensuring that the vent closure is properly installed, that it has not operated or been tampered with, and that there is no condition that might hinder its operation.

Maintenance. Preventive and remedial actions taken to ensure proper operation of vent closures.

10-3 Inspection Frequency and Procedures.

10-3.1 If required, acceptance inspections and tests should be conducted immediately after installation to establish that the vent closures have been installed according to manufacturers' specifications and accepted practices and that all operating mechanisms will function as intended.

10-3.2 Vent closures should be inspected on a regular basis. The frequency will depend on the environmental and service conditions to which the devices will be exposed. Process or occupancy changes that can introduce significant changes in condition, such as changes in the severity of corrosive conditions, increases in accumulation of deposits or debris, etc., can require more frequent inspection.

10-3.3 Inspections should also be conducted following any activity that could adversely affect the operation of a vent closure (for example, after hurricanes) or following maintenance turnarounds.

10-3.4 The recommendations of the manufacturer regarding inspection procedures and frequency should be followed.

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, access to and 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 could compromise the effectiveness of vent closures or create a hazard to personnel or equipment should be reported immediately and should receive corrective action.

10-4 Maintenance. Vent closures should receive appropriate preventive maintenance as recommended by the manufacturer.

10-5 Recordkeeping. A record should be maintained showing the date and the results of each inspection, and the date and description of each maintenance activity. The records of at least the last three inspections should be kept.

Appendix A Explanatory Material

A-2-4.1.1 At present there is no ASTM standard method for determining the minimum ignition energies of dusts (as there is for gases). Although several test methods for dusts have been developed by different companies and organizations, the test results may not be equivalent. Britton (Reference 93) (1992 Plant/Operation Progress) recently published a review of ignition energy test methods for dusts and gases that had been developed.

A-3-6.11(a) Data in Reference 41 show the effects of using 5-cm (2-in.) thick glass wool linings for propane deflagrations in a 5.2-m^3 test vessel equipped with a 1-m^2 vent for which P_{stat} = 24.5 kPa. The value of P_{red} was 34 kPa in the unlined vessel and 5.7 kPa (i.e., a reduction of 83 percent) when the glass wool lining was installed on 2 of the vessel interior walls.

(b) Data in Reference 33 illustrate the effects of a 7.6-cm (3-in.) thick mineral wool lining for natural gas deflagrations centrally ignited in a 22-m^3 test vessel equipped with a 1.1-m^2 vent for which P_{stat} = 8 kPa. The measured values of P_{red} were about 60 kPa in the unlined vessel and about 8 kPa (i.e., a reduction of 87 percent) when the lining was placed on the floor and 3 walls of the vessel.

(c) Similar dramatic reductions in P_{red} have been obtained in propane deflagration tests in a 64-m^3 enclosure using ceramic fiber blankets on 3 interior walls (Zalosh and Chaffee, 1990 and Tamanini and Chaffee, 1992).

(d) A detailed discussion of the role of acoustic flame instabilities in vented gas deflagrations can be found in Reference 39. 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 Reference 40, that are not influenced by enclosure wall linings can have a greater influence on P_{red} in other situations.

A-4-3.1 Numerous methods have been proposed for calculating the vent closure area (References 19 through 23). Some venting models use the surface area of the enclosure as a basis for determining vent area. Analysis of available data (References 26 through 41) shows that such methods overcome certain deficiencies of previous methods of calculating vent area.

A-5-2.9 Example of calculation of reaction force during venting, for the following conditions:

A_v = 1 m^2 = 1550 in.^{2}

P_{red} = 1 bar gauge = 14.5 psig

then F_r = (1550)(14.5)(1.2) = 26,970 lb.

Example of calculation of duration of thrust force resulting from venting of a dust deflagration, for the following conditions:

K_{St} = 160 bar m/sec

V = 20 m^3

P_{red} = 0.4 bar gauge

A_v = 1.4 m^2

t_F = (0.002)(sec^2)(160)($20^{1/3}$)/(0.4)(1.4)

t_F = (0.002)(sec^2)(160)(2.71)/(0.4)(1.4)

t_F = 1.6 sec.

A-6-1.1.1 Example of calculation of vent area for hydrogen venting, for the following conditions:

$V = 30\ m^3$

$P_{stat} = 0.2$ bar gauge

$P_{red} = 1.5$ bar gauge

(Fig. 6-2(d) shows vent area = 3 m^2).

$$A_v = \frac{(0.279)\ (30^{0.680})\ (2.718^{(0.755)\ (0.2)})}{(1.5^{-0.393})}$$

$$= (0.279)(10.1)(2.718^{0.151})(1/1.5^{+0.393})$$
$$= (0.279)(10.1)(1.16)(1/1.17)$$
$$= (0.279)(10.1)(1.16)(0.855)$$
$$A_v = 2.79\ m^2.$$

A-6-7.2 Test data from Reference 55 served as the basis for correlating pressures developed during venting as a function of the elevated initial absolute pressure at the time of ignition. From these data in Reference 22, the power exponent from propane varies from about 1.2 for larger vent ratios ($A_v/V^{2/3} = 0.3$) to about 1.5 for smaller vent ratios ($A_v/V^{2/3} = 0.1$). For hydrogen, the exponent ranges from 1.1 to 1.2. In the above equation A_v = vent area, m^2; and V = enclosure volume, m^3. Reference 57 and Reference 75 support the exponent value of 1.5 for propane.

Appendix B Guidelines for Deflagration Indices of Dusts and Gases

B-1 General Comments. ASTM E 1226, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts,* has been adopted by ASTM (American Society for Testing and Materials) (Reference 92). This appendix discusses how the test procedure relates to venting of large enclosures, but the test procedure is not described in detail. Since gases are not addressed in ASTM E 1226, test procedures are discussed in this appendix.

At present there is no ASTM standard method for determining the minimum ignition energies of dusts (as there is for gases). Although several test methods for dusts have been developed by different companies and organizations, the test results may not be equivalent. Britton (1992 P/OP) recently published a review of ignition energy test methods for dusts and gases that had been developed.

B-1-1 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 test work.

B-2 Basic Principles. The nomographs presented in this guide and those in VDI 3673 (Reference 62) are based on large-scale tests carried out in vented vessels using a variety of test materials and vessel sizes (References 3, 43). 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}). Use of the nomographs requires only that a single material classification (the K_G or K_{St} index) be experimentally obtained by the user. Knowing the volume and mechanical constraints of the enclosure to be protected, the user can then determine the venting requirements from the nomographs.

B-2-1 The K_G and K_{St} Indices. The test dusts used during the large-scale test work were classified according to the maximum rate of pressure rise that was recorded when each was deflagrated in a 1-m^3 closed test vessel. The maximum rate of pressure rise found in this 1-m^3 vessel was designated "K_{St}." K_{St} is not a fundamental material property, but depends on the conditions of the test. The classification work carried out in the 1-m^3 vessel provides the only direct link between small-scale closed vessel tests and the large-scale vented tests on which the nomographs are based.

The K_G index may similarly be determined in a 1-m^3 vessel, but published K_G values correspond to tests made in smaller vessels. K_G is known to be volume-dependent and should not be considered a constant. Its use is restricted to *normalizing* $(dP/dt)_{max}$ *data gathered under a fixed set of* test conditions.

B-2-2 Standardization of a Test Facility. The objective of standardization is to be able to compare the deflagration behavior of a particular material with others for which full-scale test data are available. Without access to the 1-m^3 vessel in which the original K_{St} classifications were made, it is essential to standardize the test conditions employed using samples tested either in the 1-m^3 vessel or in one standardized against it. ASTM defines the standardization requirements for dusts. The nomographs identify a series of gas mixtures that were used in the full-scale tests. In order to calibrate for gases, the actual K_G values are not critical. This is because one may compare the maximum rate of *pressure rise of a particular gas mixture with that of the* gas mixtures identified in the nomographs. If these $(dP/dt)_{max}$ values are all measured under identical conditions in a vessel meeting certain criteria (Section B-3), the nomographs may be used by interpolation. In order to calibrate for dusts, which cannot be identified by composition alone, it is necessary to obtain samples having established K_{St} values (Section B-4).

B-2-3 Determination of the K_G and K_{St} Indices. If the maximum rate of pressure rise is measured in a vessel of volume other than 1-m^3, the following relationship is used to normalize the value obtained to a 1-m^3 vessel.

$$(dP/dt)_{max}\ (V^{1/3}) = K \qquad (27)$$

Where

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

The measured maximum deflagration pressure, P_{max}, is not scaled for volume and the experimental value is adequate for design purposes. The maximum rate of pressure rise is normalized to a volume of 1 m^3 using the above equation. If the maximum rate of pressure rise is given in units of singular bar/sec and the test volume in units of m^3, the equation defines the K_G or K_{St} index for the test material.

Example: The volume of a spherical test vessel is 26 L (0.026 m^3) and the maximum rate of pressure rise, $(dP/dt)_{max}$, found from the slope of the pressure/time curve is 8300 psi/sec (572 bar/sec). Substituting these values in the equation above, the normalized index is equal to 572 $(0.026)^{1/3}$, or 169 bar m/sec.

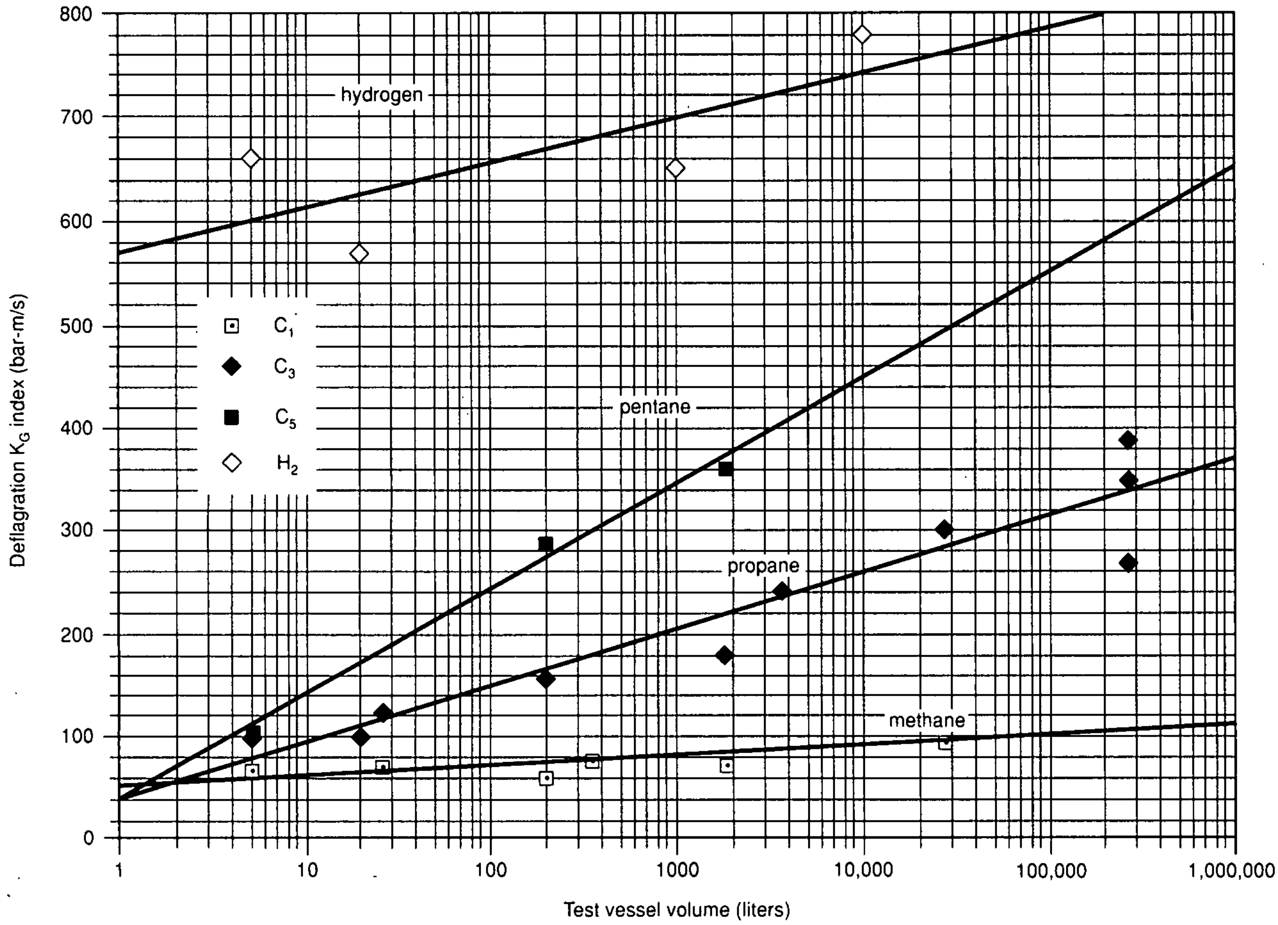


Figure B-1 Effect of test volume on K_G measured in spherical vessels.

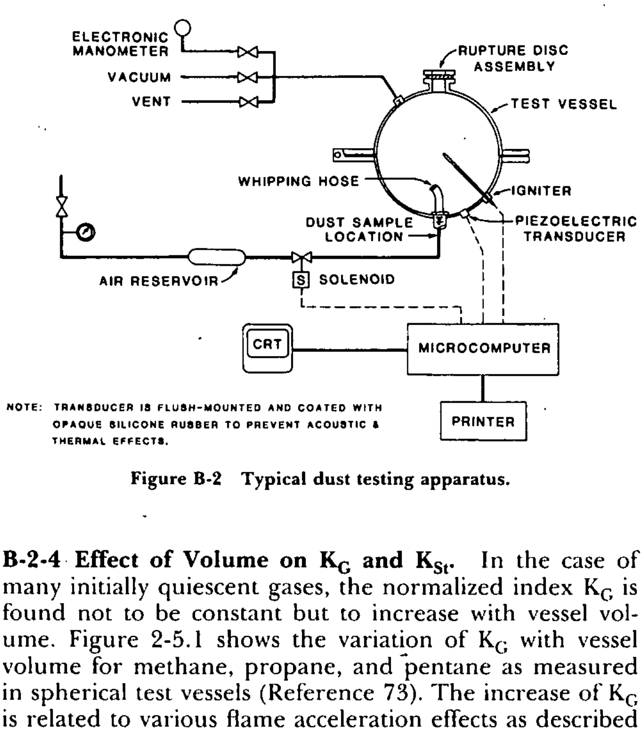


Figure B-2 Typical dust testing apparatus.

B-2-4 Effect of Volume on K_G and K_{St}. In the case of many initially quiescent gases, the normalized index K_G is found not to be constant but to increase with vessel volume. Figure 2-5.1 shows the variation of K_G with vessel volume for methane, propane, and pentane as measured in spherical test vessels (Reference 73). The increase of K_G is related to various flame acceleration effects as described in References 40, 74, and 75. It is for this reason that K_G values measured in vessels of different sizes cannot be directly compared, even if all other factors affecting K_G are held constant. Any K_G measurement should be made in a spherical vessel at least 5 L in volume and the values obtained should be used only to interpolate between the venting requirements of gases identified in the nomographs (Section B-3).

The effect of vessel volume alone on K_{St} values obtained for particular dusts has not been well established. Dusts cannot be suspended in a quiescent manner and the initial turbulence introduces a nonscaleable variable. However, it cannot be assumed that K_{St} in the equation in B-2-3 is independent of vessel volume. It has been found (Reference 43) that K_{St} values obtained in the original 1-m^3 classifying vessel cannot be reproduced in spherical vessels of less than 16 L volume nor in the cylindrical Hartmann apparatus. All existing facilities that have standardized equipment use a spherical test vessel of at least 20 L volume or a squat cylinder of larger volume (such as the 1-m^3 classifying vessel itself). The principle of K_{St} standardization in such vessels is to adjust test conditions (particularly initial turbulence) until it can be demonstrated that a series of dusts all yield K_{St} values in acceptable agreement with the values that have been established in the 1-m^3 vessel (Reference 92). If vessels of volume other than 1 m^3 are used, the equation in B-2-3 has to be used. This may lead to errors that are dependent on K_{St}. Such errors should be considered when applying test data to vent design (Reference 73).

B-2-5 Effect of Initial Pressure. The initial pressure for deflagration testing is one standard atmosphere (14.7 psia, 760 mm, Hg or 1.01 bar). Alternatively, a standard pressure of 1 bar could be used with negligible error. If initial pressures are not of standard value, they have to be reported and correction methods applied. P_{max} is proportional to initial test pressure and any difference between initial test pressure and one standard atmosphere will be multiplied by the deflagration pressure ratio (usually between 7 and 12) in the measured P_{max} value. Measured $(dP/dt)_{max}$ values will be 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 12.9 to 15.6 psia (0.89 to 1.08 bar), even at sea level, and decreases with elevation. For example, at an elevation of 2 km (1.25 miles), the average pressure in latitude 50°N is 11.5 psia (0.79 bar). It is readily seen that a P_{max} value measured at such an elevation would be about 20 percent lower than would be measured at one standard atmosphere, assuming a 10:1 deflagration pressure ratio. It is always preferable to conduct tests under standard conditions rather than to correct the measured values.

B-3 Gas Testing. The test vessel used for gas testing should be spherical with a volume of at least 5 L and preferably 20 L or greater. Since the only source of initial turbulence is the ignition source employed, an important consideration is that the flame front not be unduly distorted by the ignition process. The ignition source should be centrally placed 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 and chemical igniters may cause multipoint ignition and should not be used for routine K_G measurements in small vessels.

Standardization gas mixtures, as identified in the nomographs, must be initially tested in the system. Each gas mixture has to be verified to be well mixed and quiescent immediately prior to ignition. The maximum rates of pressure rise are measured systematically for several compositions close to the stoichiometric mixture until the maximum K_G value has been found. A table of K_G values is then established for the standardization gases as measured in the test vessel. These values will not necessarily be the same as the K_G values given in the gas nomographs (*see B-2-4*).

In order to subsequently apply the nomographs to a test gas, the maximum K_G value for the test gas has to first be found under identical conditions to those used for standardization. The test material is compared with standardization gases having K_G values above and below the test value as measured in the test vessel and the vent requirements are then found by interpolation between the requirements for the standardization gases.

A data base should be established for the test equipment in which K_G values are given for a wide variety of gases tested under the standardized conditions. K_G values should not be reported unless this data base, or at a minimum the K_G values found for the standardization gases, are also reported.

Most combustible gas mixtures at the optimum concentration may be conveniently ignited in small vessels using a capacitor spark of 100 mJ or less and this might be a normal ignition source for standardization. However, the ignition requirements for certain exceptional gas mixtures may greatly exceed this figure. Before a gas mixture is designated as noncombustible, it should be subjected to a strong ignition source (*Section B-5*).

Although the nomographs deal with deflagrations of gases in air, it may be necessary to predict the effect of other oxidants such as chlorine. It is recommended that the K_G concept not be extended to such cases except where considerable expertise can be demonstrated by the test facility. Many gaseous mixtures will be incompatible with the material of the test vessel and with trace contaminants within it, including traces of humidity. Expert opinion should be sought in applying such test data to the protection of large enclosures.

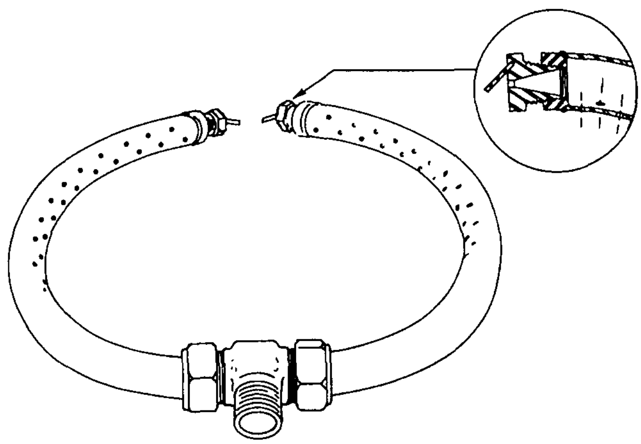


Figure B-3 Perforated ring dispersion system.

B-3-1 The composition limits for the coke gas used to develop the gas nomographs were:

45-55%	Hydrogen
6-10%	Carbon Monoxide
25-33%	Methane
4.6%	Nitrogen
0.1%	Carbon Dioxide
2-3%	Unspecified Hydrocarbons

There are no available data to indicate whether K_G varies significantly within these limits.

B-4 Dust Testing. Dust samples having the same chemical composition will not necessarily display similar K_{St} values or even similar deflagration pressures (P_{max}). The burning rate of a dust depends markedly on the particle size distribution and shape, and on other factors such as surface oxidation (aging) and moisture content. The form in which a dust is tested must bear a direct relation to the form of that dust in the enclosure to be protected. Owing to the physical factors influencing the deflagration properties of dusts, the nomographs do not identify the dusts involved in large-scale testing except by their measured K_{St} values. Although Appendix D of this guide gives both K_{St} and dust identities for samples tested in a 1-m^3 vessel, it must not be assumed that other samples of the same dusts will yield the same K_{St} values. These data cannot be used for vessel standardization, but are useful in determining trends. The test vessel to be used for routine work must be standardized using dust samples whose K_{St} and P_{max} characteristics have been established in the standard 1-m^3 chamber (Reference 92).

B-4-1 Obtaining Samples for Standardization. Samples should be obtained having established K_{St} values in Dust Classes St-1, St-2, and St-3. At the time of the writing of this guide, suitable standard samples (with the exception of lycopodium dust) were not generally available. ASTM E1226 defines the agreement required with values generated in the standard 1-m^3 chamber.

B-4-2 Effect of Dust Testing Variables. For a particular spherical test vessel (20 L or greater) and a particular prepared dust sample, the following factors affect the measured K_{St}:

(a) the mass of sample dispersed, or concentration;
(b) the uniformity of the dispersion;
(c) the turbulence at ignition;
(d) the ignition strength.

The concentration is not subject to standardization since this must be varied for each sample tested until the maximum K_{St} has been found. The maximum K_{St} usually corresponds to a concentration several times greater than stoichiometric. ASTM E1226 recommends a series of concentrations to test. A plot of measured K_{St} is made against concentration, and tests are continued until the maximum has been found. By testing progressively leaner mixtures, the minimum explosive concentration (lean limit or LFL) may similarly be determined. This limit may be affected by ignition energy.

B-4-2.1 Obtaining a Uniform Dust Dispersion. The uniformity of dust dispersion is implied by the ability to achieve consistent and reproducible K_{St} values in acceptable agreement with the established values for the samples tested. Poor dispersion will lead to low values of K_{St} and P_{max}.

A number of dust dispersion methods exist. For small vessels, the most common types are the perforated ring and the "whipping hose." The perforated ring (Reference 92, ASTM E1226, Appendix X.1) 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 Reference 43 in relation to the dust classifying work in the 1-m^3 vessel. However, a possible problem with this device is clogging 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 (Reference 73) has been used. 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 (Reference 73) indicates that they may not be interchangeable and the dispersion method should be subject to standardization.

B-4-2.2 Standardizing Turbulence at Ignition. During dust injection, the partially evacuated test vessel receives a pulse of air from the air bomb which brings the pressure to 1 atmosphere (absolute) and disperses dust placed below the dispersion system. Some time after the end of injection, the igniter is fired. The following test variables affect turbulence at ignition in the test vessel:

(a) air bomb volume;
(b) air bomb pressure;
(c) initial vessel pressure;
(d) injection time;
(e) ignition delay time.

References 73 and 76 describe combinations of these variables that have yielded satisfactory results. For example, a 26-L test vessel (Reference 73) employed a 1-L air bomb at 300 psia (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 atmosphere absolute. It should be noted that the air bomb and test vessel pressures need not equalize during dust dispersion. Injection time and ignition delay time are set using solenoid valves operated by a suitable timing circuit. For standardization, reproducibility of timing is essential and it may be found that the optimum ignition delay time is in the order of 10 milliseconds. Fast-acting valves and accurate timing devices should be employed.

Standardization using well-characterized samples (*see B-4-1*) is complete when samples in dust classes St-1, St-2, and St-3 have been shown to yield the expected K_{St} (to within acceptable error) with no adjustment of the variables listed in this section. Also, the mode of ignition (*see B-4-2.3*) should not be changed for standardized testing.

B-4-2.3 Ignition Source. The ignition source may affect the K_{St} values obtained even if all other variable are held constant. It has been found (Reference 43) that in a 1-m^3 vessel, capacitor discharge sources of between 40 mJ and 16 J gave comparable K_{St} and P_{max} data to those obtained using a 10-kJ chemical igniter. In the same vessel, a permanent spark gap underrated both K_{St} and P_{max} for a range of samples. In References 73 and 77, it is described how comparable K_{St} and P_{max} values were obtained in vessels of approximately 20 L using between 1 and 6 centrally placed electric match igniters each rated at 138 J.

Various types of electrically initiated chemical ignition source devices have proven satisfactory during routine test work, the most popular being two 138-J electric match igniters or two 5-kJ pyrotechnic devices. These ignition sources are not interchangeable and standardization must be based on a fixed type of igniter. The matches have insufficient power to ignite all combustible dust suspensions. For this reason, any dust appearing to be St-0 should be retested using two 5-kJ pyrotechnic igniters (*see Section B-5*). The routine use of the pyrotechnic igniter as a standardized source requires a method of correction for its inherent pressure effects in small vessels (Reference 73). Therefore, neither source is ideal for all applications.

B-4-3 Dust Preparation for K_{St} Testing. A dust has to be tested in a form that bears a direct relation to its form in any enclosure to be protected (*see Section B-4*). Only standardization dusts and samples taken from such enclosures are normally tested in the "as-received" state. The following factors affect the K_{St}:

(a) size distribution;
(b) particle shape;
(c) contaminants (gas or solid).

Although dusts may be produced in a coarse state, attrition can generate "fines." Fines may accumulate in cyclones and baghouses, on surfaces, and in the void space when filling large enclosures. For routine testing, it is assumed that such fines may be represented by a sample screened to sub-200 mesh (75 μm). For comprehensive testing, cascade screening into narrow-size fractions of constant weight allows K_{St} to be found for a series of average diameters. Samples taken from the enclosure help in determining representative and "worst-case" size fractions to be tested. If sufficient sample cannot be obtained as sub-200 mesh, it may be necessary to grind the coarse material. This may possibly 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.

When considering fines accumulation, the accumulation of additives also has to be considered. Many dust-handling processes can accumulate additives such as antioxidants that are added as only a small fraction of the bulk. Such accumulation might affect K_{St} and, by reducing the ignition energy necessary to ignite the mixture, might increase the probability of a deflagration (Reference 73).

Combustible gases might be present in admixtures with dusts (hybrid mixtures) and many accumulate with time owing to gas desorption from the solid phase. Where this possibility exists, both K_{St} and ignition energy might be affected. The effect of hybrid mixtures can be synergistic to the deflagration and a gas present at only a fraction of its lower flammable limit has to be considered (Reference 3). Testing of hybrid mixtures can be carried out by injecting the gas-plus-dust mixture into an identical gas mixture already present in the test vessel. The gas concentration (determined on the basis of partial pressure at the time of ignition) should be systematically varied to determine the range of hybrid K_{St} values that might apply to the practical system.

The use of a whipping hose (*see B-4-2.1*) should avoid the necessity of using inert flow-enhancing additives to help dust dispersion in most cases. The use of such additives in testing is not recommended.

B-5 Classification as "Noncombustible." A gas or dust mixture cannot be classed as noncombustible (for example, Dust Class St-0) 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 has to be established that the strong ignition source will not yield a pressure history in the vessel that might be confused with any deflagration produced by it.

It might not be possible in small vessels (for example, the 20-L vessel) to unequivocally determine whether a dust is noncombustible. This is 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 (Reference 93) have demonstrated the overdriving effect when determining minimum explosible dust concentrations. Apparently-explosible mixtures in a 20-L vessel would not propagate flame in a 1-m^3 vessel at the same concentration. These authors recommend use of 2.5-kJ igniter for lower flammable limit measurements which gave similar results to the 10-kJ igniter in a 1-m^3 vessel. The ideal solution is to use large (10-kJ) igniters in larger (1-m^3) vessels. They further recommend the ignition criterion of an absolute pressure ratio greater than 2 plus a K_{St} greater than 1.5 bar - m/sec.

An alternative to the use of the strong ignition source and its associated pressure effects in small vessels is to test finer-size fractions than the routine sub-200 mesh. Dust ignition energy varies with approximately the cube of particle diameter (Reference 73); hence, the use of electric matches may be extended to identification of St-0 dusts. Similarly, the dust lean limit concentration may be subject to ignition energy effects, which decrease with decreasing particle size of the sample. Such effects largely disappear when sub-400 mesh samples are tested. In the case of gases, a strong ignition source consisting of capacitance discharges in excess of 10 J or fused-wire sources of similar energy may be used. Such sources are routinely used for flammable limit determination.

B-6 Instrumentation Notes. Data may be gathered by analog or digital methods, but the rate at which this is done must be adequate for the purpose. The logging equipment should be capable of resolving a signal of 1 kH_Z or higher frequency (for digital methods, better than 1 data point per millisecond). For fast-burning dusts and gases, particularly in small vessels, faster rates of data logging may be required to resolve $(dP/dt)_{max}$. 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 (Reference 73). A further advantage of digital methods is that expansion of the time axis enables a more accurate measurement of slope of the pressure/time curve than can be obtained from an analog oscilloscope record. When using automated data reduction, it is essential to incorporate appropriate logic to obviate the effect of spurious electrical signals. Such signals may be reduced by judicious cable placement, grounding, and screening, but are difficult to avoid altogether. It is advantageous to manually confirm automated $(dP/dt)_{max}$ values using the pressure/time curve generated.

When making up gas mixtures by the method of partial pressures, it is important to incorporate a suitable gas temperature measuring device, e.g., a thermocouple, to ensure this is done at constant temperature. Gas analysis is preferable where such facilities exist.

It has been found that piezoelectric pressure transducers are satisfactory for deflagration pressure measurements in test systems of this kind owing to 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, it is advisable to prepare large quantities of well-characterized dust samples (Classes St-1, St-2, and St-3) of a type not subject to aging or other effects. When suitably stored, these dusts may be used for periodic system performance tests.

Appendix C Fundamental Burning Velocities for Selected Combustible Gases in Air

The values of fundamental burning velocity given in Table C-1 are based on NACA Report 1300 (Reference 78). 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 Engineer's Handbook (Reference 79) 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 gain closer agreement with more recently published data.