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EXPLOSION VENTING 1978

NFPA

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Guide for
Explosion Venting

NFPA 68 — 1978

1978 Edition of NFPA 68

This document was prepared by the Committee on Explosion Protection Systems and this present edition was adopted by the Association on November 14, 1978 at its Fall Meeting in Montreal, Quebec, Canada. It was released by the Standards Council for publication on December 4, 1978.

Origin and Development of NFPA 68

The Guide for Explosion Venting was first adopted as a temporary standard in 1945. In 1954, the temporary standard was replaced with a guide which 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 which have been 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 not been done to add to the information already known. However, work carried on in Great Britain and Germany has paved the way to a method for designing vents. The U. S. Bureau of Mines has also done some work in this direction. 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." This 1978 revision adds considerable data which should prove to be even more valuable in designing explosion relief vents.

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Guide for

Explosion Venting

NFPA 68-1978

Chapter 1 Introduction

1-1 Scope.

1-1.1 This guide provides useful information for the design and utilization of devices and systems to vent the gases resulting from deflagrations of dusts, gases, or mists in equipment, rooms, buildings, or other enclosures so as to minimize structural or mechanical damage.

1-1.2 This guide does not include venting devices designed to protect against overpressure of vessels containing liquids, liquefied gases, or compressed gases under fire exposure conditions, as now covered in existing NFPA standards.

1-1.3 This guide is not intended to be used for calculating venting or emergency relief for exothermic runaway reactions nor does it cover unconfined combustion such as free air explosions or outdoor vapor cloud explosions.

1-2 Purpose. This guide is intended to provide the user with the best available criteria for venting of deflagrations.

1-3 General.

1-3.1 Vents do not prevent the occurrence of a deflagration but are intended to limit the damage from the pressure excursion generated by the deflagration.

1-3.2 This guide applies to the deflagration of combustible dusts, gases, or mists when mixed with air during manufacturing operations and storage.

1-3.3 Typical examples of industrial equipment to which this guide applies include crushers, grinders, pulverizers, sieves, screens, bolters, dust collectors and arrestors, conveyors, screw feed conveyors, bucket elevators, driers, ovens and furnaces, spray driers, blenders, mixers, ducts, pipes, bins, silos, spreaders, coating machines, and packaging equipment.

1-3.4 This guide is not intended to cover explosion vents on equipment such as oil-insulated transformers and switchgear or excess pressure relief devices on tanks, pressure vessels, or domestic appliances in residences.

1-3.5 Explosion venting has not yet been reduced to an exact science. This guide only attempts to recommend what is thought to be the best available knowledge on the subject at this time.

1-4 Definitions. For the purposes of this guide, the following terms have the meanings shown below.

Autoignition Temperature. The ignition temperature of a substance, whether solid, liquid or gaseous, that is the minimum temperature required to initiate or cause self-sustained combustion independently of the heating or heated element. The ignition temperature of a solid is influenced by its physical condition and the rate of heating. Figures on ignition temperatures may vary, depending upon the test method, since the ignition temperature varies with the size, shape and material of the testing container, and other factors.

Blanketing. The technique of maintaining an atmosphere which is inert or enriched with a fuel above a liquid in a container or vessel. (*See Standard on Explosion Prevention Systems, NFPA 69–1978.*)

Combustible. Used synonymously with the term fuel, combustible means a gas or mist or dust capable of being burned. **Burning** can be described as the chemical reaction of a combustible and gaseous oxidant (normally the oxygen of air) with resultant production of a flame.

When a combustible is intimately mixed with an oxidant and ignited, burning in the form of deflagration or detonation may result.

Deflagration. Burning which takes place at a flame speed below the velocity of sound in the unburned medium.

Detonation. Burning which takes place at a flame speed above the velocity of sound in the unburned medium.

Dust (industrial). Any finely divided solid material 420 microns or smaller in diameter (material passing a U. S. No. 40 Standard Sieve).

Explosion. A bursting of a building or container as a result of development of internal pressure beyond the confinement capability of the building or container.

Fire Point. The lowest temperature of liquid in an open container at which vapors are evolved fast enough to support continuous combustion. It is determined by *Standard Method of Test for Flash and Fire Points by Cleveland Open Cup,* ASTM D92-1977.

Flame Speed or **Flame Velocity** is the speed at which the flame front progresses through the unburnt mixture.

Flammable Limits. In the case of most flammable liquids, gases, dusts, and mists, a minimum concentration of gas, dust, or mist in air, oxygen, or other oxidant below which propagation of flame does not occur on contact with a source of ignition. Usually, there is also a maximum concentration of gas in air, oxygen, or other oxidant above which propagation of flame does not occur. These limit mixtures of gas, dust, or mist with oxidant which, if ignited, will just propagate flame are known as "lower and upper flammable limits." In the case of gases, limits are usually expressed in terms of percentage by volume of gas in oxidant. In the case of dusts, limits are usually expressed in terms of ounces of dust per cubic foot of volume or mg/liter. The lower limit for dusts is a function of dust particle size. The upper limit for a dust usually cannot be well defined. The lower limit for mists is a function of mist particle size; the upper limit usually cannot be well defined.

Flammable Range. The concentration range lying between the lower and upper explosive or flammable limits.

Flash Point. The flash point of a liquid shall mean the minimum temperature at which it gives off vapor in sufficient concentration to form an ignitible mixture with air near the surface of the liquid within the vessel as specified by appropriate test procedure and apparatus as follows:

The flash point of a liquid having a viscosity less than 45 SUS[1] at 100°F (37.8°C) and a flash point below 200°F (93.4°C) shall be determined in accordance with the *Standard Method of Test for Flash Point by the Tag Closed Tester,* ASTM D56-75.[2]

The flash point of a liquid having a viscosity of 45 SUS or more at 100°F (37.8°C) or a flash point of 200°F (93.4°C) or higher shall be determined in accordance with the *Standard Method of Test for Flash Point by the Pensky-Martens Closed Tester,* ASTM D93-73.[2]

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[1]Saybolt Universal Seconds at 100°F (37.8°C). A viscosity of 45 SUS is about the viscosity of No. 4 Fuel Oil.

[2]Available from American Society for Testing and Materials, 1916 Race Street Philadelphia, PA 19103.

Fundamental Burning Velocity. The velocity of the gas normal to the flame front with which the unburnt mixture enters a flame and is chemically transformed. (This velocity is determined from laminar flow conditions in carefully controlled apparatus.)

Gas. In this guide, gas includes vapors.

Inert Gas. A gas which is noncombustible, nonreactive, and incapable of supporting combustion with the contents of the system being protected.

Inerting. The process of rendering a combustible mixture noncombustible through the addition of an inert gas.

Open Vent Pressure. The pressure developed by a deflagration in a container having an unobstructed vent.

Optimum Mixture. A mixture in which the combustible material and oxidant are in the proper proportion to give the most violent deflagration (that is to say, the deflagration with the highest maximum rate of pressure rise). Generally, this occurs at approximately the stoichiometric proportions.

Oxidant (oxidizing agent). Any material or substance that can react with a combustible to produce burning or combustion, or a similar exothermic reaction. Oxygen in air is the most common oxidant.

Padding. (*See Blanketing.*)

Purge Gas. A gas suitable for rendering an atmosphere noncombustible. It may be inert or combustible. Air can also be used as a purge gas.

Purging. The displacement of a gaseous oxidant or gaseous combustible by another gas to render the mixture noncombustible. The purge gas may or may not be an inert gas.

Rate of Pressure Rise. The amount of pressure rise during a particular interval of a deflagration. It is expressed as the ratio of the increase in pressure to the time interval (dP/dt) required for that increase of pressure to occur. The "average rate of pressure rise" is the ratio of the maximum pressure to the time interval from the initiation of the deflagration until the maximum pressure is reached, and the "maximum rate of pressure rise" (dPmax/dt) is computed from the slope of the steepest portion of the pressure-time curve during the development of the deflagration.

Explosion Suppression. A technique by which burning in a confined mixture is detected and arrested during incipient stages, preventing development of pressure which could result in an explosion.

Vapor. As specified in this guide, vapor means a gas.

Vent Ratio. The relationship of the area of the rupture diaphragms or relieving panels to the volume of the equipment or room subject to internal deflagration. Vent ratio may be expressed in terms of "square feet per 100 cubic feet" or as the reciprocal of the cubic feet of vented volume per square foot of vent.

Ventilation. The process of supplying or removing air, by natural or mechanical means, to or from any space.

General Ventilation. The removal of combustibles by moving air through the entire volume of space. (*See Appendix A, Part I, NFPA 69–1978.*)

Local Ventilation. The removal of combustibles from a small portion of a space and more particularly at the immediate vicinity of emission by withdrawing air from that small portion of the space. (*See Appendix A, Part I, NFPA 69–1978.*)

Chapter 2 Fundamentals of Combustion

2-1 Prerequisites for a Deflagration. Under the proper conditions, flammable and combustible gas, mist, and dust mixed with or suspended in air or other oxidant will burn when ignited. The following prerequisites are necessary for a deflagration to occur:

(a) fuel (mixed in the proper proportion with the atmosphere);

(b) air (oxygen) or other oxidant; and

(c) a source of ignition such as a flame, spark, heated surface, or glowing particle.

For an explosion to occur, in addition to all the above requirements, the combustion of a gas or dust must generate a pressure greater than the structural capability of the confining structure.

2-2 Factors Affecting an Explosion or Deflagration.

2-2.1 The development of a deflagration or an explosion depends upon certain conditions and factors. Those of principal concern are:

2-2.1.1 Fuel. The fuel may be a gas, mist, or dust or a combination (hybrid mixture) of these. Generally, gases burn more rapidly than mists or dusts.

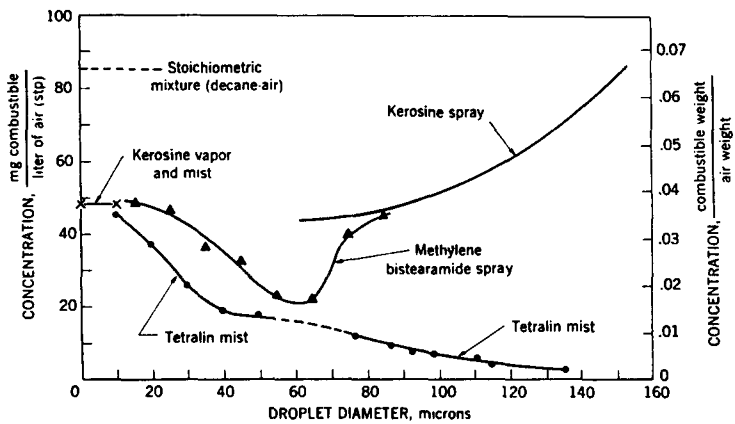


Figure 2-2.1.2(a). Variation in lower limits of flammability of various combustibles in air as a function of droplet diameter. (90)

2-2.1.2 Fuel Concentration. Most gaseous fuels have a lower and upper flammable limit; the concentration must be within these limits for a deflagration to occur. For dusts, the upper flammable limit is not well defined. [*See Figure 2-2.1.2(b).*] Some mists can be deflagrated when the temperature of the mist is such that the corresponding vapor pressure will produce a concentration less than the lower flammable limit. With fine mists and sprays, the combustible concentration at the lower limit is about the same as that in uniform vapor air mixtures. As the droplet diameter increases, the lower limit appears to decrease, as illustrated in Figure 2-2.1.2(a). In studying this problem, Burgoyne found that coarse droplets tend to fall towards the flame front in an upward propagating flame, and as a result the concentration at the flame front actually approaches the value found in lower limit mixtures of fine droplets and vapors.

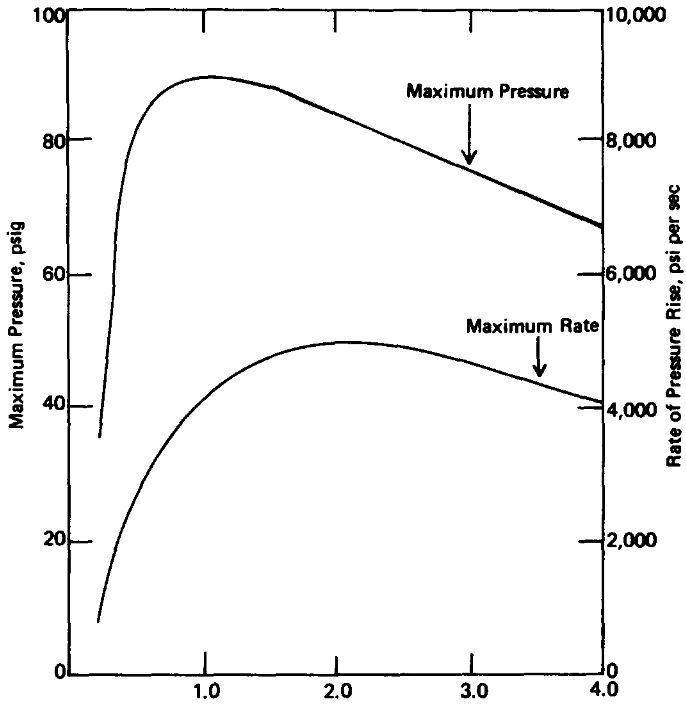


Figure 2-2.1.2(b). Maximum pressure and rate of pressure rise developed by deflagrations of zirconium dust in a 0.043 cu ft closed vessel. (40)

2-2.1.3 Oxidizer Concentration. The oxidizer is normally the oxygen present in the atmosphere. Oxygen concentrations higher than 21 percent intensify the reaction rate of combustion and increase the probability for transition into detonation. Less than 21 percent oxygen decreases the rate of reaction. (*See Figure 2-2.1.3.*)

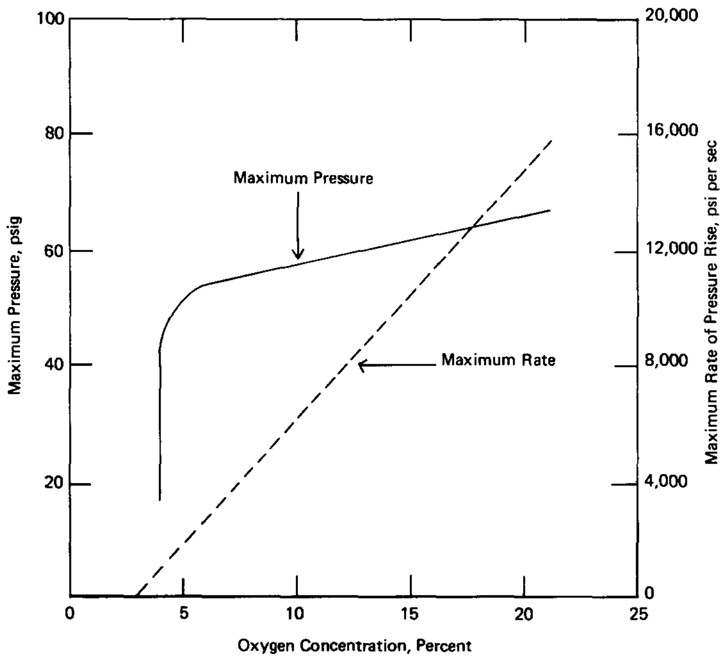


Figure 2-2.1.3. Effect of oxygen concentration on pressure and maximum rate of pressure rise of 0.5 oz per cu ft atomized aluminum deflagrations in a closed 0.043 cu ft vessel. (54)

2-2.1.4 Fundamental Burning Velocity and Flame Speed. The destructive forces of a deflagration increase with the pressure and velocity developed. The speed at which a fuel-oxidant mixture burns is dependent upon the fundamental burning velocity which is a characteristic of the fuel consumed and other factors. Fundamental burning velocities for most gases are on the order of 10 in. (25.4 cm) to 20 in. (50.8 cm) per second; values for dusts are generally lower. (*See Appendix A-4.2.*) Flame speed may be many times higher but never lower than the fundamental burning velocity.

Flame speed is most rapid and the highest pressures are obtained when the fuel concentration is optimum and uniformly distributed throughout the whole vessel or confinement. The primary difference between a dust and a gas is that burning time may be slightly longer for the dust.

Sometimes dusts produce explosions more disastrous than gases. This is due, in part, to the slower flame speed and, therefore, longer duration which results in greater total impulse during the burning process.

During the initial stages of most deflagrations, there is an induction or ignition-lag period attributed by some authorities to the initiation of a chain reaction. The time that elapses between the instant the mixture is raised to its ignition temperature and a visible flame appears is generally called the ignition-lag period.

2-2.1.5 Ignition Source. The rate of pressure development and the maximum pressure increase as the strength of the ignition source increases. (*See Figure 2-2.1.5.*) Location of the ignition source at the geometrical center of a confined fuel-oxidant mixture results in development of the highest pressure and rate of pressure rise.

Ignition can result from a hot surface, flame, or spark. In many cases the location of the ignition source cannot be predicted. Simultaneous multiple ignition sources may produce high initial turbulence. An ignition may occur within one piece of equipment and be conveyed by a connecting duct to a second piece of equipment. The flame from the duct may enter the second piece of equipment in a highly turbulent state. This presents a large ignition source in the second vessel resulting in more severe combustion than normally would occur from a small ignition source. The ignition source in the case of dusts may produce a cloud. (*See nomographs, Appendix A, for effect of ignition energy.*)

In order to ignite a gas or dust, a minimum amount of energy must be available. Minimum energy required for ignition of some materials is listed in Table 2-2.1.5. Data listed in the table were obtained with dusts which passed through No. 200 U.S. Standard Sieve. These values are only intended as a guide and should not be construed as absolute.

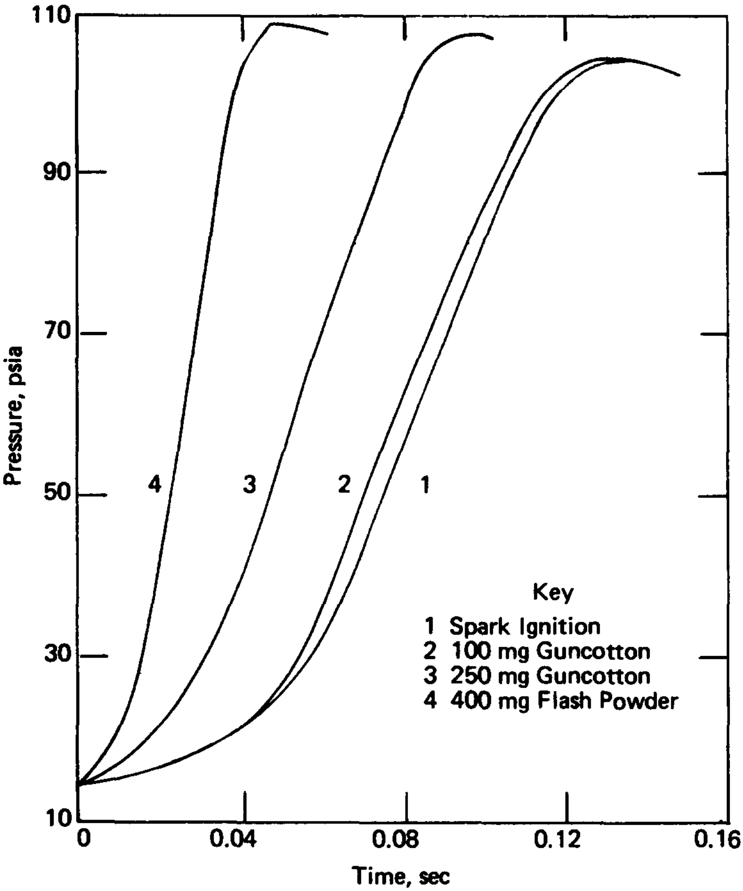


Figure 2-2.1.5. Effect of ignition source on the development of deflagrations of 9.4 percent methane-air mixtures in a closed 1 cu ft vessel. (57)

NOTE: The tabulated data were determined by capacitive spark discharge wherein the energy of ignition is calculated by the expression: $E = 1/2\ CV^2$. However recent experiments (Reference 91) indicate that the values for dusts may be in error by at least one order of magnitude. In fact, the minimum ignition energies for dusts may be quite comparable to those for vapors.

Table 2-2.1.5 Minimum Energy for Ignition (29, 50)

Material	Energy, millijoule
Mixtures with Air	
Agricultural:	
Alfalfa	320
Cinnamon	30–40
Cocoa	100
Cornstarch	30–40
Lycopodium	25–40
Rice	40
Soybean	50
Sugar	30
Wheat flour	50
Carbonaceous:	
Asphalt	40
Carbon black (Spheron, grade 9)	180
Charcoal	20
Coal, Illinois	50
Coal, Kentucky	30
Coal, Pennsylvania	50
Coal, West Virginia	60
Gilsonite	25
Pitch	20
Chemicals: *	
Acetone	1.15
Acrolein	0.13
Acrylonitrile	0.16
Benzene	0.2
Carbon disulfide	0.009
Cyclohexane	0.22
Cyclopentadiene	0.67
Cyclopentane	0.54
Diethyl ether	0.19
Dihydropyran	0.36
Diisobutylene	0.96
Diisopropyl ether	1.14
2,2-Dimethylbutane (neohexane)	0.25
Dimethyl ether	0.29
2,2-Dimethylpropane (neopentane)	1.57
Diphenyl	20
Ethyl acetate	1.42
Ethylamine	2.4
Ethyleneimine	0.48
Fumaric acid	35
Furan	0.22
Heptane	0.24
Hexane	0.24

(con't)

Material	Energy, millijoule
Chemicals: (con't)	
Methanol	0.14
Methyl ethyl ketone	0.53
Methylbutane (isopentane)	0.25
Methylcyclohexane	0.27
i-Octane	1.35
i-Pentane	0.21
n-Pentane	0.22
2-Pentene	0.18
i-Propyl alcohol	0.65
i-Propylamine	2.0
i-Propyl chloride	1.55
n-Propyl chloride	1.08
Propylene oxide	0.13
i-Propyl mercaptan	0.53
Sorbic acid	15
Sulfur	15
Tetrahydrofuran	0.54
Tetrahydropyran	0.22
Thiophene	0.39
Triethylamine	0.75
2,3-Trimethylbutane	1.0
Vinyl acetate	0.7
Gases:	
Acetaldehyde	1.15
Acetylene	0.017–0.018
1,3-Butadiene*	0.13
Butane*	0.25
Cyclopropane*	0.17
Ethane*	0.24
Ethylene	0.07–0.08
Ethylene oxide*	0.06
Hydrogen	0.017–0.018
Hydrogen — Nitric oxide	8.7
Hydrogen sulfide*	0.068
Methane*	0.28
Methane — Nitric oxide	8.7
Methylacetylene*	0.11
Propane*	0.25
Propylene*	0.28
Vinylacetylene*	0.082
Metals:	
Aluminum	10–50
Boron	60
Iron	20
Magnesium	20–80
Manganese	80–320
Titanium	10–40
Uranium	45
Zinc	100
Zirconium	5

Material	Energy, millijoule
Plastics:	
Cellulose acetate	10–15
Methylmethacrylate	15–20
Nylon	20
Phenolic resin	10–25
Polycarbonate	25
Polyethylene	10–30
Polypropylene	25–30
Polystyrene	15
Polyurethane foam	15
Rayon	240
Urea formaldehyde	80
Admixtures with Oxygen	
Chemicals:	
Diethyl ether	0.0012
Diethyl ether with 86 vol. % nitrous oxide	0.0012
Gases:	
Acetylene	0.0002
Ethane	0.0019
Ethylene	0.0009
Hydrogen	0.0012
Methane	0.0027
Propane	0.0021

*Values from "Electrostatic Hazards, Their Evaluation & Control," Heinz Haase, Verlog Chemie, NY, 1977.

Other values from References 29 and 50.

2-2.1.6 Particle Size of Dusts. Experimental data show that a sufficient concentration of particles, passing a No. 40 U.S. Standard Sieve (420-micron) must be present for a dust deflagration.

2-2.1.6.1 The particle size of dust has little effect on maximum pressure, but the rate of pressure rise increases significantly with a decrease in particle size. (*See Figure 2-2.1.6.1.*)

2-2.1.6.2 A decrease in particle size lowers the minimum energy required to ignite dust clouds. (*See Figure 2-2.1.6.2.*)

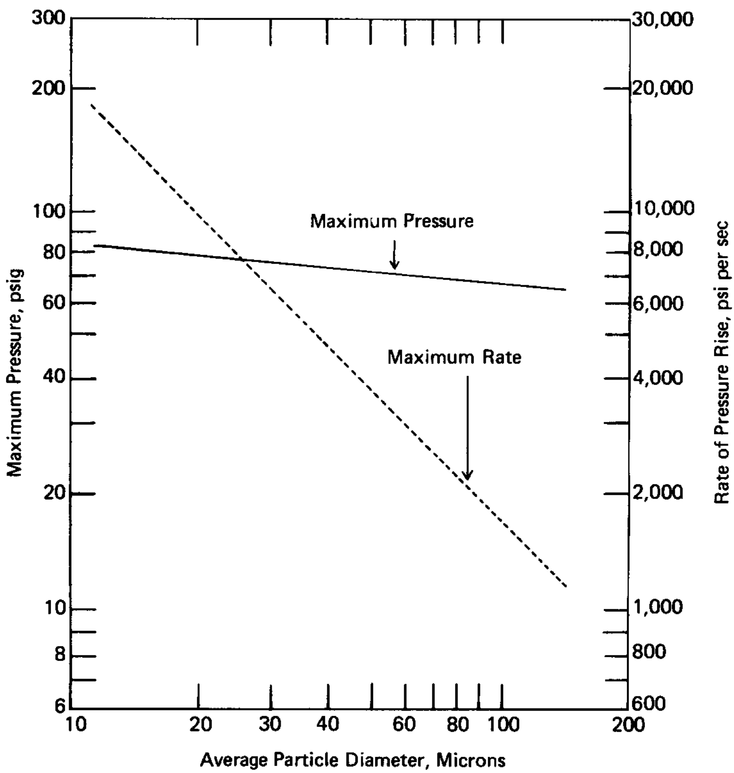


Figure 2-2.1.6.1. Effect of average particle diameter of atomized aluminum on maximum pressure and rate of pressure rise developed by deflagrations in a closed 0.043 cu ft vessel. (44)

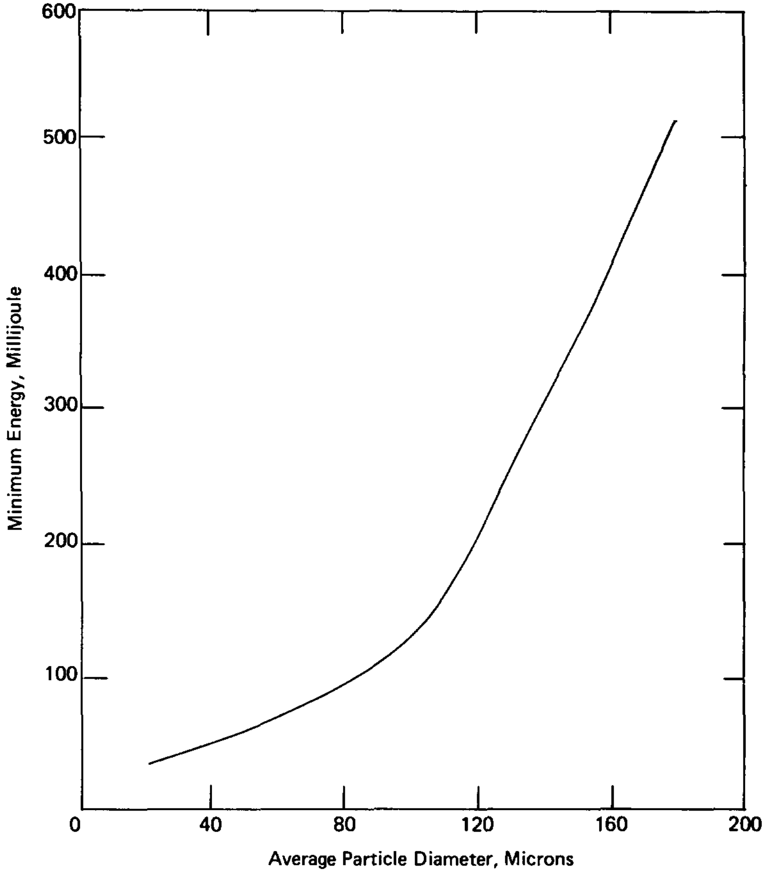


Figure 2-2.1.6.2. Effect of particle size on the minimum energy required to ignite dust clouds of cornstarch. (*Unpublished data, courtesy of U.S. Mine Safety and Health Administration.*)

2-2.1.7 Initial Temperature and Pressure of Mixture. A change in initial pressure (absolute) of the fuel-oxidant mixture produces a proportionate change in maximum pressure resulting from deflagration. A change in initial temperature (absolute) produces an inverse change in maximum pressure resulting from deflagration. (*See Figure 2-2.1.7.*)

Increase of temperature in most cases results in an increase in maximum rate of pressure rise.

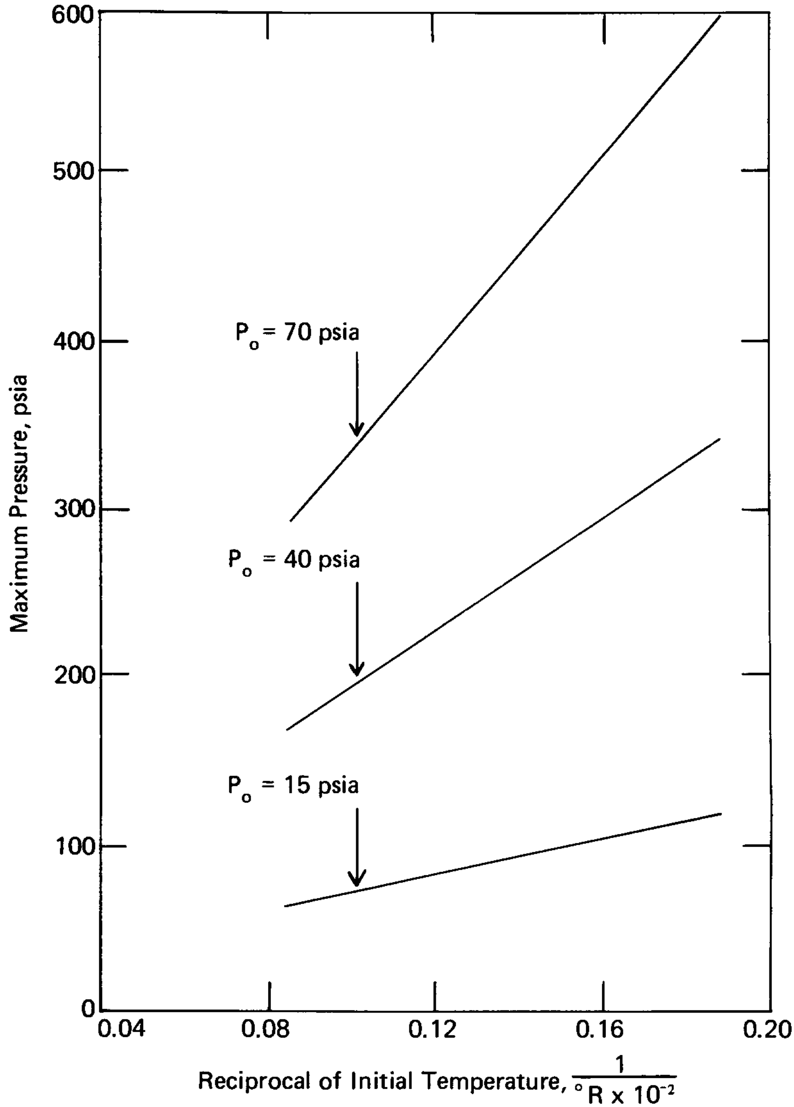


Figure 2-2.1.7. Effect of initial temperature on the maximum pressure developed in a closed vessel for deflagrations of 9.9 percent methane-air mixtures at several initial pressures. (27)

2-2.1.7.1 Theoretically and experimentally, it can be shown that at a given pressure an increase of temperature in most cases results in a decrease in maximum explosion pressure. This is because a decrease in moles results in a corresponding decrease in the pressure generated from the combustion.

2-2.1.7.2 However, as a practical matter, an increase in temperature generally causes an increase in the final pressure because, under confinement, the initial pressure will increase as the temperature increases. Furthermore, a decrease in the generated pressure (even in the rather hypothetical case of temperature increase at a given pressure) approximately offsets the increase in flame speed.

2-2.1.8 Turbulence. Initial turbulence slightly increases

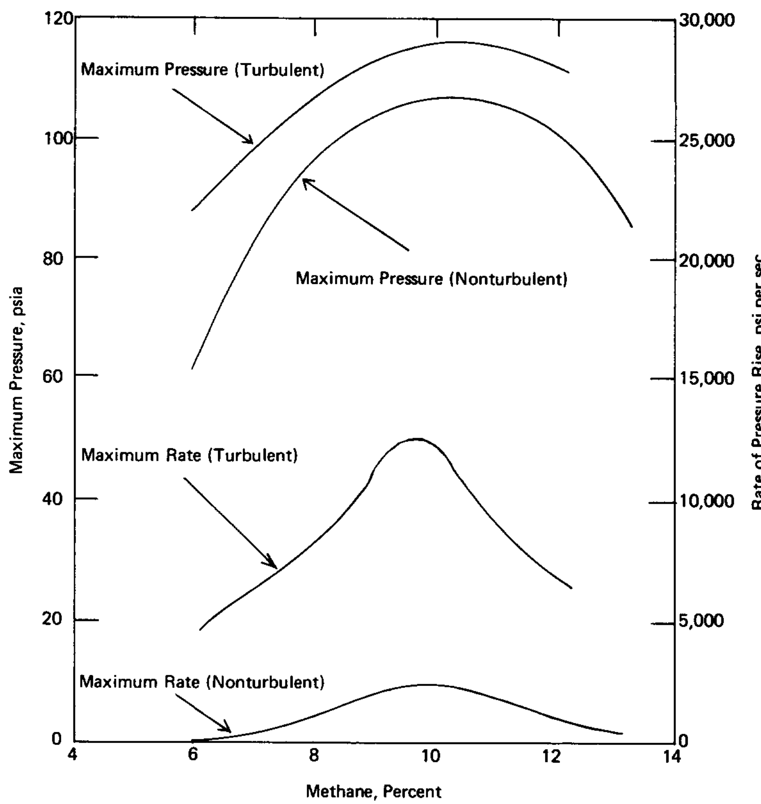


Figure 2-2.1.8. Maximum pressure and rate of pressure rise for turbulent and nonturbulent methane-air mixtures in a 1 cu ft closed vessel. (57)

the maximum pressure, while the rate of pressure rise is markedly increased. (*See Figure 2-2.1.8.*) Turbulent mixing of dusts with the oxidizing medium enhances diffusion of the oxidizer to the reacting surfaces and promotes the rate of oxidation of the dust. (*See Appendix A.*)

2-2.1.9 Presence of Admixed Moisture or Inert Dilutents. Moisture or inert materials in sufficient quantity will quench a dust deflagration partly through absorption of heat and radiant energy and partly by hindering diffusion of oxygen and gases into and from the burning fuel. Moisture in dust particles raises the ignition temperature of the dust because of the heat absorbed during heating and vaporization of the moisture. The moisture in the air surrounding a dust particle has no significant effect on the course of a deflagration once ignition has occurred. There is, however, a direct relationship between moisture content and minimum energy required for ignition, minimum explosive concentration, maximum pressure, and maximum rate of pressure rise. For example, the ignition temperature of cornstarch may increase as much as 122°F (50°C) with an increase of moisture content from 1.6 percent to 12.5 percent. As a practical matter, however, moisture cannot be considered an effective ignition preventive since most ignition sources provide more than enough heat to vaporize the moisture and to ignite the dust. In order for moisture to prevent ignition of a dust by common sources, the dust would have to be so damp that a cloud could not be formed. Factors affecting inerting requirements for deflagrations are type of fuel and its concentration, strength of the igniting source, ignition temperature of mixture, composition of the substance used for inerting, and the particle size with respect to dust. The effect of admixed moisture and inert dust on the lower flammability limit of several dusts are shown in Figure 2-2.1.9(a).

The effect of moisture on pressures and rates of pressure rise for cornstarch deflagrations are shown in Figure 2-2.1.9(b).

For most flammable gases, the addition of water vapor to the gas-air mixtures affects combustion properties much as does the addition of an inert diluent like nitrogen. Some gases are exceptions. Bone-dry carbon monoxide burns relatively slowly in bone-dry air. Addition of a little water vapor results in appreciably faster burning.

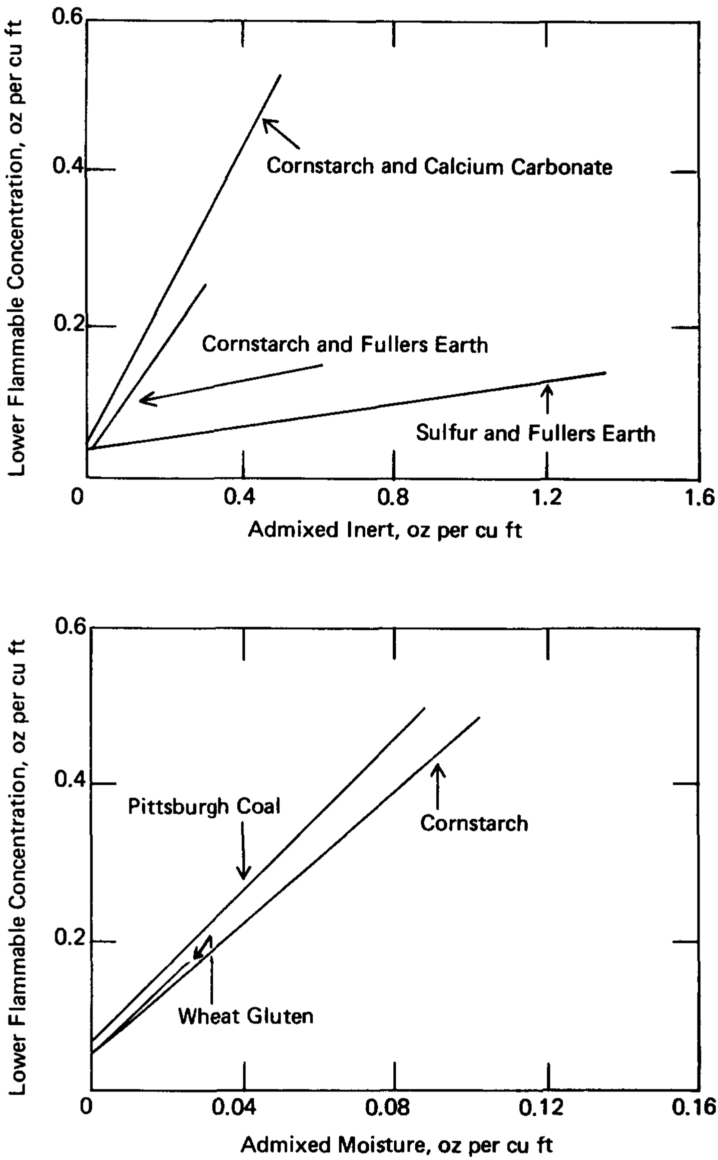


Figure 2-2.1.9(a). Effect of admixed inert powder and moisture on the lower flammable concentration of various dusts. (55)

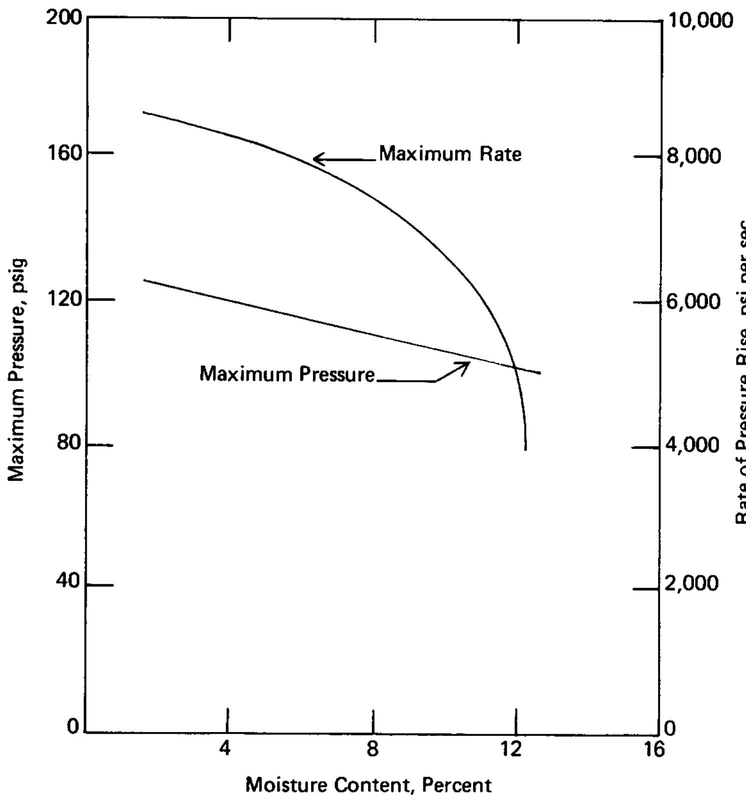


Figure 2-2.1.9(b). Effect of moisture on pressures and rates of pressure rise developed by 0.5 oz per cu ft of cornstarch deflagrations in a closed 0.043 cu ft vessel. (34)

2-2.1.10 Hybrid Mixtures. Mixtures containing flammable gas and dust in air or oxidant are referred to as "hybrid mixtures." The presence of gas may have a considerable influence on the burning characteristics of a combustible dust. The extent of this influence depends on the type and concentration of flammable gas.

There are concentrations of dusts which, by themselves, will not burn, even with a large or intense ignition source, but in the presence of small quantities of flammable gases can burn even at concentrations below the flammable limit of either material.

Figure 2-2.1.10 shows the effect of low concentrations (1 to 5 percent of methane) on the maximum pressure developed by coal dust. In general, maximum pressure was increased by the addition of methane with dust concentrations up to about 0.5 oz per cu ft; at higher concentrations (up to 2.0 oz per cu ft) maximum pressure was decreased by the addition of methane. The presence of a small amount of flammable gas will also dramatically reduce the minimum ignition energy required to ignite the dust mixture. Since the flammable gases generally require much lower ignition energies, as the ratio of flammable gas to combustible dust increases, the ignition energy required decreases.

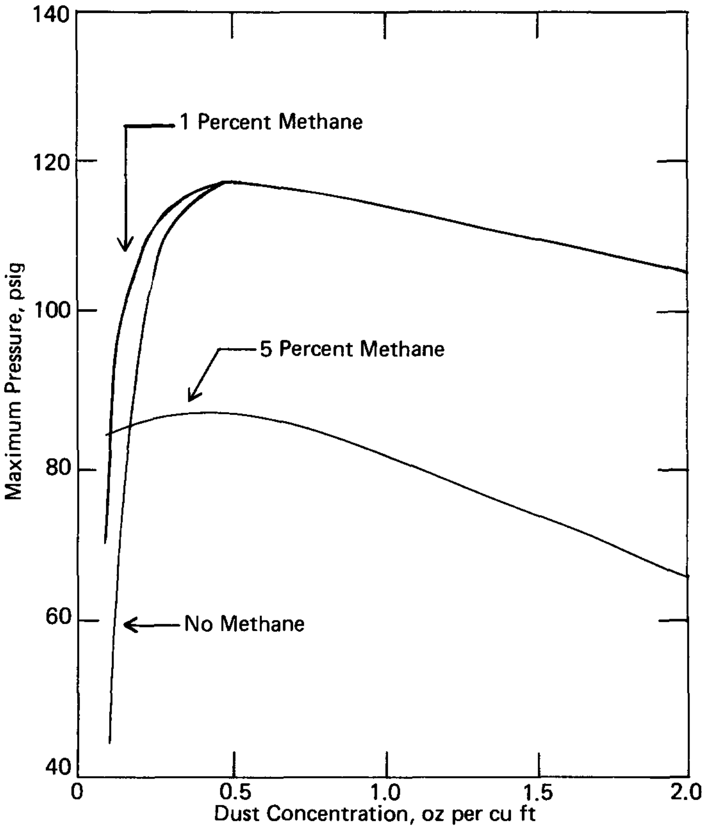


Figure 2-2.1.10. Effect of low percentages of methane in the atmosphere on pressure developed by coal dust deflagrations in a closed 0.32 cu ft vessel. (56)

2-2.1.11 Volume and Shape of Enclosure. Pressure developed during a deflagration results from gaseous products of combustion and from heating and expansion of the atmosphere within a vessel or confinement.

Generally, maximum pressure is unaffected by the size and shape of the vessel; however, the rate of pressure rise is markedly affected.

Increasing the volume of a vessel or enclosure produces a decrease in the rate of pressure rise during a deflagration; the rate of pressure rise is proportional to the ratio of the surface area of the vessel to its

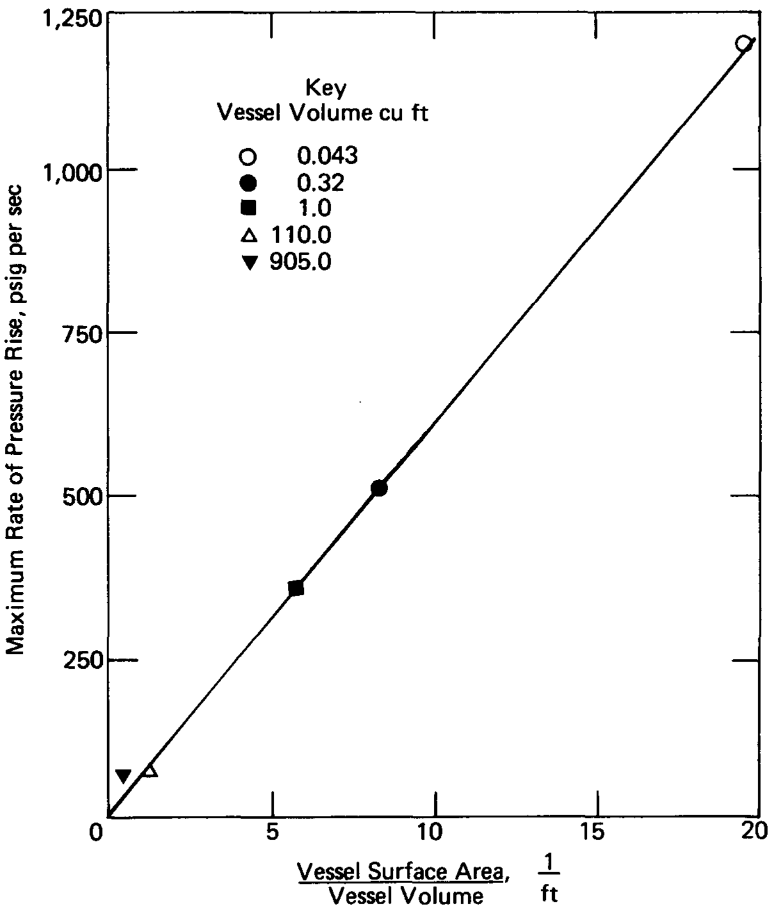


Figure 2-2.1.11. Effect of vessel dimension on the rate of pressure rise developed by 9.0 percent methane-air deflagrations. (57)

volume. This is shown in Figure 2-2.1.11. The following table indicates the size and shape vessels used to obtain data for this curve:

Table 2-2.1.11

Symbol, Geometry	**Volume (cu ft)**	**Dimensions**
○ cylindrical	0.043	2¾ in. dia., 12 in. high
● cylindrical	0.32	7¾ in. dia., 12 in. high
■ cubical	1.00	1 ft x 1 ft x 1 ft
△ rectilinear	110	4 ft x 5 ft x 6 ft
▼ spherical	905	12 ft dia.

For spherical or nearly spherical vessels, the rate of pressure rise varies with the cube root of the vessel volume. (*See "cubic law," Appendix A.*)

Chapter 3 Fundamentals of Venting

3-1 Venting Deflagrations.

3-1.1 A vent in an enclosure (building, room, or vessel) is an opening through which newly formed or expanding gases may flow. The purpose of the vent is to limit the maximum pressure resulting from a deflagration in order to limit damage to the enclosure.

Extensive destruction may result if combustion occurs within an enclosure too weak to withstand the full force of the deflagration. An ordinary building wall (8-in. brick or an 8-in. concrete block) will not withstand a sustained internal pressure as small as 1 psig (144 lbs per sq ft or 6.9 kPa).

Unless the enclosure is designed to withstand the maximum pressure resulting from a possible deflagration, venting should be considered to minimize damage due to rupture. The area of the vent opening must be sufficient to limit pressure build-up to a safe value. (*See Appendix A.*)

Combustion venting of an enclosure normally implies the need to vent in such a manner that the maximum pressure development is low. The maximum pressure should be lower than the pressure which the weakest building or structural member can withstand. The weakest building member may be a wall, roof or floor if the enclosure is elevated. On equipment the weakest section may be a joint.

3-1.2 No data are available on actual forces or loads applied to the walls of full-size structures by different types of deflagrations. Designs must be based upon the specific equipment, the enclosure and material of construction, shock resisting ability, and the effect of vent openings on the pressure developed and duration. Pressures produced by deflagration of dust and gas-air mixtures in laboratory test chambers at atmospheric pressure are on the order of 100 psig (690 kPa). An enclosure need not be constructed to withstand such pressures if the volume is adequately vented. In most instances it is impractical to construct a building or some large equipment to withstand 100 psig (690 kPa).

3-2 Pressure and Rate of Pressure Rise.

3-2.1 The rate of pressure rise is an important factor in venting; it determines the time interval available for the combustion products to escape. A rapid rate of rise means that only a short time is available for venting and, conversely, a slower rate permits a longer time.

More vent area is required for effective venting of deflagrations having a high rate of pressure rise. Fundamental data on dust deflagrations in a closed vessel are shown in Appendix E, Table E-1. Pressure and corresponding flame development for deflagration in an open vented vessel is shown in Figures 3-2.1(a) and 3-2.1(b).

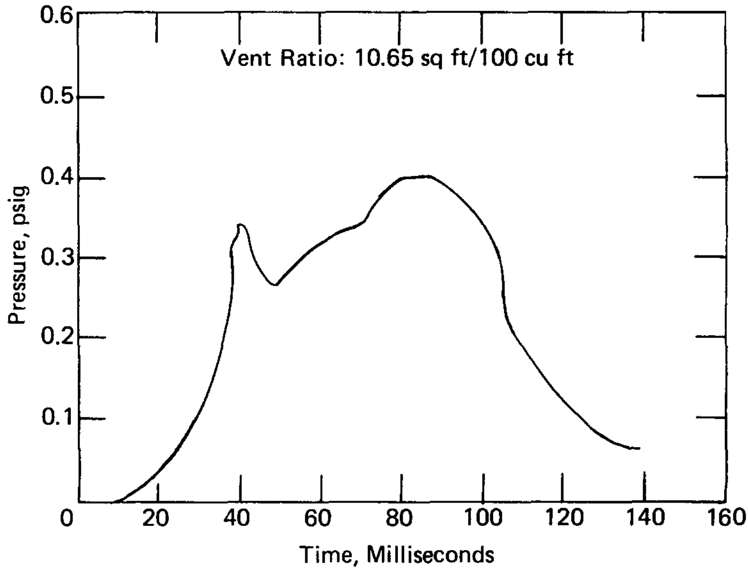


Figure 3-2.1(a). Pressure-time record of 9.4 percent methane-air deflagration in a 0.32 cu ft vented cylindrical vessel. *(Unpublished data, courtesy of U.S. Mine Safety and Health Administration.)*

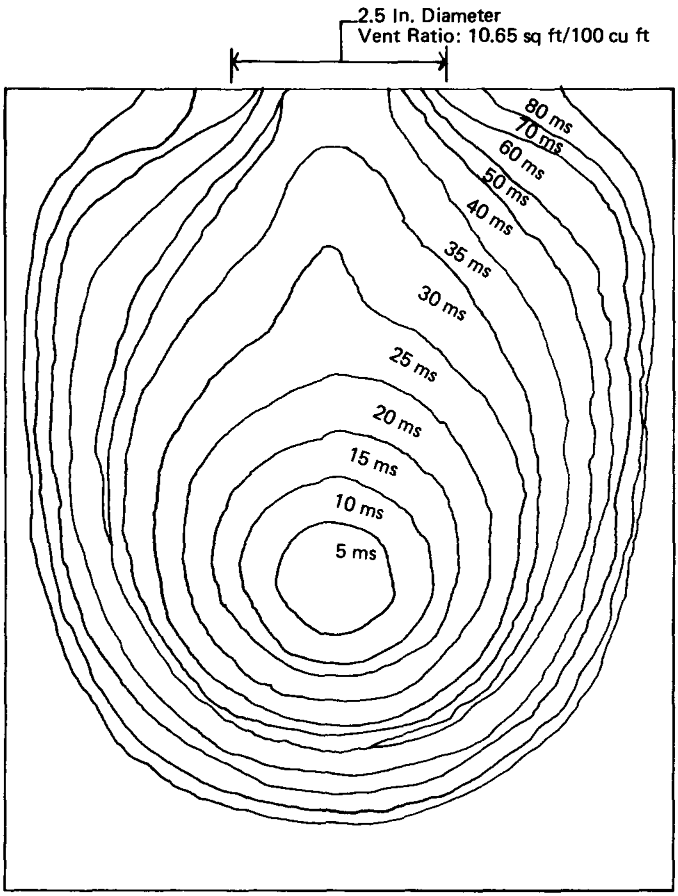


Figure 3-2.1(b). Flame development for a 9.4 percent methane-air deflagration in a 0.32 cu ft vented cylindrical vessel. Maximum pressure of 0.4 psi occurs at 80 milliseconds. (*Unpublished data, courtesy of U.S. Mine Safety and Health Administration.*)

3-2.2 The maximum pressure developed in a laboratory test chamber does not fully define the true force imposed on walls and other surfaces. This is because a given force applied to a panel for a long period may be more destructive than the same or even greater force applied for a short period. Moreover, the pressure is not constant. The area under the pressure-time curve determines the total impulse exerted and hence the dynamic effect of the explosion on the structure. [*See Figure 3-2.1(a).*] Briefly, the effects of a deflagration depend upon the maximum pressure developed, the rate of pressure rise and the duration of pressure.

Data for methane-air deflagrations in various size vented vessels (0.32 to 216 cu ft) show that a linear relationship exists between maximum pressure and average rate of pressure rise.

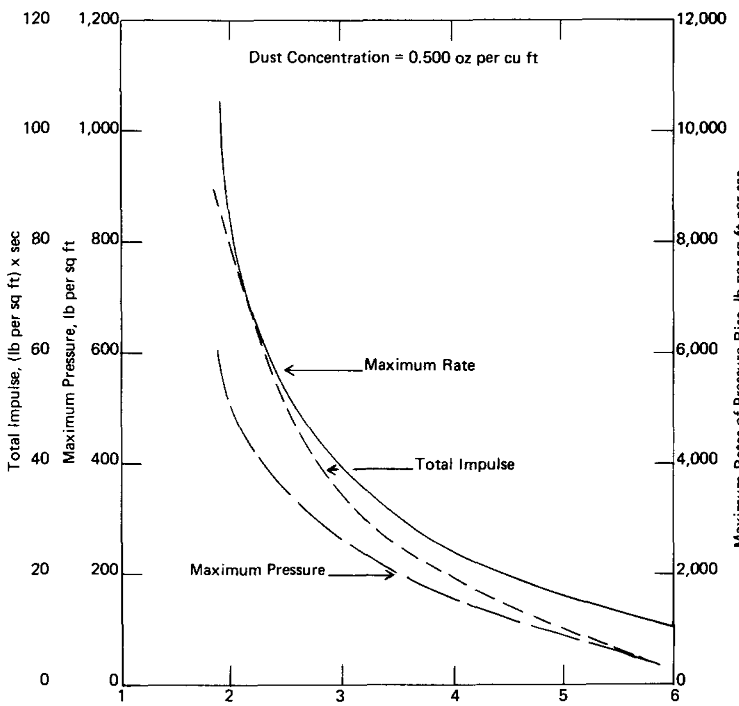


Figure 3-2.2. Variation of pressures, rates and impulses with vent ratios in magnesium deflagrations in a vented 64 cu ft vessel. (36)

3-3 Venting Formulas.

3-3.1 There are a number of empirical formulas for computing size of vent openings for a specific vessel or structure, but, unfortunately, none of these can be considered entirely satisfactory.

Theoretical calculations have been made by several research organizations to determine and evaluate the ability of various structures to withstand the shock of an external pressure; both full-scale and model tests were conducted on structures and component structural elements by the coordinated activity of many governmental agencies and private industrial and engineering organizations. These studies dealt with the ability of various structures and shelters to resist external bomb blasts. Most enclosed structures, by reason of tie-ins and bracing, can usually withstand more pressure from without than from within. At times, this may be in the ratio of 2 to 3 times greater.

3-3.2 The present knowledge of the mechanism of a large-scale deflagration and the resistance of enclosures to internal forces does not permit precise recommendations for the computing vent relief. The calculation procedures in this guide are given in Appendix A. It is known from experience and testing that generally it may not be practical to provide sufficient vent area to prevent serious damage from an optimum-mixture deflagration in a large-volume enclosure. Experience has shown that most dust and gas combustions do not involve a large part of the total volume of the enclosure and that ignitions of vapors frequently occur near the limits of the flammable range. Consequently, such deflagrations are rather weak and venting can be effective.

3-4 Venting Variables. Venting is a measure that limits development of destructive pressures in an enclosure incapable of withstanding the full force of a deflagration. Determination of vent area for an enclosure is mostly empirical. Generally, the vent area should be made as large as practical and the remaining enclosure constructed as strongly as economically feasible.

3-4.1 Vent Size and Shape. The maximum pressure (as well as total impulse) in vented vessels decreases as the vent area increases. [*See Figure 3-4.1(a).*] One large vent will relieve the pressure of a deflagration in a small enclosure as effectively as several small vents whose area equals the area of the large vent. However, this may not be true for large enclosures and the distribution

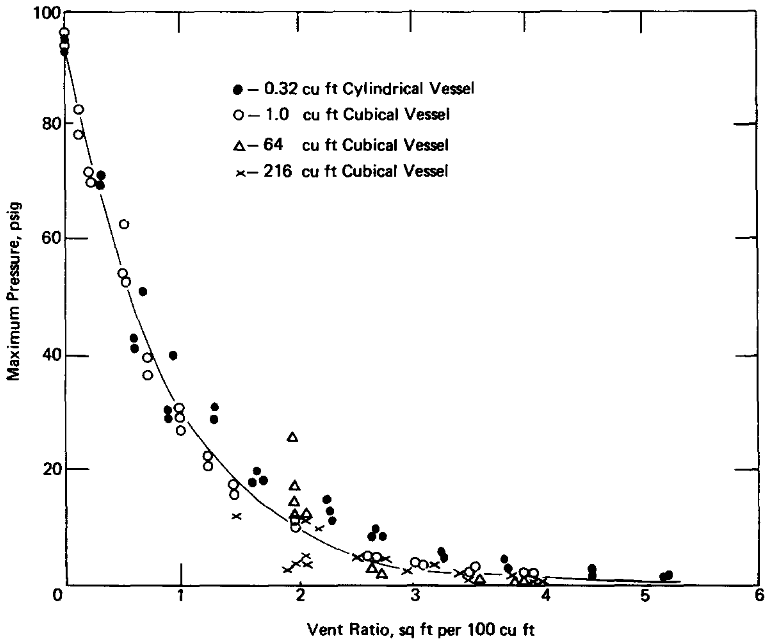


Figure 3-4.1(a). Effect of unrestricted vents on pressure developed by the deflagration of nominal 9.4 percent methane-air mixtures. (*Unpublished data, courtesy of U.S. Mine Safety and Health Administration.*)

of vents relative to the location of the initiation of the deflagration is important. Rectangular vents are almost as effective as square vents of equivalent area for pressure relief. [*See Figure 3-4.1*(*b*).] Vents with rounded edges to facilitate gas flow and minimize friction are most efficient.

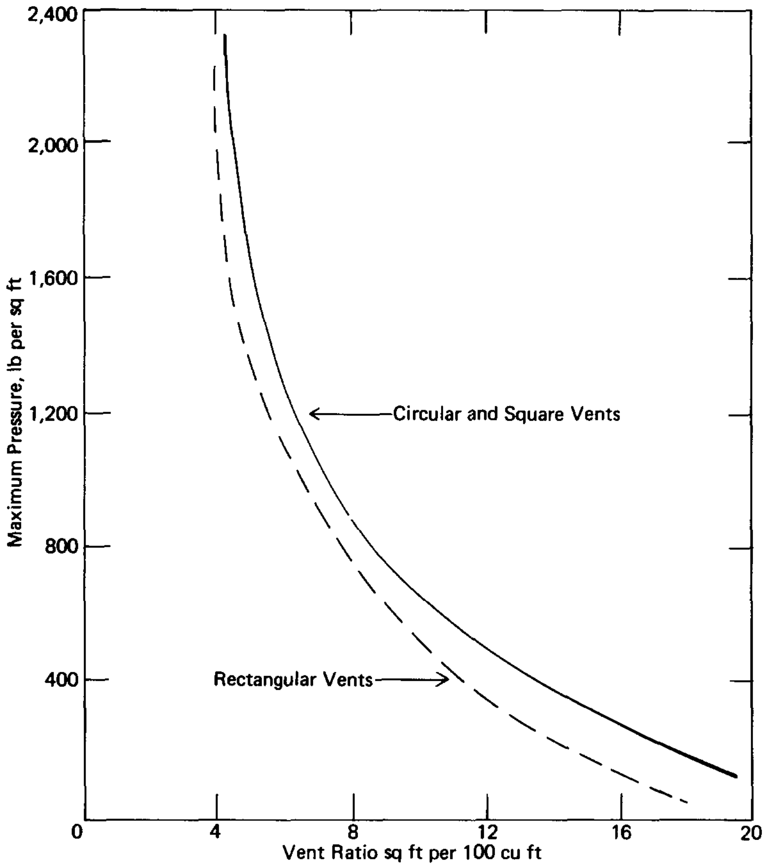


Figure 3-4.1(b). Effect of vent shape on pressures produced by deflagrations of cornstarch in a 1 cu ft vessel. (*Unpublished data, courtesy of U.S. Mine Safety and Health Administration.*)

3-4.2 Type of Vents. Open or unrestricted vents are most effective in relieving pressure build-up. Vents covered with a diaphragm, swinging door, bursting disc, some type of weak construction material or other device require inertia to be overcome; therefore, such vents are less effective than unrestricted (open) vents. Chapter 4 contains some illustrations of various methods of providing vents to reduce the forces of a deflagration.

3-5 Basic Recommendations for Venting. Since venting is a complex subject on which essential information is lacking, this is only a general guide for best current practices. Important recommendations for reducing damage by venting are summarized below.

3-5.1 Vents are generally required in buildings or enclosures containing operations or processes where dust, gas, or mist may be present in sufficient amounts to create flammable concentrations in air or other oxidizing media.

3-5.2 The required areas of vents depends upon such characteristics as the rate of pressure rise, maximum pressure developed, the strength of the enclosure, and design of vent closure. Empirical methods and nomographs may be used to determine vent area. (*See Appendix A.*)

3-5.3 Vents should be located as close as possible to potential sources of ignition which may originate the deflagration. However, experiments show that for spherical or cubical containers with central ignition, the shape and location of a vent is not significant. Where points of ignition cannot be determined in large enclosures, vents should be evenly distributed. Vents with no constructional members to impede gas flow and vents with rounded edges to promote gas flow are most efficient.

3-5.4 Whenever possible, vented products should be directed to a safe location outside of an enclosure to avoid injury to personnel and minimize damage to property. In congested locations, substantial ducts or diverters should be provided to direct explosive force and combustion products to a safe area.

As a precautionary measure, it may be necessary to install indoor railings along floor edges near vent panels to prevent personnel from falling against the panels. Warning signs should also be provided to alert personnel that panels are easily knocked loose.

Vents should not be obstructed. Wherever possible, vents should be designed to minimize the accumulation of ice and snow and should be cleared to permit proper operation.

Where sashes are used for venting, precautions should be taken during cold weather. Ice crystals may form between the venting sash and the frame due to high humidity in the area and produce a cementing action on the vent allowing greater pressures to build up before the vent will open; a coating of grease on the adjacent surfaces may prevent the bridging of ice crystals between the members of the vent. Corrosion and paint may also increase friction in opening a vent.

Vents, particularly those with discs, diaphragms, or other closure devices, should be located where flame, gases, or flying material cannot injure people. In addition, a vent closure such as a swinging door should be designed to prevent development of a vacuum after heated gases from a deflagration have cooled. (*See Chapter 4 and Appendix D for discussion and description of vent devices and vent closures.*)

3-5.5 Structural damage can be minimized by locating hazardous operations or equipment outside of buildings and segregated from other operations. This is particularly true of dust collectors, arrestors, bucket elevators, and reactors. Multiple physical interconnections between the ductwork system of each collector should be avoided. Furthermore, such equipment should be properly vented and a device should be provided at the inlet of the collector which will prevent a deflagration from blowing back through the ductwork and into the building or structure.

3-5.6 Highly hazardous operating equipment should be separated into individual units by pressure resisting walls, and each unit so formed should be vented outdoors. Exterior walls may be made of heavy construction if equipped with suitable vents or adequate lightweight panels which blow out easily. Locating hazardous operations or equipment in basements or areas partially below grade should be avoided due to the difficulty of providing adequate venting.

3-5.7 When it is impractical to locate hazardous operations or equipment outdoors, they should be located adjoining outdoor walls, in a single-story building or on the top floor of a multistory building, or in a lightly constructed penthouse and vented directly to the outside through ducts of adequate cross-sectional area.

3-5.8 Vent ducts used to conduct combustion products outdoors should be constructed to withstand the maximum pressure of a deflagration. Duct length should be minimal and bends should be avoided. It should be realized that any duct will decrease the effectiveness of the vent in proportion to the duct length. Increasing duct diameter with duct length compensates, but design data are not presently available. Figure 3-5.9 shows the effect of length of ducts attached to a 1-cu ft vessel on pressures developed by deflagrations of coal dust. Under certain conditions, detonation may occur in piping or duct systems and effective venting cannot be accomplished. Additional information on vent ducts is given in Appendix A.

3-5.9 External wind pressure or suction may operate venting devices and these effects should be considered in their design. Wind pressures in severe storms may reach over 30 lbs per sq ft (1.44 kPa) and vents designed to open at a higher pressure in the event of a deflagration may not provide for building safety. Therefore, the vent design should take into consideration the local wind conditions and building safety.

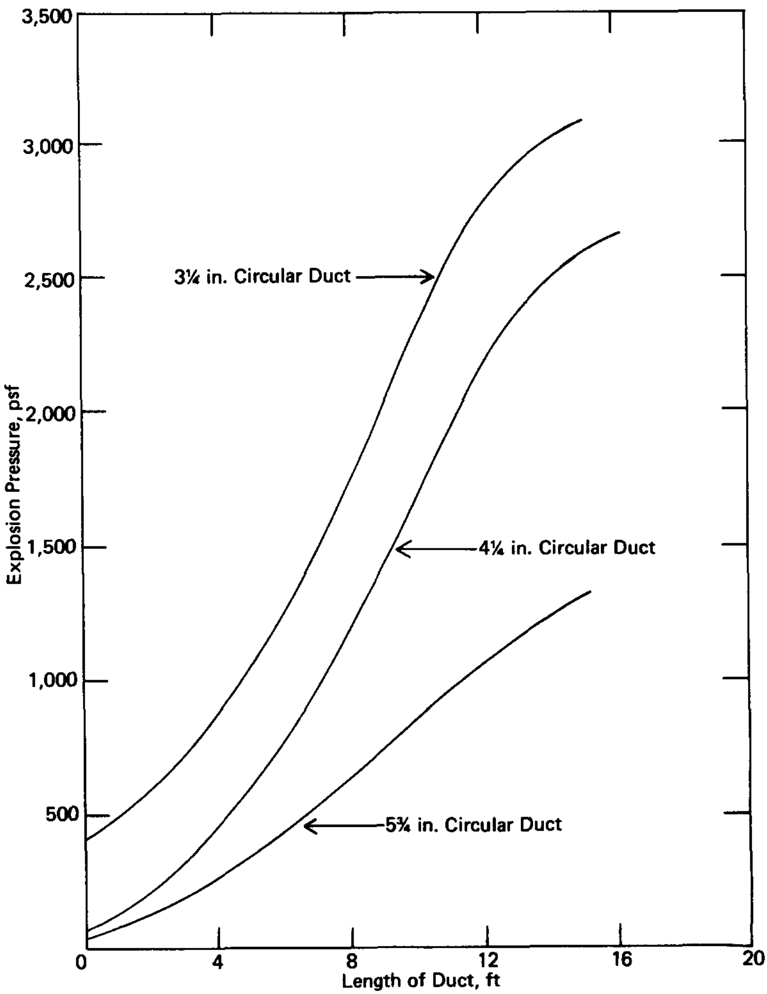


Figure 3-5.9. Effect of vent duct diameter on pressures developed by deflagrations of coal-dust in the 1 cu ft chamber. (*Unpublished data, courtesy of U.S. Mine Safety and Health Administration.*)

Chapter 4 Description of Vents and Vent Closures

4-1 General. The vents described in this section have been designed or developed for the release of pressure from enclosures in which explosions of dusts or gases may occur. In most cases, the described vents are effective only in deflagrations in which the rate of pressure rise is moderate and where, in large enclosures, only a part is involved in the deflagration. The devices described are not generally suitable for protection of pressure vessels, which is outside the scope of this guide, nor for protection against pressure or shock waves produced in detonations of explosives.

Some types of vent closures are commercially available and may be purchased ready to install in buildings or equipment. The following descriptions should be used as the basis for development of suitable vents and vent closures which will provide the desired protection. Examples of vents and vent closures are shown in Appendix D.

4-2 Open or Unobstructed Vents. The most effective vent for the release of deflagration pressure from enclosures is an unobstructed opening. However, there are comparatively few operations with inherent deflagration hazards that can be conducted in open equipment installed in buildings without walls.

Often some form of vent closure must be provided to protect against the weather, to conserve heat, to bar unauthorized entry, to preclude dissemination of the combustible material, or to prevent contamination of the product by the entrance of dirt or moisture from the outside.

Open equipment is recommended wherever a more serious deflagration hazard is not created through dispersion or dissemination of the material and where closed equipment is not necessary to prevent contamination of the material.

4-2.1 Louvers. Although openings containing louvers cannot be considered completely unobstructed vents, they do provide a large percentage of free space for the release of deflagration pressure and have served effectively as vents. They are recommended especially as wall vents where windows are not required to maintain controlled atmosphere conditions within the enclosures. Louvers can be used effectively as vents where it is necessary or desirable to prevent unauthorized entry or egress. However, compensation for pressure drop must be considered.

4-2.2 Hangar-type Doors. Large hangar-type or steel curtain doors installed in side walls of rooms or buildings can be opened to provide unobstructed vents during the operation of any process or equipment in which there is an inherent deflagration hazard. Such doors can be closed to prevent unauthorized entry when the equipment is unattended or not in operation. This type of venting has been effective and is highly recommended, but strict supervisory control is essential in cold climates to insure that employees do not sacrifice safety for comfort by keeping the doors closed during operations.

4-2.3 Open Roof Vents. Large roof openings protected by weather hoods can serve as deflagration vents on one-story buildings or the top story of a multiple-story building. This type of venting is effective particularly where lighter-than-air gases may escape from processing equipment and create a hazard near the ceiling of the enclosure. In addition to serving as vents for the release of pressures, such roof openings reduce the possibility of a deflagration by providing a channel through which the gas can escape from the building.

4-3 Closed or Sealed Vents. Where large openings cannot be permitted in a building, the most desirable arrangement is an isolated single-story building. Such a building can be most easily designed for explosion resistance and venting. Equipment which requires venting should be located close to outside walls so that duct-work, if necessary, can be short.

Building vent closures are necessary in air-conditioned plants or where heat is provided for the comfort of occupants during all or part of the year. Vent closures are required on processing equipment whenever it is necessary to retain dust or gas or where processes are conducted under pressure, vacuum or other controlled atmospheric conditions.

The fundamental principle in the design of vent closures is that the vent will open at as low a pressure as possible. It should have no counterweights; counterweights add to inertia. The effect of various vent closures is illustrated in Table 4-3.

Table 4-3

Maximum Pressures Produced by Deflagrations in Enclosures with Unrestricted Openings or Different Types of Vent Closures (36)

Type of Dust	Vent Ratio sq ft/100 cu ft	Type of Vent or Vent Opening: Unrestricted Opening	Heavy Paper Diaphragm	Light Swinging Door	Heavy Swinging Door
		Maximum Pressure, lbs/sq ft			
Coal	1.56	81	292	101	—
Coal	3.52	29	158	36	55
Aluminum (Atomized, fine)	3.52	71	205	161	232

Construction of the closure should be light so that full opening can be quickly obtained; yet the structural strength must be sufficient to withstand natural forces such as wind or snow loads.

When vents are sealed by paper, plastic, metal diaphragms, hinged panels, or other closures, the maximum pressure developed is higher than when the vent is unrestricted. Therefore, the vent areas must necessarily be larger. [*See Figure 4-3(a).*]

Rupture of paper, plastic, or metal diaphragms during the initial stages of a deflagration is greatly facilitated by saw-toothed or piercing cutters along the periphery or at the center of the diaphragms. Cutters permit the use of smaller relief vents. [*See Figure 4-3(b).*]

It is not possible to describe all of the devices that have been developed to serve as vent closures, but certain representative types can be grouped under separate headings.

4-3.1 Building or Room Vent Closures. These type closures may be manually or mechanically operated, such as doors, windows, and skylights, or may have weak structural features, such as large glass areas or light wall and roof panels built or sealed in place but designed to open due to overpressure.

4-3.1.1 Doors. To serve effectively as building vent closures, doors must be installed to swing outward and have latches or locking hardware that will function automatically to permit the door to open under slight internal pressure. Friction, spring, or magnetic latches of the type designed for doors on driers and ovens are recommended. Maximum weight per unit area should be limited to 2 lbs/ft^2 (10 kg/m^2).

4-3.1.2 Windows. Normally, windows installed to provide light or ventilation can frequently be arranged or adapted to serve as vent closures when they are properly hinged to open outward. A number of different styles designed especially for this purpose are commercially available.

4-3.1.3 Movable Sash. Top or bottom hinged movable sash or projected type, which are commercially available, have been widely used for venting. It is usually necessary to have such sashes equipped with some form of latch or friction device to prevent undesired opening due to wind action or to prevent intrusion, but care should be taken to avoid the use of any latch or lock which is not well maintained and not always ready to operate when a deflagration occurs.

When swinging panels, windows, or other hinged devices are used, care must be taken to prevent closure of the vent opening after the initial positive pressure wave of the deflagration subsides. This will prevent the development of destructively high negative pressures as the remaining combustion products cool.

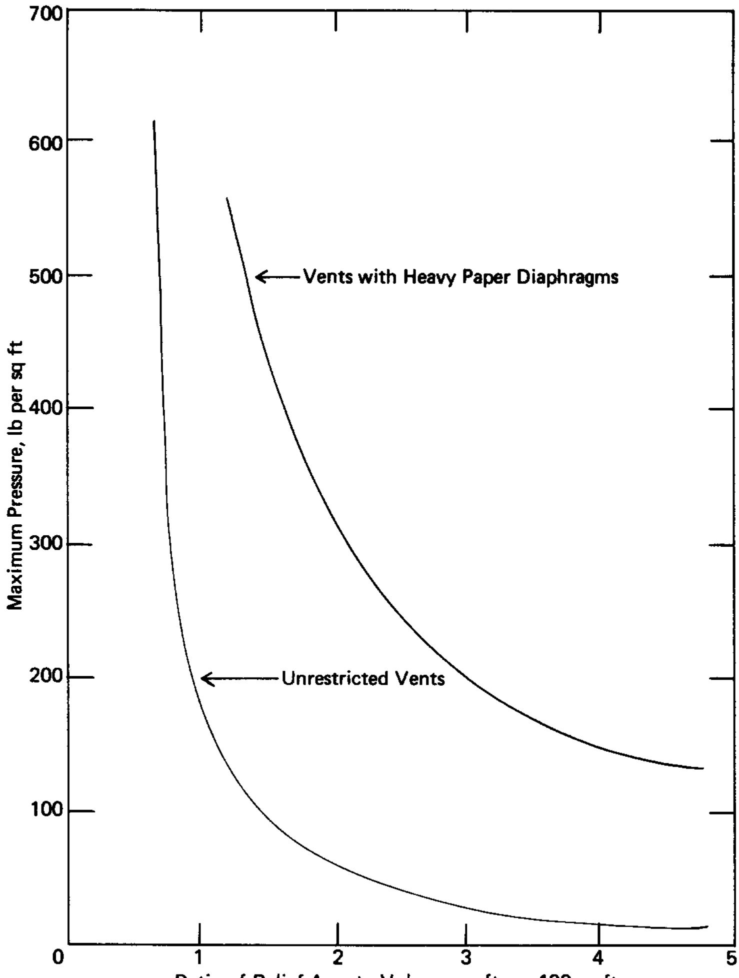


Figure 4-3(a). Relative effectiveness of unrestricted openings and of heavy-paper diaphragms in relieving pressures from coal-dust deflagrations initiated by electric spark. (36)

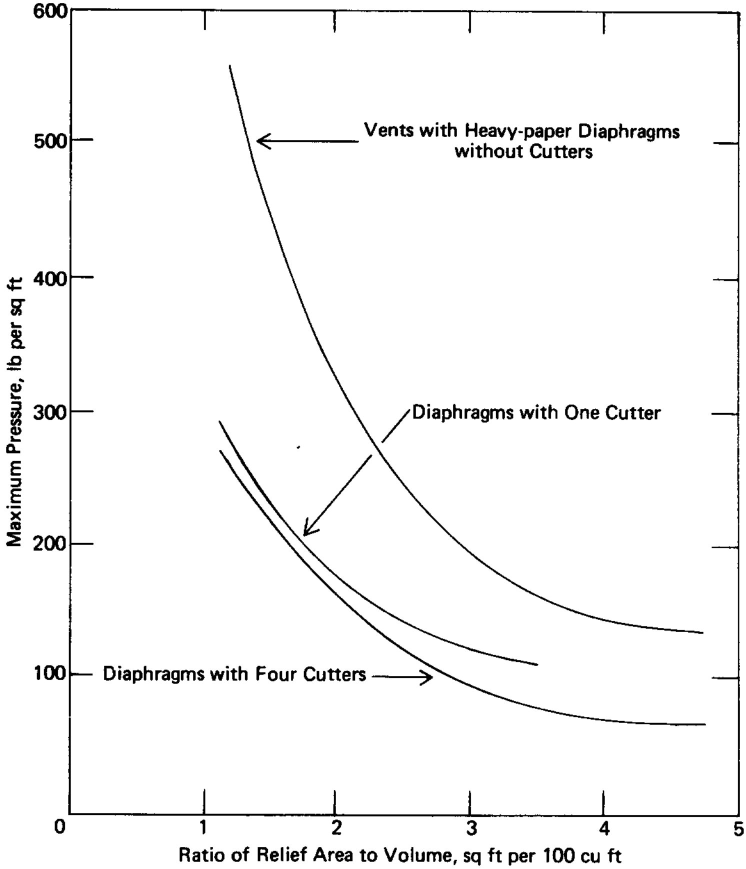


Figure 4-3(b). Effectiveness of cutters to facilitate rupture of heavy-paper vent diaphragms on pressure relief of coal-dust deflagrations. (36)

4-3.1.4 Roof or Wall Panels. Such panels are more economical than fixed sash or moveable windows and can provide very effective protection against damage. In this type of venting, a portion of the roof or an exterior wall between strong partition walls is constructed to blow out readily if an explosion occurs. The panels may be of very light construction such as sheet metal, corrugated plastic paneling, roofing paper, or roofing paper supported by coarse mesh wire. The total weight of the explosion panel assemblies should be less than 1.5 lb/ft^2 (7.3 kg/m^2). In some instances, the entire roof over a room has been constructed as a panel or cover to lift or blow off if an explosion occurs. However, the roof must be securely anchored to prevent the wind from blowing it off. (The authority having jurisdiction should be consulted regarding required type of anchorage for the panels.) Metal roofs can be designed and installed with crimped edges, like can lids, that will normally hold them in place.

4-3.1.5 Skylights or Monitors. Such closures with moveable sash that will open outward or fixed sash containing panes of plastic that will blow out readily under pressure from within can be used to supplement wall vents or windows in buildings.

This makes it possible to use larger floor areas than would be permissible when only side wall vents are used. Resistance to displacement or opening of skylights or monitor windows by pressure should be as low as consistent with the requirements for structural strength.

4-3.2 Equipment Vent Closures. Very few types of equipment can be operated without closures and numerous methods of providing satisfactory closures have been developed by plant operators, engineers, and equipment builders. Some of the closures described may have a very limited application, but the general principle involved can frequently be used in the design of similar devices for other specific purposes. Equipment should be vented directly to the outside of the building through short ducts of adequate cross-sectional area.

4-3.2.1 Charging Doors or Inspection Ports. Such doors or ports may be designed to function as automatic vent closures when their action does not endanger personnel. They can be used on totally enclosed mixers, blenders, driers, and similar equipment. Hinged doors or covers held shut with spring latches are most frequently used for this form of protection. It is difficult to vent equipment of this type especially if the shell, drum, or enclosure revolves, turns, or vibrates.

4-3.2.2 Venting Devices. Venting devices generally used on tanks or equipment that are normally closed at all times are not intended to be used as doors or inspection ports and are expected to open only when the internal pressure exceeds a predetermined limit. The cover of the vent opening is usually fitted with a gasket and held in place by spring action. In applications of this principle on larger equipment, on low pressure air ducts, settling chambers, etc., the travel of the cover can be restricted by chains installed at corners or points on the periphery. Springs may be used to anchor chains to absorb the deceleration forces. Magnetic latches, where the magnetic lines of force must be ruptured, can be adjusted to release at a predetermined pressure.

4-3.2.3 Diaphragms. Many different kinds of diaphragm materials have been used or are available for use as closures on explosion vents. Only a few of the many types can be described, but mention of these few will, no doubt, suggest others which may prove to be equally or more effective. The criterion in choosing a vent material is that its bursting strength will be considerably less than the walls of the enclosure.

4-3.2.3.1 Paper. Waterproofed kraft paper, building paper, and roofing paper have all been used as vent closures. The usual method of application consists of pasting or clamping a sheet of paper onto a wooden or metal frame designed to fit over the vent opening or to slide into a vent duct. The breaking strength of the paper and the resistance to be offered to normal pressure within the enclosure will determine the best type of paper to select. Papers that weaken when exposed to water or moisture should be used only in dry places. Flame retardant paper and several different types of plastic impregnated paper have been developed and used effectively under certain conditions for vent closures.

4-3.2.3.2 Cloth. Cloth impregnated with paraffin or plastic, varnished cambric, and plastic-covered cloth netting are a few of the different forms of cloth diaphragms used as explosion vent closures. These materials are generally available in rolls or sheets and the vent closures are made by cutting pieces to the proper size and gluing, tacking, clamping, or otherwise fastening them over the openings through which deflagration pressure is to be released. Such vent closures have certain properties that make them suitable for use in places where paper diaphragms would not be satisfactory.

4-3.2.3.3 Plastic. Plastic vent closures are of two types: flexible and frangible. Both types are usually available in sheets. Pieces cut to the desired size may be installed in place of glass in window or observation port frames. The material may also be used instead of paper or cloth to seal vents.

Flexible plastic sheets are usually installed in slotted frames in such a way that pressure from within bulges the sheet and releases it from the holding frame. Transparent or translucent plastic sheets can be used instead of glass in certain types of window frames that will permit the sheet to function as a pull-out diaphragm vent closure.

Frangible sheets are usually selected to serve as vent closures on the basis of their brittleness. It is possible to obtain thin sheets of plastic that will crack or rupture under less pressure than single-strength glass. For this reason, it can be advantageous to use transparent or translucent plastic sheets instead of glass in window sash.

4-3.2.3.4 Metal. Metal foil is sometimes used to seal vents. This type of material can be substituted for flexible diaphragms where the material being processed would react with the diaphragm.

Under other conditions where higher pressure is maintained within the enclosure or the vent area is very large, heavier, rigid sheets of metal may be used as vent covers. They should be designed to prevent generation of shrapnel.

4-3.2.4 Diaphragm Cutters. Cutters designed to expedite the openings of vents closed or sealed with diaphragms have been used in many instances. Even a delay of a few thousandths of a second in relieving deflagrations of dusts or gases having high rates of pressure rise may cause extensive damage to equipment. To reduce this delay between the initial indication of pressure within an enclosure and the opening of the vent, some plant operators have installed saw teeth, spear points and other cutting devices designed to initiate the tearing or rupturing of the diaphragm as soon as the pressure causes the least distortion from the normal position of the vent closure.

Appendix A Recommendations for Deflagration Venting of Gas and Dust Mixtures

This Appendix is not a part of this NFPA document but is included for information purposes only.

A-1 General Comments. At the time of the drafting of this guide, the state of technology of deflagration venting is still only partially developed. Venting deflagrations involves many variables. Only some of the variables have been investigated to any extent. The investigations which have been conducted do allow for certain generalizations to be made. The recommended calculation bases given below have been developed from these generalizations. The calculation bases must be recognized as approximate only. An attempt was made to evaluate the data and correlations in recently published papers and to make use of those which were considered reliable.

The maximum pressure which can be developed during venting can be significantly higher than the pressure at which the venting device releases. A number of variables affect this maximum pressure. Several of these are discussed in Chapter 2.

A-2 Venting of Deflagrative Combustion Inside Buildings. As discussed in Chapter 3, most buildings cannot withstand high pressures from within. Damage to buildings by combustion within them can be minimized by adequate venting. As discussed in Chapter 2, the venting must be such that the maximum pressure developed will be lower, by a safety margin, than the pressure which the weakest building member desired not to break or vent can withstand. The weakest building member may be a wall, the roof, or, if the building is elevated, the floor.

A-2.1 Vent Panel Construction Material. Special consideration should be given to the material of construction of the vent panel. It should not be of a material that tends to break into pointed shards; specifically, it should not be of glass or the cement-asbestos type board. It is desirable that the vent panel weigh no more than 1.5 lb/ft^2 (7.3 kg/m^2) of effective vent opening. Material which meets most of the desired criteria fairly well is thin gage corrugated paneling made of polyvinyl chloride (PVC) or fiberglass-reinforced plastic with a flame spread rating no greater than 25 as determined by *Method of Test of Surface Burning Characteristics of Building Materials*, NFPA 255–1972.

A vent panel made of light material and designed to release at a low pressure in the range of 10–30 lbf/ft^2 (0.5–1.5 kN/m^2) cannot be counted upon to hold people in case they should fall against such panels. As pointed out in 3-5.4, it may be necessary to install indoor railings along floor edges near the vent panels. Also, as pointed out in that subsection, vents should be unobstructed from both the inside and outside of the building protected.

A-2.2 Calculating Vent Area. A number of factors complicate combustion inside buildings as discussed in References 41, 52, 66, and 70. References 41 and 70 discuss the "Runes" equation for calculating vent area. The equation is as follows:

$$A_v = \frac{CL_1L_2}{\sqrt{P}} \qquad \text{(Eq 1)}$$

A_v = necessary building vent area, ft^2 or m^2

C = constant, characteristic of the fuel gas, as discussed below.

NOTE: C is dependent upon the units (English or SI) used.

L_1 = smallest dimension of the rectangular building enclosure to be vented, feet or meters.

L_2 = second smallest dimension of the rectangular building enclosure to be vented, feet or meters.

P = maximum internal building pressure which can be withstood by the weakest building member which is desired not to vent or break, $lbf/in.^2$, or kN/m^2.

For most gases such as natural gas, propane, gasoline, benzene, acetone, and many others, values of fundamental burning velocity are nearly the same. For such gases the value of C in Equation 1 is approximately 2.6 in English units and 6.8 in SI units. Note in this connection that the actual flame speed will be many times the fundamental burning velocity. The value of C, in fact, allows for the actual flame speed under conditions of a certain amount of flame turbulence increase due to (1) physical obstructions such as process equipment, piping, and building structural members; (2) flow-induced turbulence due to venting; and (3) turbulence induced directly by a large flame. For ethylene the suggested value for C is 4 in English units and 10.5 in SI units; for hydrogen, 6.4 in English units and 17 in SI units. The last two sets of values suggested for C have not been tested in actual building venting incidents. The first set of values was calculated from one building venting incident (*see Reference 41*). Turbulence effects, and hence flame speeds, can differ as the turbulence producing situations vary.

For venting of combustion of most organic dusts, the recommended value for C is 2.6 in English units and 6.8 in SI units. For metal dusts having high flame speeds, the recommended value of C is 4 in English units and 10.5 in SI units.

For mists of organic liquids, the recommended value of C is 2.6 in English units and 6.8 in SI units.

The following table summarizes the recommended values of C:

Fuel Identity	C for Equation in English Units	C for Equation in SI Units
Gases with Flame Speed like Propane	2.6	6.8
Ethylene	4	10.5
Hydrogen	6.4	17
Organic Dust	2.6	6.8
Organic Mists	2.6	6.8
High Flame Speed Metal Dusts	4	10.5

A-2.3 Applicable Building Dimensions. It is believed that the venting equation is suitable for combustion venting of spaces in buildings having a nominal length/width (i.e., L/D) ratio up to 3. For spaces having an L/D greater than 3, the space should be subdivided into multiple units, each having an L/D of no more than 3. In a rectangular building when L_1 and L_2 are not equal, the effective value of D is $\sqrt{L_1 L_2}$.

Wherever it is possible, combustion vents for a building should be distributed over the walls of that building rather than confined to one wall.

A-2.4 Special Points Relative to Spills Inside Buildings. Two important points relative to spill situations should be noted about the venting of combustion inside buildings. (1) Building ventilation rates even as high as one air change per minute will not necessarily prevent formation of flammable mixtures from spills inside buildings. (2) Concentrations of gas from spills inside buildings can vary greatly throughout the building space. Gas at a concentration above the upper flammable limit can burn rapidly because the thermal drafts caused by the initial flame will promote further mixing of air into the unburned fuel. Furthermore, the initial flame raises the temperature of the unburned mixture, thereby increasing the flammability limits.

Appendix B contains a sample calculation for combustion venting for buildings.

Location of flammables-handling equipment in open structures with or without roofs obviates many of the problems of gas accumulation in buildings and of necessary building venting. (*See the Flammable and Combustible Liquids Code, NFPA 30–1977.*)

A-3 Venting of Dust Combustion Inside Vessels. The most comprehensive known design bases for venting of dust deflagrations are given in VDI Richtlinie 3673 (Reference 87). This work was published in Germany and is based on data obtained from a very extensive test program. This program involved venting tests with four dusts in containers of four sizes: 1, 10, 30, and 60 cubic meters. The nomographs prepared from the data for venting of dust deflagrations are reproduced here as Nomographs A–F. The necessary venting area as a function of the class of dust, the vessel volume and strength, and the relieving pressure of the combustion vent can be determined from these nomographs.

For the purposes of the nomographs, combustible dusts were divided into three classes according to their maximum rates of pressure rise. At the present time most of the available data on rates of pressure rise for various dusts have been obtained in the Hartmann test apparatus of the Bureau of Mines, U.S. Department of Interior. Those dusts giving maximum rates of pressure rise in the Hartmann apparatus, up to 7,300 psi/sec, or 50,000 kN/(m^2) (sec), were designated Dust Class St-1. Those giving rates of 7,300–22,000 psi/sec, or 50,000–150,000 kN/(m^2) (sec), were designated Dust Class St-2. Those above 22,000 psi/sec, or 150,000 kN/(m^2) (sec), were designated Dust Class St-3. (*See Table A-3(a).*)

A more reliable basis for dust classification may be obtained by conducting dust flammability tests, similar to those in the Hartmann apparatus, in a larger vessel which approaches the geometry of a sphere. In recent years, for example, tests for determining rates of pressure rise for a number of dusts have been conducted in nearly spherical vessels of volume approximately 1 m^3. Such data have been found to be more dependable than the Hartmann data in terms of projecting to venting requirements for equipment of commercial size.

Basic to the nomographs is the concept of what is called the "cubic law." This takes the form of the following equation for combustion inside completely closed vessels, i.e., with no venting of the deflagration.

$$(dp/dt)_{max} \cdot (V^{1/3}) = \text{constant}$$

where

$(dp/dt)_{max}$ = maximum rate of pressure rise for dust or gas combustion in a particular vessel

V = volume of the particular vessel

The constant is referred to as K_{St} for dusts and K_G for gases. For rate of pressure rise in bar/sec and vessel volume in m^3 the constant is expressed in bar $\cdot$ m $\cdot$ sec^{-1}.

Application of the cubic law to the venting of deflagrations is made possible by the findings of Donat (Reference 23 and 24) and Bartknecht (Reference 5), whose data indicated pressure development with venting did, in fact, approximately follow the cubic law. This holds so long as the combustion is deflagration; it does not hold for detonations.

On the basis of the cubic law the equation for the necessary venting area is as follows:

$$F_2 = \frac{F_1 V_2 V_1^{1/3}}{V_1 V_2^{1/3}} \quad \text{or,} \quad F_2 = \frac{F_1 V_2^{2/3}}{V_1^{2/3}}$$

where

F_1 = vent area on test vessel found necessary to prevent pressure during combustion from exceeding a given value

F_2 = vent area which will be necessary on a second vessel to prevent pressure during combustion from exceeding the same value

V_1 = volume of test vessel

V_2 = volume of second vessel

While venting of dust deflagrations in vessels of various volumes may not exactly follow the cubic law, it does appear to follow this more closely than other relations which have been used previously. The ratio of vessel length to diameter, for application of the cubic law, needs to be less than 5. When the constant is determined for dust combustion in vessels of 1 m^3 or more, and when the constant is expressed in bar · m · sec^{-1}, the hazard classes are as follows:

Table A-3(a)
Hazard Classification of Dust Deflagrations

Hazard Class	K_{St} (bar·m·sec^{-1}) for weak ignition source (energy Approx. 10 W·sec)*	K_{St} (bar·m·sec^{-1}) for strong ignition source (energy approx. 10,000 W·sec)	Maximum rate of pressure rise in Hartmann apparatus psi/sec
St-1	≤ 100	≤ 200	≤ 7,300
St-2	101–200	201–300	7,300–22,000
St-3	> 200	> 300	> 22,000

*W.sec = Watt-seconds.

The following table lists some characteristic values of K_{St} for typical dusts. These are given in various papers published in the work by Donat and Bartknecht. It is noteworthy that the value of K_{St} is affected by the dust particle size and shape as well as by its composition. Thus another dust of any one of the materials in the table may give another value of K_{St} under the same test conditions.

Note also the comparison of some K_{St} values determined in the Hartmann apparatus. The Hartmann apparatus values do not extrapolate as well for industrial-size equipment as do those from tests in equipment of larger volume such as 1 m³.

Table A-3(b)
Values of K_{St} for Typical Dusts

	Tests in 1 m³ or larger vessels, length-to-diameter about 1				Tests in Hartmann apparatus 1.3L vol, large L/D
	Chemical igniter $E \sim 5000$ W·s*		Elec. spark E = a few W·s		
Dust Identity	P_{max}' bar	K_{St}' bar·m·sec⁻¹	P_{max}' bar	K_{St}' bar·m·sec⁻¹	K_{St}' bar·m·sec⁻¹
Coal	7.7	85	no ignition		
Dextrin	8.7	200	8.5	100	33
Organic pigment	10.0	300	9.7	200	73
Aluminum	11.5	550	11.0	450	73
Flour	8.6	57			
Methyl cellulose	10	160			
Starch	10	170			
Epoxy resin	8.2	180			
Pharmaceutical product	9	200			
Polyethylene	9	200			
Powdered sugar	7.8	160			
Wood	—	230			

*W·s = Watt-seconds.

Tests were also conducted in France (Reference 62) with flammable dust ignition in vessels of 1, 10, and 100 m³ volume. The length-to-diameter ratio of each of the vessels was approximately three. The conclusion from these tests was that the cubic law is reasonably valid. It was in fact found that this law leads to some overestimation of the vent area needed for large volumes. However, use of the law provides less overestimation than the assumption that the necessary vent area-to-volume ratio found for a small volume remains constant through all sizes up to large volumes. Thus, use of the cubic law prevents overexpenditure of money for fabrication of excessively large vent areas. This and the ability to predict venting areas quantitatively are the primary developments in recent years in the determination of necessary venting areas for deflagrations.

The tests from which the nomographs were developed were conducted from initial pressures of essentially atmospheric. Most dust handling equipment operates at pressures near atmospheric. No specific correlations have been developed and extensively tested for cases of initial pressure substantially different from atmospheric. It is believed, however, that the nomographs will apply to venting deflagrations for dust handling equipment operating at the normal (low) gage pressures.

For large vessels, such as vertical cyclindrical storage hoppers or silos for combustible dusts, the required venting area may be as large as, or larger than, the cross section of the vessel. In this case the entire vessel roof can be made a venting area by constructing it as a weak seam roof as described in American Petroleum Institute Standards 650 and 2000.[1] Space must be available above the roof for it to open sufficiently. Usually such a roof opens only partway around its periphery to vent a dust combustion. Obviously the roof thickness should be as small as possible, consistent with the strength demands upon it. Large diameter roofs of this type cannot be made self-supporting within the roof slope constraints imposed by the API Standards. Rather, internal roof supports will be needed. The roof sheets must not be welded or otherwise attached to the roof supports.

If the required vent area is larger than the vessel cross section, the vessel needs to be further strengthened to take a pressure consistent with the vent area that can be provided. In all cases, the total volume of the vessel should be assumed to contain the combustible dust in suspension, i.e., no credit should be taken for the vessel being partly full of settled material.

The nomographs, as presented for two different ignition energies, hold a significance for industrial equipment. The graphs using the small value of ignition energy are intended to represent the case where ignition occurs directly within the vessel which is vented and where the ignition energy is relatively small. This could, for example, be ignition from a hot surface or an electrical spark. For this case, then, venting areas should be chosen according to the nomographs presented for this (weak ignition) case.

Another class of ignition source can occur in industrial equipment. Large pieces of dust-handling equipment are often connected by intervening ducts. In a case such as this, an ignition could begin within one piece of large equipment and thence be conveyed by a connecting duct and enter a second large piece of equipment. As discussed in 2-2.1.5, the burning dust from the duct enters the second piece of equipment as a large, highly turbulent tongue

[1]Available from the American Petroleum Institute, 2101 L Street, NW, Washington, DC 20037.

of flame. This presents a very large ignition source in the second vessel and also increases turbulence within that second vessel. This results in much more severe combustion than that normally resulting from a small ignition source. For this latter case, the nomographs for large ignition energy should be followed.

The use of vent ducts can lead to substantially increased pressure. Donat (Reference 22) cites a specific example. A vent area and vent opening pressure on a particular vessel were such that the maximum pressure developed during the combustion was 2.8 psig (0.2 bar). This vessel had no vent duct. When a vent duct of length 3–10 ft (1–3 m) was attached, the maximum pressure developed during venting increased to 9.9 psig (0.7 bar). With a vent length greater than 10 ft (3 m), the maximum pressure during venting increased to 24.2 psig (1.7 bar). Thus, if only a low pressure can be tolerated by a particular piece of equipment, the attachment of a vent duct must be considered very carefully. If a vent duct is absolutely necessary, both the vessel and the duct must be designed to withstand the full pressure which can be developed during combustion venting. In order to support reasonably high pressures it is often necessary to construct a vent duct in circular cross section. The percentage increase in pressure as a result of addition of a vent duct is greater for dusts with high values of K_{St} than for dusts with low values of K_{St}. It is also greater for the case of large vent areas than for small vent areas. When duct lengths exceed about 10 ft (about 3 m), gas and dust velocity in the duct during venting can be expected to become sonic. In some cases in longer vent ducts, a detonation can occur with resulting pressures going as high as 30 bars.

In any case, vent ducts for combustion venting need to be kept as short and straight as possible.

Venting panels or "doors" are often used for venting equipment such as bag filters. Such vent panels should weigh no more than 2 lbs/ft^2 (10 kg/m^2) of effective vent opening, preferably less. Such panels need to be hinged in such a manner that they will not fly off of the primary equipment in the course of venting a deflagration.

In many cases, the dust-handling equipment to be vented is some form of dust collector such as a bag filter. Filter bags inside the filter vessel, and located close to combustion vents, can be expected to interfere with venting with the result that the pressure increase during the venting can be expected to be appreciably higher than that predicted by the nomographs. In the general case, it is better to provide free space just inside the vent area.

Appendix B contains a sample calculation for venting dust deflagrations.

A-4 Venting of Gas Combustion Inside Vessels. In the usual industrial situation, the venting of gas combustion inside vessels is the most difficult of the different types of venting. Many of the variables listed above under Chapter 2 may come into play in a single case. It is not at all unusual for the gases in industrial equipment to be at a pressure above atmospheric. There may also be a significant degree of initial turbulence and of turbulence nonuniformity in the gas mixture before ignition occurs. Often the turbulence is brought about by the mode of introduction of feed gas streams into the vessel. For various reasons, the vent opening pressure may have to be appreciably above atmospheric. Geometry of the gas space in the vessel may be far from an ideal shape such as a sphere or cube. For various geometric reasons, the vent may have to be at a nonpreferred location. The likely location of ignition source usually cannot be determined. Hence, it usually cannot be known whether the gases going through a vent, after opening, will be primarily unburned or burned or a mixture of the two.

Because of such factors the estimation of necessary combustion venting area for a vessel is complicated. Yet, the estimation is frequently necessary. Because of uncertainties yet existent in the technology of venting deflagrations, the most conservative case should be assumed. For example, even though a mixture of fuel gas and oxidant in a vessel would normally be outside the flammable limits, it should be assumed that under the abnormal conditions the mixture may deflagrate and venting should be considered.

A-4.1 Nomographs for Venting Combustion of Gases. Gas combustion can be vented when that combustion is a deflagration. Detonations cannot be vented satisfactorily. This guide relates to venting for deflagrations only.

The test program from which resulted the Richtlinie (Reference 87) for venting dust deflagrations also involved a very large number of tests of venting gas deflagrations. Tests were done in vessels ranging in size from 1 m^3 to 60 m^3. The initial pressure in the vessels for these tests was atmospheric. Vent areas were varied, as were the pressures at which the vents opened. The vents had low values of mass per unit area.

Again, as in the case of combustible dusts mentioned above, it was found that the cubic law holds reasonably well for the venting of gas deflagrations inside vessels. It is noteworthy that data in Reference 33 for venting of pentane combustion in a 60 cu ft (1.7 m^3) vessel checked fairly well with the data in Reference 23 for venting of propane in a 35 cu ft (1 m^3) vessel. The data from the gas combustion venting tests in vessels of various sizes including

60 m^3 were used to construct nomographs for combustion venting (Reference 2). The nomographs are included in this Appendix. An example calculation is given in Appendix B. The nomographs relate to the burning characteristics of the gases just as the dust nomographs relate to the burning characteristics of the dusts. The burning characteristic of a gas is called the K_G value. For the purposes of this guide, it is expressed in units of bar · m · sec^{-1}. This is, in fact, the "constant" derived from the first equation quoted above in Section A-3. The value of K_G is influenced not only by the identity of the fuel gas but also by other conditions affecting the combustion, such as initial turbulence of the gas mixture and the type of ignition source. The value of K_G which is considered to be fundamentally characteristic of a given gas is obtained by combustion of the corresponding gas-air mixture inside an unvented vessel with the gas mixture under initially static conditions and with an ignition source consisting of an electric spark of about 10 Ws energy. The following table gives characteristic values of K_G for several fuel gases. Also included in the table, for illustration, is a tabulation for K_G values for some of the gases for the condition where the gas-air mixture was highly turbulent at the time of ignition.

Table A-4.1(a)
K_G Values for Gases

	Values determined with electric spark ignition source of about 10 Ws*	
Fuel Gas	**Initially static gas mixture**	**Initially highly turbulent gas mixture**
Methane	55	460
Propane	75	500
Hydrogen	550	1270
Propyl acetate	40	
Methyl ethyl ketone	56	
Toluene	56	
Methanol	66	
Ethyl acetate	67	

*Ws = Watt-seconds.

The mode of ignition can also have an effect on flame speed and, hence, on the value of K_G. This is shown in the table below, where some of the effects are not what might be expected.

Table A-4.1(b)
Influence of the Type of Ignition, the Ignition Energy, and the Degree of Turbulence on the K_G Value of Propane (3)

Turbulence	Type of ignition	Ignition energy, Ws*	Max pressure from combustion in closed vessel, bar	K_G, $bar \cdot m \cdot sec^{-1}$
None, Static	Continuous AC Spark	~10	7.5	75
	Condenser Discharge	100	9.5	750
	Pyrotechnic Ignition Device	10,000	9.5	280
Weak	Continuous AC Spark	~10	8.8	370
	Pyrotechnic Ignition Device	10,000	9.5	400
Strong	Continuous AC Spark	~10	8.9	520

*Ws = Watt-seconds.

The nomographs are limited to air-gas mixtures in vessels having length-to-diameter ratios not exceeding about 3 to 5. They also pertain only to initial gas pressure, before ignition, of approximately atmospheric. They also relate only to a small ignition energy from a spark having an energy of about 10 watt-seconds.

As explained above, the value of K_G can be increased by initial gas turbulence and by high energy of ignition source. If the conditions are such as to produce a high value of K_G, a nomograph based on such high K_G values should be used. For example, if conditions are such that the K_G value for propane could be raised from 75 to about 500, it is recommended that Nomograph I be used. This was developed for hydrogen, which has a characteristic K_G value of 550.

A-4.2 Effect of Fundamental Burning Velocity. The pressure developed during combustion venting is determined in part by the speed with which gases burn during deflagration. This burning speed is in turn determined at least partially by the characteristic rate at which flames proceed through different fuel gases. This characteristic rate is normally measured in terms of maximum fundamental burning velocity, tables of values for which can be found in various handbooks. Some characteristic values are given in Table A-4.2.

Table A-4.2

Gas	Maximum Fundamental Burning Velocity ft/sec	m/sec
Methane (natural gas)	1.2	0.37
Propane	1.5	0.46
Butane	1.3	0.4
Hexane	1.3	0.4
Ethylene	2.3	0.7
Acetylene	5.8	1.8
Hydrogen	11.0	3.4

NOTE: Additional values are available in Perry, R. H., et. al., *Chemical Engineers' Handbook*, 5th edition, McGraw-Hill, New York (1973), pp. 9–19, and also in Reference 32.

The above values are definitely not the speed with which flames move through a flammable mixture in a vessel. Flame speeds in a vessel are normally much higher than the fundamental burning velocity. However, the fundamental burning velocity is a basic measure of the flame characteristics of a fuel gas. Note that the ratios which the fundamental burning velocities bear to each other for the gases methane, propane, and hydrogen are similar to the ratios of the K_G values for these respective gases tabulated earlier. By the same token, as mentioned above, the effects of turbulence on K_G values for low flame speed gases are much higher than they are for high flame speed gases.

From the table for maximum fundamental burning velocities and the table for K_G values it is seen that materials having similar maximum fundamental burning velocities have similar K_G values. This observation leads to a method for estimating K_G values for gases when these have not been experimentally determined. For example, it is noted that butane has a maximum fundamental burning velocity of 1.3 ft/sec (0.4 m/sec). This is close to the value of 1.5 ft/sec (0.46 m/sec) for propane. Hence, in the absence of experimental measurement, a K_G of 75 would be assumed for butane.

Significantly, the gases of most organic compounds have nearly the same fundamental burning velocity. Thus, their flame speeds, and the pressure developed during venting, will be nearly the same. In general, the substitution of a halogen, such as chlorine, or certain other atoms in an organic molecule, retards the combustion. On the other hand, introduction of unsaturation into the molecule, as in the cases of ethylene and acetylene, speeds up the combustion.

Data from References 13 and 23 can be used to compare the pressures developed during combustion venting for propane-air and hydrogen-air mixtures. As mentioned earlier, Nomographs G–J have been developed for venting of mixtures of air with propane, methane, hydrogen, and coke gas. (*See Reference 3.*)

A-4.3 Effect of Initial Elevated Pressure. The effect of initial pressure must be correlated on the basis of absolute pressures. The data from Reference 13 serve as a basis for correlating pressures developed during venting as a function of the initial absolute pressure of gases in a vessel and as a function of the absolute pressure at which a vent opens. If the ratio of vent bursting pressure to initial gas pressure in a vessel is kept constant, and if vessel size and vent size is kept constant, the pressure developed during the venting of propane combustion will vary as approximately the 1.5 power of the initial pressure. The power exponent for propane varies from about 1.2 for larger vent ratios (6 ft^2/100 ft^3) to about 1.5 for smaller vent ratios (2 ft^2/100 ft^3). For hydrogen, the exponent ranges from 1.1 to 1.2.

It is recommended that the 1.5 power be used in extrapolating from Nomograph G, which is for gases having K_G values close to 75. (*See sample calculation, Appendix B.*)

For hydrogen, the recommended exponent for increased initial pressure is 1.2. For ethylene, it is recommended that an exponent of 1.4 be used; this is untested. The correlation may apply to initial pressures up to about 4 atmospheres absolute.

A-4.4 Effect of Initial Turbulence. Initial turbulence presents special problems in approximating combustion venting requirements. Industrially it is often difficult to quantify turbulence inside equipment at the time ignition may occur. This is due to several factors. If the gas in a vessel is in motion, there will be turbulence; the turbulence may be nonuniform. The gas flows may be abnormal at the time of ignition. Ignition may even be caused by breakage of some internal piece of the equipment and that breakage may itself result in change in the turbulence pattern. For these reasons, it is generally assumed that any turbulence in industrial equipment at the time of ignition of combustible mixture within it will be considered "highly turbulent."

In those published tests on the effects of turbulence, the turbulence has usually been quantified in terms of operation of the device used to create the turbulence. References 5, 33, and 57, for example, give data on effects of turbulence on pressures developed during combustion. The tables in A-4.1 above show effects of turbulence on K_G values for selected gases. The effects of initial high turbulence are greater on slow flame-speed gases such as methane and propane than on high flame-speed gases such as hydrogen. This in turn means corresponding effects on K_G values for these gases.

A-4.5 Effect of Initial Temperature. The effect of initial temperature is discussed in this guide in 2-2.1.7. Overall, increase in initial temperature in most cases results in an increase in maximum rate of pressure rise and a decrease in the pressure generated from the combustion. It is therefore believed that no adjustment in estimated pressure development during combustion venting needs to be made for increase in temperature. The same may be true for temperature decrease below ambient, but this has not been proven.

A-4.6 Effects of Combinations of Variables. At the present state of technology, there are insufficient data to know definitely just how combinations of variables may affect the maximum pressure developed during combustion venting. For the present, it is suggested that the effects of the variables be assumed to be cumulative. This pertains to the variables discussed in A-4.1 through A-4.5 above.

A-4.7 Effects of Additional Variables.

A-4.7.1 Inertia of Vents. Sometimes a rupture disc will not provide a suitable vent and a hinged panel or similar device must be used instead. The weight per unit area of such a device must be as low as possible. Tonkin and Berlemont (Reference 82) presented test data on effects of vent panel weight-per-unit-area on pressure developed during the venting of dust deflagrations. Doubling of the weight-per-unit-area of a vent panel of fixed area resulted in a doubling of the pressure developed during venting of deflagrations. Tripling of the weight per unit area resulted in a tripling of the pressure developed during the combustion venting. Suggestions have been stated above for limiting the weight-per-unit-area for venting devices. Normally, venting devices should have a mass/area ratio less than 2 lbs/ft^2 (10 kg/m^2).

A-4.7.2 Vent Ducts. Preferably there should be no ducts in the venting system. If a duct must be employed, it should have just as short an effective length (including effective length of bends in producing pressure drop) as possible. Any such bends should be minimal; the vent duct should preferably be straight. The effect of ducts on the pressure developed during combustion venting of gases is the same as that discussed for dusts in Section A-3. Combustion can take place in the vent duct itself, i.e., unburned gases may be the first to exit from the vent. This has two implications. First, the duct should be capable of withstanding a pressure at least as high as that expected to develop in the vessel during venting. Second, high turbulence can develop in the duct and could possibly lead to transition of the deflagration to detonation. In that case, far higher pressure could develop in the duct. The vessel could be exposed to similarly high pressures.

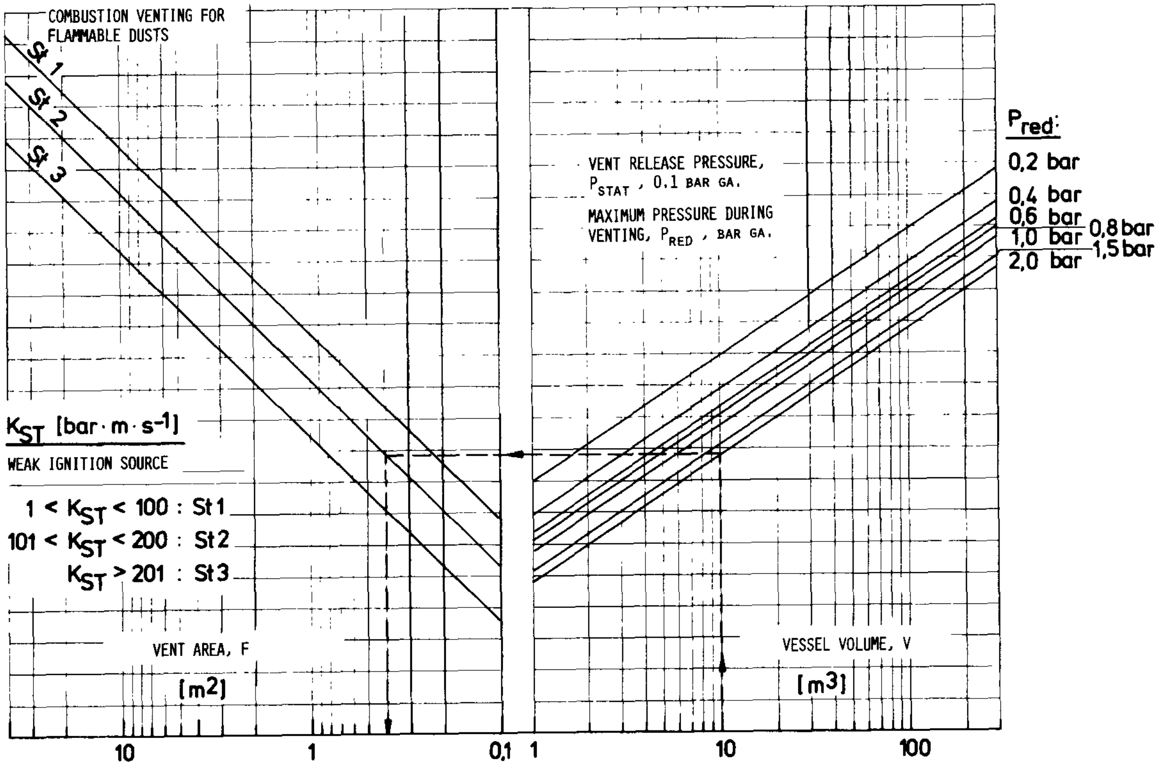
A-4.7.3 Ignition Source Location. There are few data on the effects of ignition source location on the pressure developed during combustion venting. In the normal industrial case, the potential ignition source location most frequently cannot be predicted. It is generally assumed that the ignition source will be at such a location as to generate the maximum pressure during venting of a deflagration, as stated by the nomographs.

In cases where multiple simultaneous sources of ignition are probable, it is suggested that the multiple ignition be assumed to produce the effect of initial high turbulence. (*See 2-2.1.5 for further discussion.*)

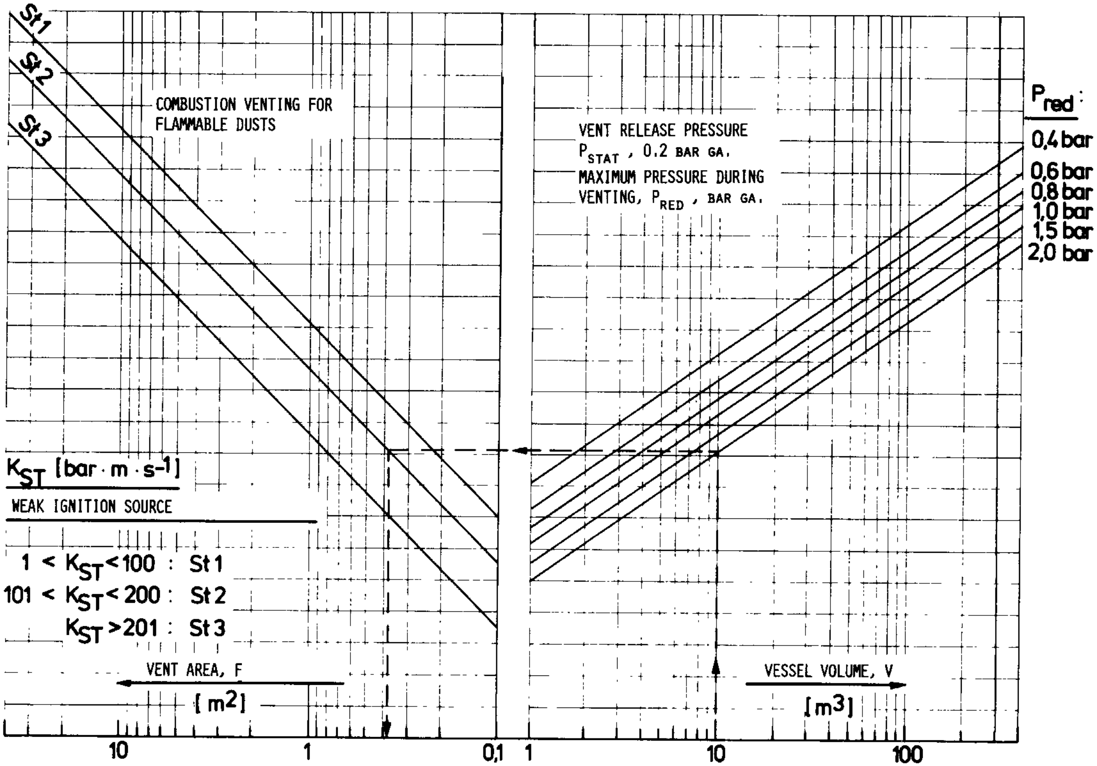
A-4.7.4 Other Oxidants. Relative to the data on venting gas/air deflagrations, there are little data on effects of other oxidants. This is discussed in 2-2.1.3. In addition to various oxygen concentrations, other oxidants can include oxides of nitrogen and halogens. These are not covered in this guide. If direct data are not available for the system being considered, tests are recommended.

A-4.7.5 Fogs and Mists. Flames can propagate through fogs and mists at mixture temperatures below the flashpoint of the liquid involved. It is suggested that fogs and mists be treated as gases in estimating pressures developed during venting of deflagrations.

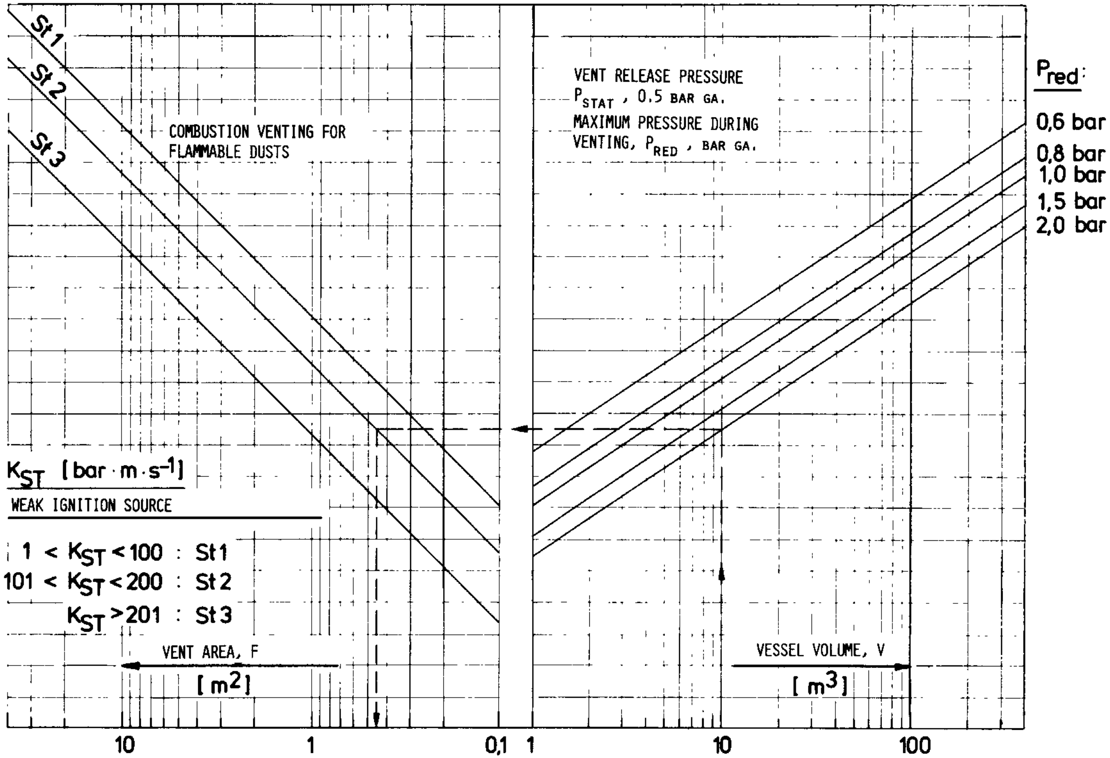
A-5 Venting of Gas Combustion Inside Air Conveying Ducts. Most of the cases of flammable gas mixtures inside ducts of the air ventilation type occur at initial internal pressure of nearly atmospheric. The venting of combustion in such ducts is discussed in Appendix C.


COMBUSTION VENTING FOR FLAMMABLE DUSTS
St 1
St 2
St 3
K_{ST} [bar · m · s^{-1}]
WEAK IGNITION SOURCE
1 < K_{ST} < 100 : St 1
101 < K_{ST} < 200 : St 2
K_{ST} > 201 : St 3
VENT RELEASE PRESSURE, P_{STAT}, 0.1 BAR GA.
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA.
P_{red}:
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
VENT AREA, F
[m2]
VESSEL VOLUME, V
[m3]
10
1
0,1
1
10
100

Nomograph A

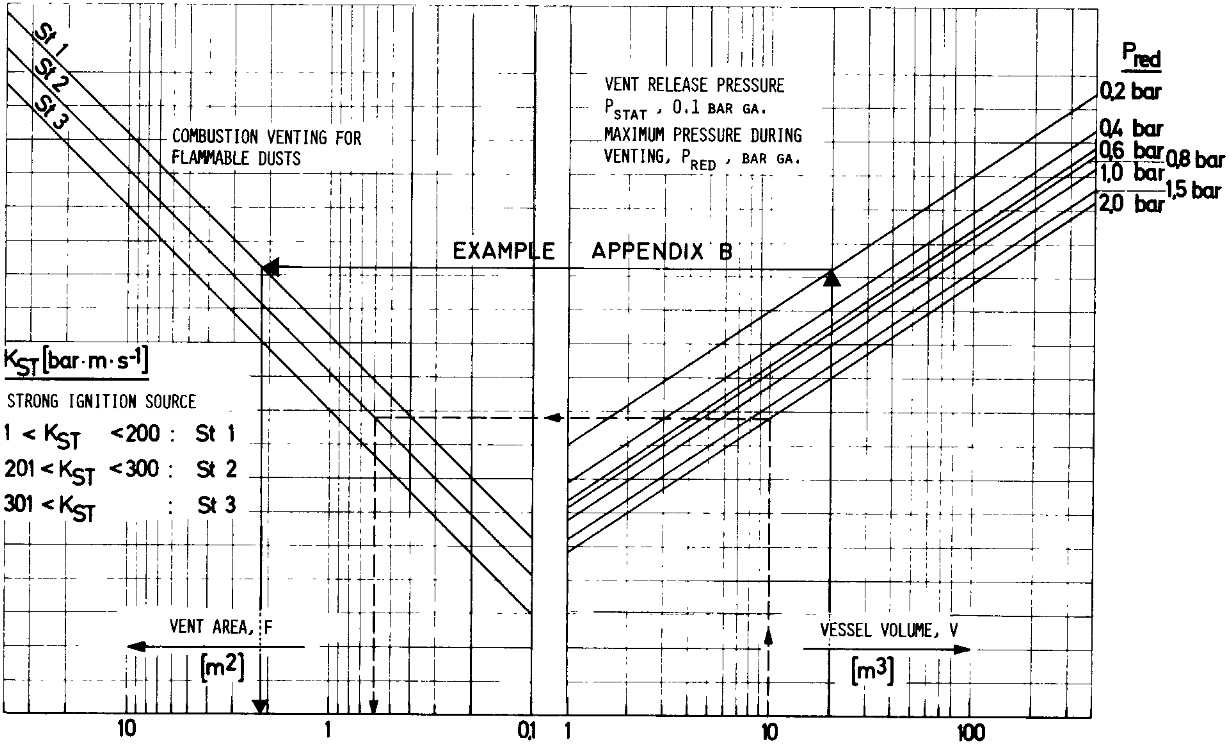

St1
St2
St3
COMBUSTION VENTING FOR FLAMMABLE DUSTS
VENT RELEASE PRESSURE
P_{STAT}, 0.2 BAR GA.
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA.
P_{red}:
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
K_{ST} [bar · m · s^{-1}]
WEAK IGNITION SOURCE
1 < K_{ST} < 100 : St 1
101 < K_{ST} < 200 : St 2
K_{ST} > 201 : St 3
VENT AREA, F
[m^2]
VESSEL VOLUME, V
[m^3]
10
1
0,1
1
10
100

Nomograph B

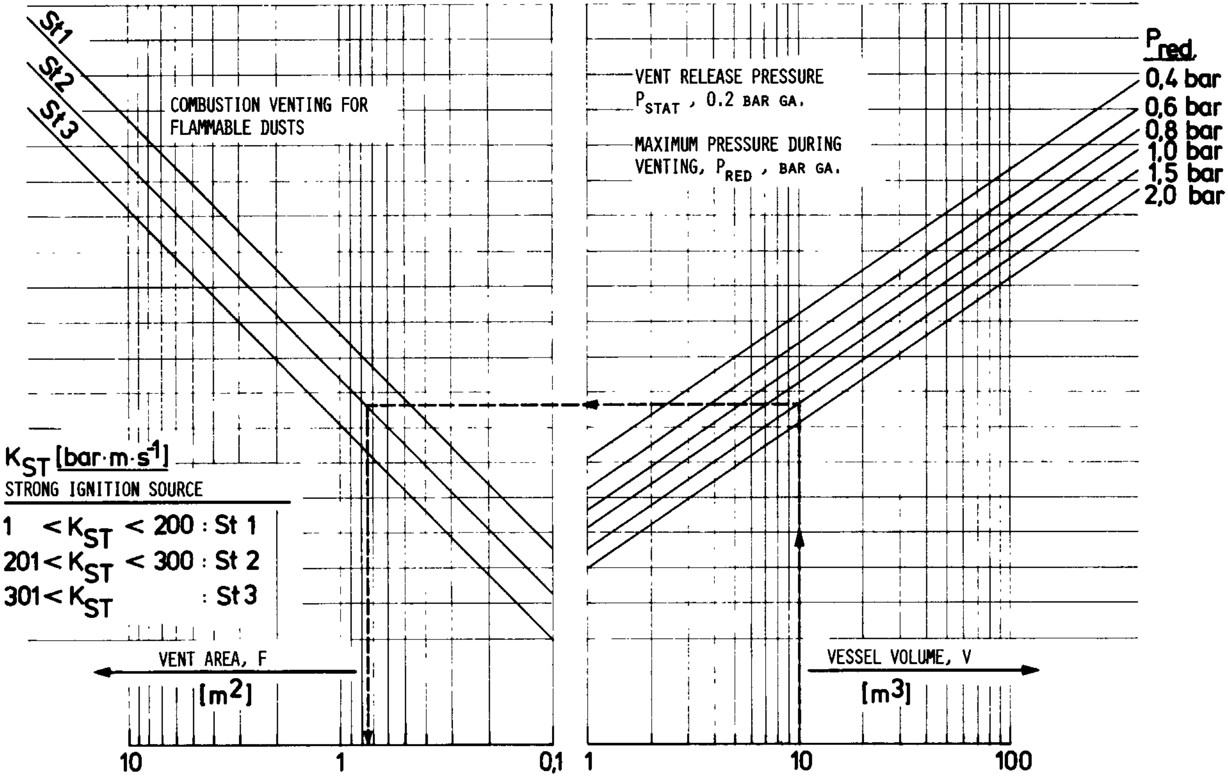


St 1
St 2
St 3
COMBUSTION VENTING FOR FLAMMABLE DUSTS
VENT RELEASE PRESSURE
P_{STAT}, 0,5 BAR GA.
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA.
P_{red}:
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
K_{ST} [bar · m · s^{-1}]
WEAK IGNITION SOURCE
1 < K_{ST} < 100 : St 1
101 < K_{ST} < 200 : St 2
K_{ST} > 201 : St 3
VENT AREA, F
[m^2]
VESSEL VOLUME, V
[m^3]
10
1
0,1
1
10
100

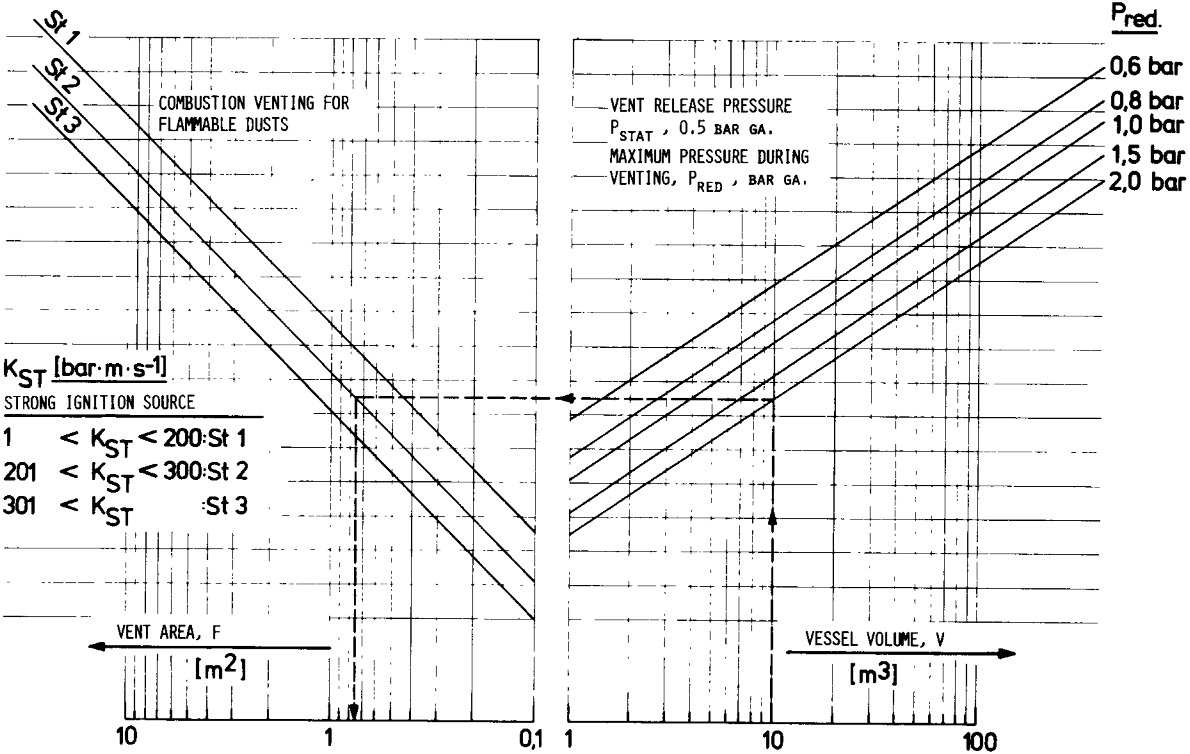
Nomograph C


St 1
St 2
St 3
COMBUSTION VENTING FOR FLAMMABLE DUSTS
VENT RELEASE PRESSURE
P STAT , 0.1 BAR GA.
MAXIMUM PRESSURE DURING
VENTING, P RED , BAR GA.
P red
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
EXAMPLE APPENDIX B
K ST [bar·m·s-1]
STRONG IGNITION SOURCE
1 < K ST < 200 : St 1
201 < K ST < 300 : St 2
301 < K ST : St 3
VENT AREA, F
[m2]
VESSEL VOLUME, V
[m3]
10
1
0,1
1
10
100

Nomograph D

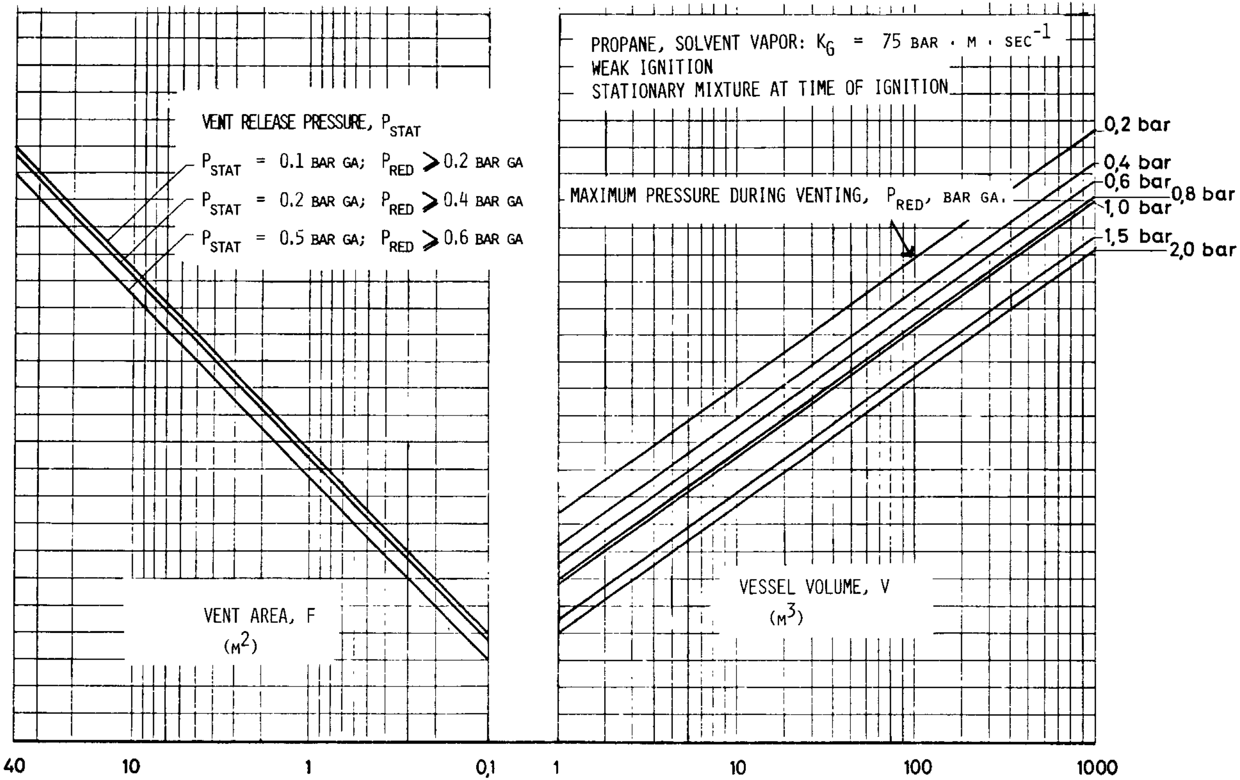

St1
St2
St3
COMBUSTION VENTING FOR
FLAMMABLE DUSTS
VENT RELEASE PRESSURE
P_{STAT}, 0.2 BAR GA.
MAXIMUM PRESSURE DURING
VENTING, P_{RED}, BAR GA.
P_{red}
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
K_{ST} [bar·m·s^{-1}]
STRONG IGNITION SOURCE
1 < K_{ST} < 200 : St 1
201 < K_{ST} < 300 : St 2
301 < K_{ST} : St 3
VENT AREA, F
[m^2]
VESSEL VOLUME, V
[m^3]
10
1
0,1
1
10
100

Nomograph E

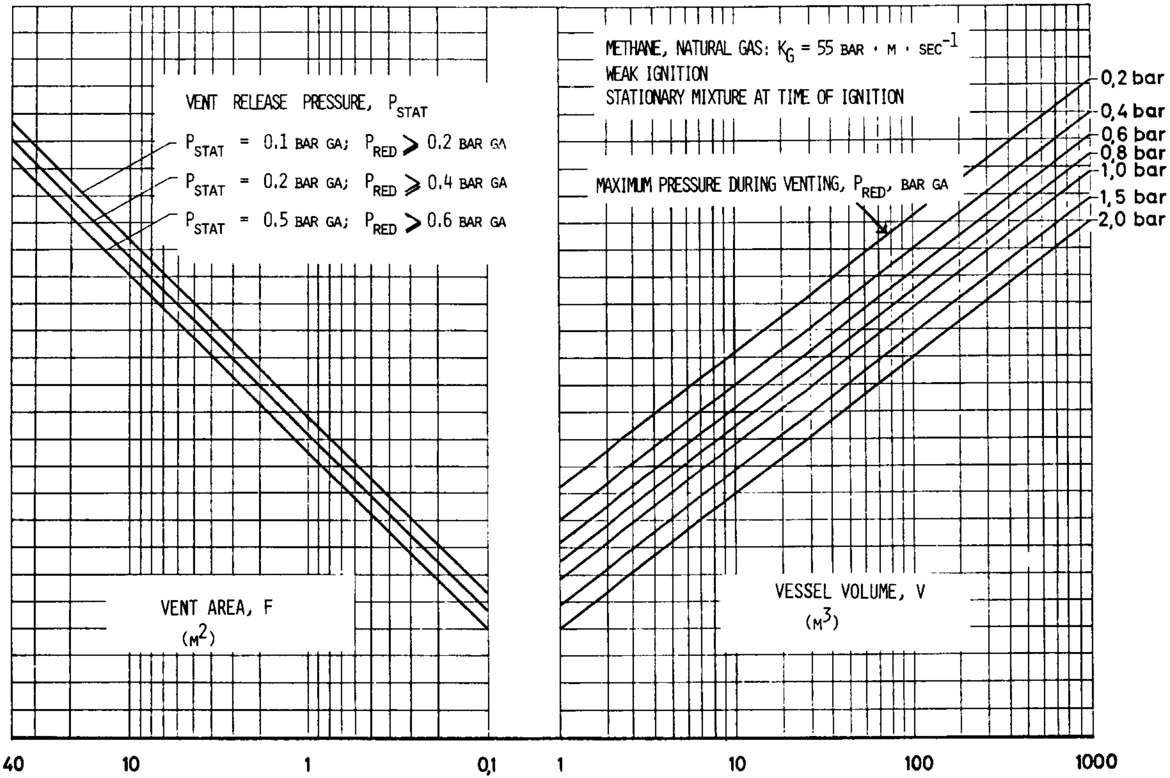


St 1
St 2
St 3
COMBUSTION VENTING FOR FLAMMABLE DUSTS
VENT RELEASE PRESSURE P_{STAT}, 0.5 BAR GA.
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA.
$P_{red.}$
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
K_{ST} [bar·m·s-1]
STRONG IGNITION SOURCE
1 < K_{ST} < 200: St 1
201 < K_{ST} < 300: St 2
301 < K_{ST} : St 3
VENT AREA, F
[m2]
VESSEL VOLUME, V
[m3]
10
1
0,1
1
10
100

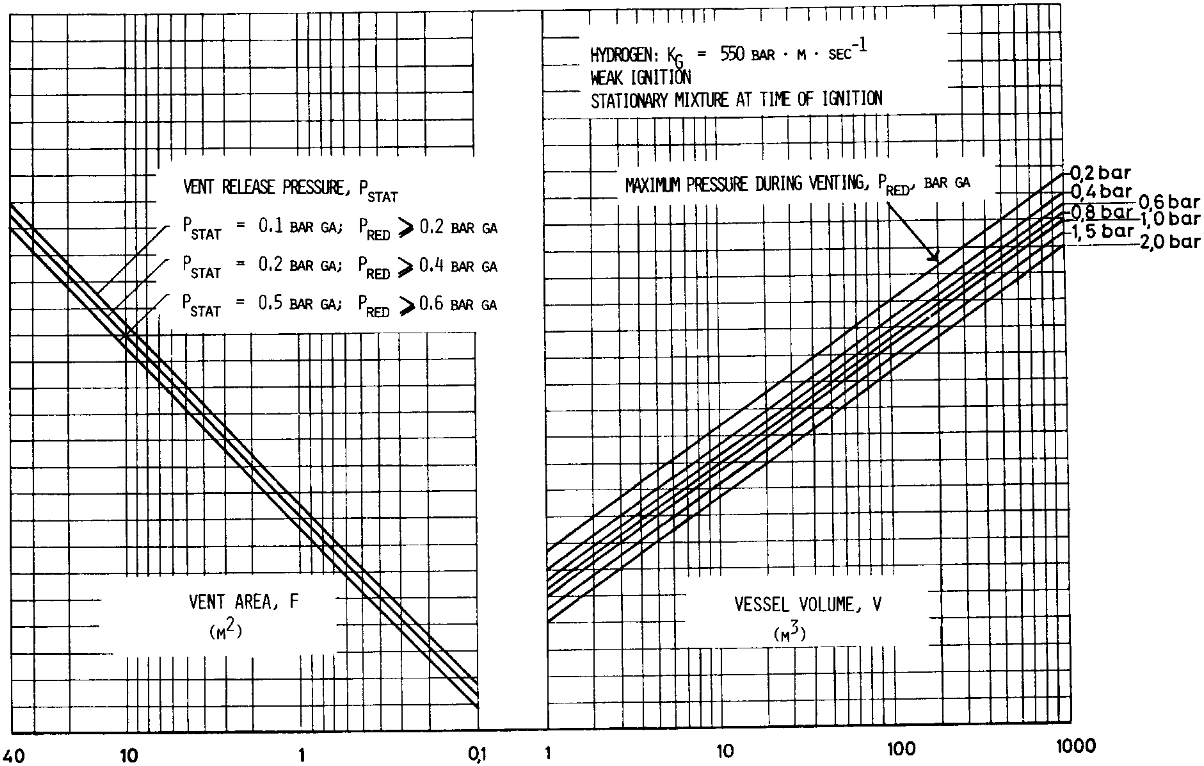
Nomograph F


PROPANE, SOLVENT VAPOR: K_G = 75 BAR · M · SEC^{-1}
WEAK IGNITION
STATIONARY MIXTURE AT TIME OF IGNITION
VENT RELEASE PRESSURE, P_{STAT}
P_{STAT} = 0.1 BAR GA; P_{RED} ≥ 0.2 BAR GA
P_{STAT} = 0.2 BAR GA; P_{RED} ≥ 0.4 BAR GA
P_{STAT} = 0.5 BAR GA; P_{RED} ≥ 0.6 BAR GA
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA.
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
VENT AREA, F
(M^2)
VESSEL VOLUME, V
(M^3)
40
10
1
0,1
1
10
100
1000

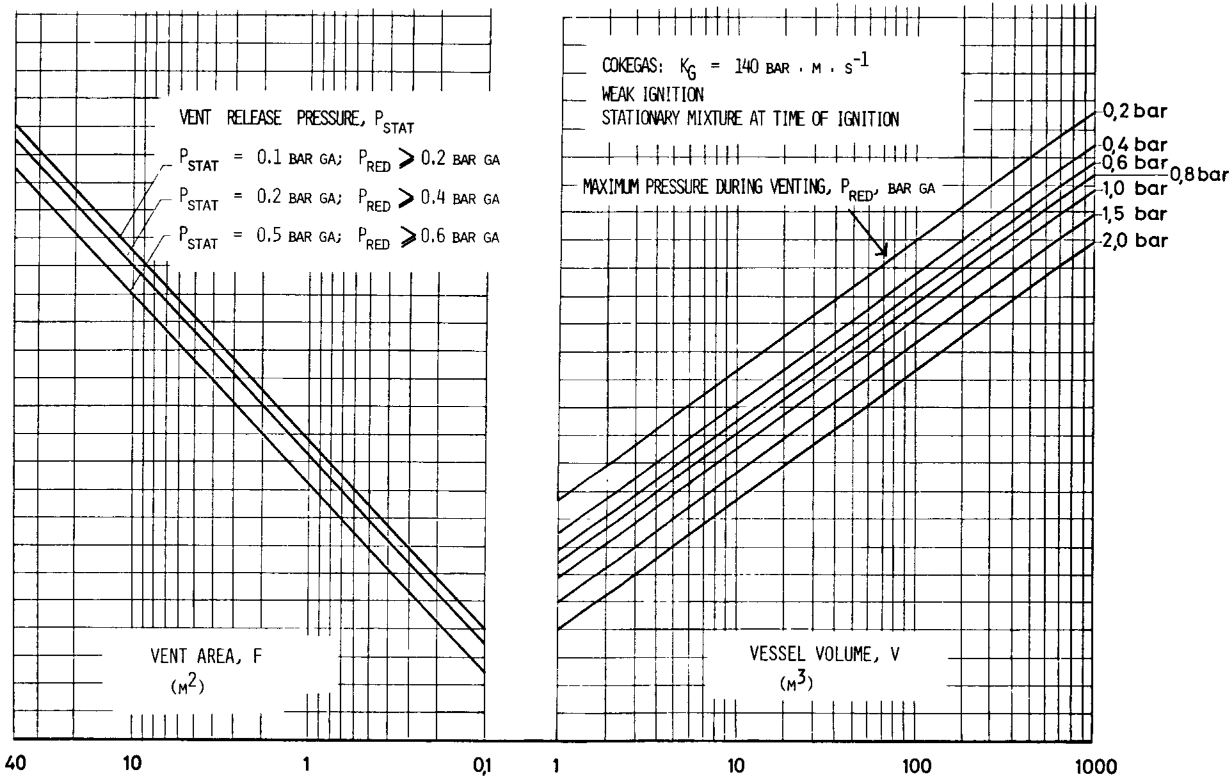
Nomograph G


VENT RELEASE PRESSURE, P STAT
P STAT = 0.1 BAR GA; P RED > 0.2 BAR GA
P STAT = 0.2 BAR GA; P RED ≥ 0.4 BAR GA
P STAT = 0.5 BAR GA; P RED > 0.6 BAR GA
VENT AREA, F
(M2)
METHANE, NATURAL GAS: KG = 55 BAR · M · SEC-1
WEAK IGNITION
STATIONARY MIXTURE AT TIME OF IGNITION
MAXIMUM PRESSURE DURING VENTING, P RED, BAR GA
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
VESSEL VOLUME, V
(M3)
40
10
1
0,1
1
10
100
1000

Nomograph H


HYDROGEN: K_G = 550 BAR · M · SEC^{-1}
WEAK IGNITION
STATIONARY MIXTURE AT TIME OF IGNITION
VENT RELEASE PRESSURE, P_{STAT}
P_{STAT} = 0.1 BAR GA; $P_{RED} \geq$ 0.2 BAR GA
P_{STAT} = 0.2 BAR GA; $P_{RED} \geq$ 0.4 BAR GA
P_{STAT} = 0.5 BAR GA; $P_{RED} \geq$ 0.6 BAR GA
MAXIMUM PRESSURE DURING VENTING, P_{RED}, BAR GA
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
VENT AREA, F
(M^2)
VESSEL VOLUME, V
(M^3)
40
10
1
0,1
1
10
100
1000

N h I


VENT RELEASE PRESSURE, P STAT
P STAT = 0.1 BAR GA; P RED ≥ 0.2 BAR GA
P STAT = 0.2 BAR GA; P RED ≥ 0.4 BAR GA
P STAT = 0.5 BAR GA; P RED ≥ 0.6 BAR GA
VENT AREA, F
(M²)
COKEGAS: K G = 140 BAR · M · S⁻¹
WEAK IGNITION
STATIONARY MIXTURE AT TIME OF IGNITION
MAXIMUM PRESSURE DURING VENTING, P RED, BAR GA
VESSEL VOLUME, V
(M³)
0,2 bar
0,4 bar
0,6 bar
0,8 bar
1,0 bar
1,5 bar
2,0 bar
40
10
1
0,1
1
10
100
1000

Nomograph J

Appendix B Sample Calculations

This Appendix is not a part of this NFPA document, but it is included for information purposes only.

Part I

Sample Calculations for Combustion Venting for Buildings

B-1 Summary. The equation for combustion venting for buildings is given in A-2.2 as follows:

$$A_v = \frac{CL_1L_2}{\sqrt{P}} \qquad \text{(Eq 1)}$$

There is an important constraint:

$$L_3 \leq 3\sqrt{L_1L_2}$$

L_3 = longest building dimension, ft or m

B-2 Other Important Considerations.

B-2.1 Maximum Allowable Overpressure, P. The purpose of building venting is to prevent serious structural damage and production of lethal projectiles. The maximum allowable overpressure, P, is the static loading which the weakest member of the structure can withstand.

Care must be taken to be sure the weakest member is recognized. All members of the structure, walls, windows, floors, ceilings, and roofs need to be considered. It is important to keep in mind that floors and roofs are not often designed to take much loading from beneath.

A qualified structural designer is needed for making the evaluation. His analysis must be based on the actual design and condition of the structure to be protected.

B-2.2 The Constant, C. The value of the constant depends on the type of flammable gas or dust present and whether the calculation is made in English units (ft, lbf/in.^{2}) or in SI units (m, kN/m^2). For gases such as natural gas, pentane, benzene, acetone, or vinyl acetate, and for most flammable mists and dusts, the recommended value for the constant is 2.6 in English units, 6.8 in SI units.

Gases like ethylene, butadiene and hydrogen burn faster than aliphatic or aromatic hydrocarbons. The recommended value of the constant for ethylene or butadiene is 4 in English units, 10.5 in SI units; for hydrogen 6.4 in English units, 17 in SI units.

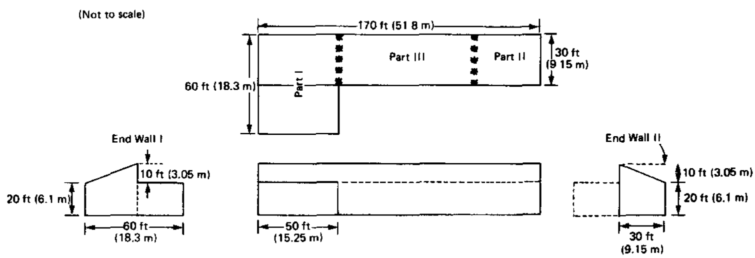
B-2.3 Vent Area. As mentioned earlier, the procedure is based on the assumption of open, unobstructed vents. See Appendix A for vent panel design criteria which permit venting performance to approach that of open vents.

B-2.4 Building Reinforcing. It is not always feasible to obtain the vent area required to protect the integrity of a building unless some of the weaker members of the structure are reinforced. When reinforcement is required, the expected overpressure needs to be calculated, using the actual vent area. Weak members must be reinforced to withstand the expected overpressure.

$$Pe = (P)(A/Aa)^2 \qquad \text{(Eq 2)}$$

Pe = expected overpressure, lbf/in.^{2}, i.e., psi, or kN/m^2
P = overpressure used in calculating required vent area, lbf/in.^{2} or kN/m^2
A = required vent area, ft^2 or m^2
Aa = vent area actually obtainable, ft^2 or m^2

B-3 Sample Calculation. Consider the following building:



B-3.1 Calculate the required vent area according to equation (1) in Section B-1. Before the calculations can be made, the shape of the building should be "normalized," and the building considered as several separate parts. Normalizing consists of combining several irregular portions of a building into a simple rectangular structure of equivalent surface area and volume. The building shown here can be divided into three parts and each part normalized as follows:

B-3.1.1 Consider the "foot" of the "L" as one structure, called Part I in the illustration. Normalize the height to the area of End Wall I.

$$\text{Wall I area} = (60 \times 20) + (0.5 \times 30 \times 10)$$
$$= 1{,}350 \text{ ft}^2 \ (125.4 \text{ m}^2)$$
$$\text{Normalized height} = 1{,}350 \text{ ft}^2/60 = 22.5 \text{ ft} \ (6.88 \text{ m})$$

The vent area required for Part I will be the same as for a structure with:

$$L_1 = 22.5 \text{ ft} \ (6.86 \text{ m})$$
$$L_2 = 50 \text{ ft} \ (15.25 \text{ m})$$
$$L_3 = 60 \text{ ft} \ (18.30 \text{ m})$$

B-3.1.2 The "leg" of the "L" is normalized on the basis of the area of End Wall II.

$$\text{Wall II area} = (30 \times 20) = (0.5 \times 30 \times 10)$$
$$= 750 \text{ ft}^2 \ (69.7 \text{ m}^2)$$
$$\text{Normalized height} = 750/30 = 25 \text{ ft} \ (7.62 \text{ m})$$

Therefore,

$$L_1 = 25 \text{ ft} \ (7.62 \text{ m})$$
$$L_2 = 30 \text{ ft} \ (9.15 \text{ m})$$

The maximum permissible length to which L_1 and L_2 can be applied is:

$$L_3 = 3\sqrt{L_1L_2} = 3 \times 27.4 = 82.2 \text{ ft} \ (25.1 \text{ m})$$

The actual length of the leg is 170 ft − 50 ft = 120 ft (36.6 m). Therefore, the leg needs to be considered as two parts. These are designated Part II and Part III in the illustration. Part II and Part III require the same vent area according to the calculation procedure. The boundary between Part II and Part III should be located in a way which permits symmetrical distribution of vent area over the entire building. Sometimes it is not necessary to locate the boundary to make calculations. Sometimes it is. Both cases will be illustrated.

B-3.2 Calculate the Vent Area for Normalized Parts I, II, and III. Let us assume for purpose of illustration that the maximum allowable overpressure for the building has been estimated by a structural engineer to be 0.5 psi (3.45 kN/m²) and that the flammable material in the building is a typical aliphatic or aromatic hydrocarbon for which the C value is 2.6 in English units, 6.8 in SI units. The vent area required for each part of the building can be calculated as follows:

B-3.2.1 For Part I:

$L_1 = 22.5$ ft (6.86 m)
$L_2 = 50$ ft (15.25 m)
$A_1 = 2.6 \times 22.5 \times 50/(0.5)^{1/2} = 4{,}137\ ft^2$, or
$A_1 = 6.8 \times 6.86 \times 15.25/(1.857)^{1/2} = 384.3\ m^2$

It is recommended practice to locate vents only in roofs and outside walls. Inside walls and the imaginary boundaries used to facilitate calculation of vent areas cannot be included as vents. Consequently, for Part I the maximum area available for locating vents is:

$$\text{Wall surface} = (60 \times 20) + (0.5 \times 30 \times 10) + (50 \times 20 \times 2) + (50 \times 10) + 30 \times 20 = 4{,}450\ ft^2\ (413.4\ m^2)$$

$$\text{Roof surface} \cong 50 \times 60 = 3{,}000\ ft^2\ (278.7\ m^2)$$

The total maximum available surface $\cong 7{,}450\ ft^2\ (692.1\ m^2)$. For Part I, the vents can be confined to the walls only if virtually all the wall surfaces are available. In actual practice, wall surfaces are rarely totally available for the location of explosion vents. In a real case some of the vent area would have to be located in the roof. If roof locations were not available, some members of the structure would have to be reinforced to prevent serious damage.

B-3.2.2 For Parts II and III:

$L_1 = 25$ ft (7.62 m)
$L_2 = 30$ ft (9.15 m)
$A_2 = 2.6 \times 25 \times 30/(0.5)^{1/2} = 2{,}758\ ft^2$, or
$A_2 = 6.8 \times 7.62 \times 9.15/(3.45)^{1/2} = 256.2\ m^2$

The total vent area required for Parts II and III combined is:

$$2A_2 = 5{,}516\ ft^2\ (512.4\ m^2)$$

This is the vent area required to protect the "leg" of the "L" of our illustration.

The total wall surface available on the "leg" is:

$$750 + 120 \times (30 + 20) = 6{,}750\ ft^2\ (627.1\ m^2)$$

The roof surface is about:

$$30 \times 120 = 3{,}600\ ft^2\ (384.4\ m^2)$$

The required vent area needs to be distributed as symmetrically as possible over the available surfaces.

Since there is plenty of available vent area, location of the boundary between Part II and Part III is not required in this example.

B-3.3 Estimate the Effect of Actual Vent Area on Expected Overpressure. It is not always possible to get sufficient vent area to assure that the maximum allowable overpressure will not be exceeded. For example, let us assume that the leg of our "L" shaped building has certain venting restrictions; namely, that only the end and front walls are available for venting. The back wall and roof cannot be used. The available wall surface in this example is:

$$750 + 120 \times 30 = 4{,}350 \text{ ft}^2 \ (404.1 \text{ m}^2)$$

This is not enough vent area to keep the maximum expected overpressure below 0.5 psi (3.45 kN/m^2). Serious explosion damage could be expected unless the structure is strengthened. There are two ways to proceed.

B-3.3.1 Consider the leg as a single structure. From equation (2) the expected overpressure with the limited vent area is:

$$\begin{aligned} Pe &= (P)\,(A/Aa)^2 \\ &= (0.5)\,(5{,}516/4{,}350)^2 = 0.80 \text{ psi } (5.5 \text{ kN/m}^2) \end{aligned}$$

The members of the structure, walls, ceilings, roof, etc., which cannot withstand this amount of overpressure will need to be strengthened so that they can withstand the expected overpressure.

B-3.3.2 Consider the leg as two parts (Part II and Part III). By proper location of the imaginary boundary, Part II can be sized with sufficient vent area to keep its expected overpressure to 0.5 psi. In this case the length, L_3, of Part II needs to be enough for the required vent area of 2,758 ft^2 (256.2 m^2) to be provided.

$$\begin{aligned} 750 \text{ ft}^2 + 30\,L_3 &= 2{,}758 \text{ ft}^2 \\ L_3 &= (2{,}758 - 750)/30 = 67 \text{ ft } (20.44 \text{ m}) \end{aligned}$$

Since this dimension is greater than L_2 and less than $3\sqrt{L_1L_2}$, it meets the criteria for length and results in acceptable proportions for Part II. With these dimensions, Part II would not need to be reinforced. The length of Part III is consequently 120 − 67 = 53 ft (16.2 m). This length likewise falls between L_2 and $3\sqrt{L_1L_2}$ for Part III, so that the proportions of Part III are acceptable. However, the area available for venting is only 30 x 53 = 1,590 ft^2 (147.7 m^2). The expected overpressure is then $Pe = (0.5)\,(2{,}758/1{,}590)^2 = 1.5$ psi (10.3 kN/m^2). The structural members which comprise Part III would therefore need to be strengthened to withstand this overpressure.

B-3.3.3 Finally, we can consider the case where a major part of the building cannot be vented except into another section of the building. Assume, for example, that Part I can only vent into Parts II and III. In this case the effective vent area for Part I is only 750 ft^2 (69.6 m^2), and the expected overpressure is:

$$Pe = (0.5)(4{,}137/750)^2 = 15.2 \text{ psi } (104.9 \text{ kN/m}^2)$$

Structural failure will almost certainly occur in Part I.

The case illustrates the need for symmetrical distribution of vents. It shows that if vents are not symmetrically distributed significant overpressures can develop in parts of a building. Severe damage will occur.

B-4 Compartments. Buildings are often compartmentalized into several rooms and levels. Usually each compartment must be treated as an independent unit for purposes of evaluating its explosion protection requirement. It is not recommended practice to vent one compartment into another; venting needs to be outside.

Consider, for example, a fully enclosed room with dimensions 15 x 20 x 30 ft located on the second floor of a building. The dimensions of the outside wall available for venting are 15 x 20 ft. For a typical hydrocarbon combustion the expected overpressure, by rearrangement of equation (1) is:

$$P = (2.6\ L_1L_2/A)^2 = [2.6 \times (15 \times 20)/(15 \times 20)]^2$$
$$= 6.8 \text{ psi } (46.9 \text{ kN/m}^2)$$

The inside walls, doors, windows, duct seals, floor, ceiling, etc., must all be able to withstand this overpressure in order to prevent structural failure of the rooms. A thorough investigation of the room and its components is required to be sure every member is reinforced as necessary.

Part II

Sample Calculations for Combustion Venting for Dust Deflagrations Inside Equipment

B-5 Introduction. The object of venting is to allow for the relief of the products of combustion of a dust before a pressure can develop which will cause damage to the containing vessel. Closed vessel combustion of most dusts with air, at atmospheric pressure, can develop a maximum pressure of about 100 psig (7 bar ga.). A vent which has low mass per unit area, opens at a low pressure, and has sufficient area can reduce the maximum pressure developed to a lower value.

The required vent area, for a vent of low mass/area, is a function of vessel volume, dust class, vent release pressure, ignition energy, and the maximum pressure not to be exceeded during the dust deflagration. These variables and their effects are discussed in Chapters 2 and 3, and in Appendix A. Nomographs A–F, attached to Appendix A, can be used to determine the vent area required for a vessel. Units of length are expressed in the nomographs as meters, units of pressure as bars gage.

B-5.1 Vessel Volume (m^3). For venting calculations, the worst case must be assumed. This is the full volume of the vessel.

B-5.2 Dust Class (St-1, St-2, St-3). "Dust Class" is related to the maximum rate of pressure rise during a dust combustion. This must be determined in a closed (unvented) test vessel of sufficient pressure capability and equipped with high-speed pressure recording equipment. The recorder gives a graph of pressure versus time. From this graph the maximum slope can be determined. This is called $(dp/dt)_{max}$ and can be expressed in units of bar/sec. This value is then multiplied by the cube root of the volume of the test vessel, $V^{1/3}$. Vessel volume can be expressed in cubic meters. The product of the two terms thus determined gives the value, K_{St}, for the dust:

$$(dp/dt)_{max} \cdot V^{1/3} = K_{St}$$

The units of K_{St}, thus calculated, are bar · meter · sec^{-1}. The following are the ranges of K_{St} for the various dust classes.

Dust Class	K_{St}, bar · m · sec^{-1}
St-1	≤ 100
St-2	101–200
St-3	< 200

B-5.3 Vent Release Pressure (bar ga.; P_{stat}). Opening of a vent during combustion will reduce the pressure development. The lower the pressure at which the vent opens, the lower will be the maximum pressure developed during the combustion. Vent release pressure should be as low as possible without being so low that normal pressure variations in the vessel will open the vent.

The venting device needs to have a low inertia, below 2 lb/sq ft (10 kg/m^2). A thin, rupture-type membrane device is available for this purpose. In some cases a venting panel, not exceeding the maximum allowable inertia, is used. The design must prevent buildup of deposits on the inside of the venting device. It must also prevent malfunction due to snow or ice on the outside. The venting device must not impose hazard to people or equipment when it opens. For example, a vent panel will need suitable hinging. Similarly, the large ball of flaming dust that comes out during venting must not impose hazard to people or equipment.

B-5.4 Ignition Energy (Weak, Strong). The nomographs for dusts (Nomographs A–F) provide for two types of ignition of a dust deflagration. A "weak" ignition occurs within the vessel, for instance, from a hot surface or a static spark. A "strong" ignition occurs when a burning cloud of dust enters the vessel through a duct, or if an open fire exists when the dust cloud is formed in the vessel. If there is any doubt about potential ignition sources, assume a strong ignition.

B-5.5 Desired Maximum Pressure (bar ga.; P_{red}). When a dust deflagration occurs, the maximum pressure to be reached during venting should be no more than two-thirds of the pressure which will cause the weakest part of the vented vessel to break. This location is usually a welded joint at the roof or at a bottom cone.

B-5.6 Sample Calculations.

B-5.6.1 Assume:

(a) Vessel has a flammable mixture of air with a dust of class St-1.

(b) Vessel volume is 20 m^3; vessel L/D is 2.

(c) Initial pressure is atmospheric.

(d) Ignition energy is assumed to be large.

(e) Vent release pressure is 0.1 bar ga.; venting device has mass per unit area less than 2 lb/ft^2 (less than 10 kg/m^2).

Determine the vent area to prevent pressure from exceeding 0.2 bar ga.

Use the dust venting nomograph, Nomograph D, for vent release pressure of 0.1 bar ga. and strong ignition source. On the right hand side of the nomograph draw a line vertically upward to 20 m^3 to intersect the 0.2 bar line for P_{red}. From the intercept draw a horizontal line to the left to intersect the line for dust class St-1. From that intercept draw a line vertically downward to the line showing vent area. The necessary vent area is 2.3 m^2.

See Appendix A for discussion of the need to vent to the outdoors and the limitations of vent ducts.

Part III

Sample Calculation for Venting Gas Deflagrations Inside Equipment

B-6 Introduction. The object of venting is to allow for the relief of the products of combustion of a gas before a pressure can develop which will cause damage to the containing vessel. A non-vented deflagration of most gases with air, beginning with an initial pressure of atmospheric, can develop a pressure of about 100 psig (7 bar ga.). A vent which has low mass per unit area, opens at a low pressure, and has sufficient area can reduce the maximum pressure developed to a lower value.

The required vent area, for a vent of low mass/area, is a function of a vessel volume, gas K_G value, vent release pressure, amount and type of ignition energy, initial turbulence, and the maximum pressure not to be exceeded during the gas deflagration. These variables and their effects are discussed in Chapters 2 and 3, and in Appendix A. Nomographs G–J in Appendix A can be used to determine the vent area required for a vessel. Units of length are expressed in the nomographs as meters, units of pressure as bars gage.

B-6.1 Vessel Volume (m^3). For venting calculations, the worst case must be assumed. This is the full volume of the vessel.

B-6.2 Gas K_G Value. The K_G value for a gas is a function of the fundamental burning velocity of that gas. The K_G value is related to the maximum rate of pressure rise during a gas deflagration. This must be determined in a closed (unvented) test vessel of sufficient pressure capability and equipped with high-speed pressure recording equipment. The recorder gives a graph of pressure versus time. From this graph the maximum slope can be determined. This is called $(dp/dt)_{max}$ and can be expressed in units of bar/sec. This value is then multiplied by the cube root of the volume of the test vessel, $V^{1/3}$. Vessel volume can be expressed in cubic meters. The product of the two terms thus determined gives the value, K_G, for the gas:

$$(dp/dt)_{max} \cdot V^{1/3} = K_G$$

The units of K_G, thus calculated, are bar · meter · sec^{-1}.

Gases of most organic compounds have similar fundamental burning velocities and hence have similar values of K_G. The K_G value for such materials is about the same as that for propane, i.e., 75. This includes K_G values for materials like butane, benzene, gasoline, acetone, ethyl acetate, and many others.

As shown in Table A-4.1(a), hydrogen has a K_G of 550. Certain other gases also have higher K_G values than 75. If there is substantial doubt about the K_G value for a particular gas, that gas should be tested as described above for determining K_G values.

B-6.3 Vent Release Pressure (bar ga.; P_{stat}). Opening of a vent during combustion will reduce the pressure development. The lower the pressure at which the vent opens, the lower will be the maximum pressure developed during the combustion. Vent release pressure should be as low as possible without being so low that normal pressure variations in the vessel will open the vent.

The venting device needs to have a low inertia, below 2 lb/sq ft (10 kg/m^2). Since operating pressures in gas handling equipment are often substantially above atmospheric, the venting devices are frequently some form of rupture disc. The design must prevent buildup of deposits on the inside of the venting device. It must also prevent malfunction due to snow or ice on the outside. The venting device must not impose hazard to people or equipment when it opens. Similarly the large tongue of flaming gas issuing from the vent must not impose hazard to people or equipment.

B-6.4 Ignition Energy (Amount and Type). The nomographs for gases (Nomographs G–J) are based on a small or weak ignition energy, about 10 Ws (watt-seconds), from a small, continuous electric discharge. Other forms of ignition can result in high flame speeds with the consequent need for larger vent area. For example, the normal K_G for propane is 75. As shown in Table A-4.1(b), the K_G for propane changes to about 750 when the ignition is by 100 Ws of energy from a condenser discharge in a spark. If ignition in the practical case could give a high K_G value for propane or other similar K_G-value gas, the nomographs for hydrogen (Nomograph I, K_G = 550) can be used instead of that for propane (Nomograph G). A slight extrapolation of required vent area may be advisable on account of the 750 value for propane K_G versus the 550 value for hydrogen.

B-6.5 Initial Turbulence. Nomographs G–J are for fuel gas mixtures with air which are quiescent at the time of ignition. The test vessels also contained no internal obstructions that would lead to turbulence increase during combustion. Turbulence leads to increase of K_G for the gas. Thus, as shown in Table A-4.1(a), initial high turbulence increases the K_G for propane from 75 to 500. For such a case the nomograph for hydrogen, K_G = 550 (Nomograph I), can be used.

Note that, as shown in Table A-4.1(a), the effects of initial turbulence vary with the basic K_G value for the gas.

B-6.6 Desired Maximum Pressure (bar ga.; P_{red}). When a gas deflagration occurs, the maximum pressure to be reached during venting should be no more than two-thirds of the pressure which will cause the weakest part of the vented vessel to break.

B-6.7 Initial Elevated Pressure. Quite often, industrial equipment which must be vented for combustion is operated at pressures significantly above atmospheric. Nomographs G–J are for gases at initial pressure of atmospheric. In A-4.3 the calculation for effect of initial elevated pressure is discussed. For gases having a K_G of about 75 the pressure resulting from venting of a vessel at initial elevated pressure will vary approximately as the 1.5 power of the absolute pressure of gas in the vessel before ignition. The exponent for gases having higher K_G values is discussed in A-4.3.

B-6.8 Sample Calculations.

B-6.8.1 Assume:

(a) Vessel has flammable mixture of air and acetone.
(b) Vessel volume is 20 m^3; vessel L/D is 2.
(c) Initial pressure in vessel at time of ignition is 2 bar absolute.
(d) Ignition energy is small, say 10 Ws or less; no initial turbulence and no internal obstructions to cause turbulence generation.
(e) Vent release pressure is 2.2 bar absolute; vent device has low mass/area, less than 1.5 lb/ft^2 (less than 7.5 kg/m^2).

Calculate the pressure resulting from venting with a vent area of 2.0 m^2.

Assume the flame speed in air-acetone mixture will be approximately the same as that for propane. On this basis, assume K_G is 75 and use Nomograph G.

Vent release absolute pressure/initial pressure = 2.2/2 = 1.1. Therefore read from Nomograph G where vent release pressure = 0.1 bar ga. Enter the nomograph on the left hand side at vent area of 2 m^2. Draw a line vertically upward to intersect the slanting line for P_{stat} of 0.1 bar. From the intercept draw a horizontal line to the family of lines for P_{red}. Also draw a line vertically upward at 20 m^3 to intersect the horizontal line just drawn. These two lines intersect at the slanting line for 0.6 bar ga.

The 0.6 bar ga. equals 1.6 bar absolute. On the basis of an initial pressure of 2 bar absolute, the peak pressure reached during venting will be $(2 \text{ bar abs}/1 \text{ bar abs})^{1.5} \times 1.6$ bar abs. The calculation result is a final pressure of 2.83 x 1.6, or 4.53 bar abs, or 3.53 bar ga. The 3.53 bar ga. equals 51.2 lb/in. ga., or 353 kN/m^2.

As an alternate, a series of tests could be made in a smaller vessel of, say, 1 m^3 volume. The tests could be conducted with a propane-air mixture in which the propane concentration is 10 percent higher than stoichiometric. Initial pressure would be 2.0 bar abs. Vents of low mass/area and of various areas would then be tested. To achieve, with the 20 m^3 vessel, the same pressure as that found in a test on the 1 m^3 vessel with a given vent area, that vent area would be calculated over the 20 m^3 volume on the basis of the cubic law. The equation to use is:

$$F_2 = \frac{F_1 V_2^{2/3}}{V_1^{2/3}}$$

For definition of terms see Section A-3 of this guide.

Appendix C Explosion Reliefs for Ducts and Elongated Vessels (31)

This Appendix is not a part of this NFPA document but is included for information purposes only.

Wherever flammable vapors and gases occur inside an industrial plant, there is the danger of a gaseous explosion. The main precaution taken to avoid an explosion is to prevent the concentration of the flammable gas or vapor from falling within the flammable limits in air. Thus, when pure methane is passed through a duct there is no danger of explosion unless an accident occurs which results in an approximately seven-fold dilution with air of the methane in the duct; this would bring the concentration of methane down to the upper explosive limit. Conversely, in other systems precautions can be taken to reduce the concentration of flammable gas to well below the lower explosive limit. For many processes, it is not possible to be sure that at all times the concentration of flammable gas will be outside the flammable limits. Under these conditions, the plant has to be designed so that if an explosion were to occur the minimum amount of damage would ensue. One of the ways in which this is done is to use explosion reliefs. These are provided on the side of the piece of equipment concerned and are designed to open very early in an explosion and allow the harmless release of the products of combustion of the explosion. The area of these vents should be large enough to relieve the explosion gases sufficiently quickly to prevent the maximum pressure from reaching a value greater than the pressure the container can withstand.

Plants in which flammable gases and vapors are handled in industry vary widely in size and shape and duct systems of differing degrees of complexity are used to connect items for plants in which various processes are carried out. Information on the provision of explosion reliefs for containers approximately cubical in shape have been published elsewhere following the work of the Gas Council on Explosion Reliefs for Drying Ovens (Reference 71). In this note, design data for explosion relief for ducts and elongated vessels are provided. These data are based mainly on work carried out at the Joint Fire Research Organization on the venting of gaseous explosions in ducts (References 81 and 82). The ducts varied in dimensions from 3 in. diameter to 12 in. square section and from 6 to 30 ft long. In most experiments, propane/air or pentane/air mixtures were used as the explosive gas, although a few experiments were carried out with ethylene/air and methane/air mixtures. The correlation of the results of this work and also the inclusion of other sources of information do allow, however, the results to be extrapolated to ducts with diameters up to about 2 ft 6 in. and to a number of other gases.

Scope.

This guide may be used to design explosion reliefs for ducts and elongated vessels where L/D is equal to or greater than 6 and D does not exceed 2 ft 6 in. The basic formula given in the section entitled "Size and Spacing of Explosion Reliefs for Stationary Gases or Gases Moving at Speeds of less than 10 ft/s" will provide design data for straight, unobstructed ducts containing propane/air mixtures moving at velocities of less than 10 ft/s.

If the ducts are not straight or contain obstacles, additional relief is required and this may be calculated by using the information given in the section entitled "Size and Spacing of Explosion Reliefs for Stationary Gases or Gases Moving at Speeds of less than 10 ft/s."

The section entitled "Size and Spacing of Explosion Reliefs for Gases Moving at Speeds of 10–60 ft/s" deals with propane/air mixtures which are moving at velocities of between 10 ft/s and 60 ft/s.

Correction factors given in the section entitled "Data for Gases other than Propane" should be employed when vessels containing gases other than propane are to be protected.

Where L/D is less than 6, the design data given by Simmonds and Cubbage (Reference 71) may be used, but since this work was carried out on vessels where L/D did not exceed 3, it may lead to the provision of explosion relief with an increased factor of safety as L/D approaches 6.

Principle of Relief Venting for Ducts and Long Vessels.

When a gas is ignited at the center of a long vessel, the products of combustion can first expand freely until the flame reaches the vessel walls. Thereafter, the products of combustion expand in two directions along the length of the vessel. During this period, if the flammable gas is hydrocarbon vapor, the flames travel initially at a speed of about 10–20 ft/s. The expansion of the burnt combustion products behind the flame in the duct causes a motion of the unburnt gas ahead of the flame. After a short time this moving unburnt gas becomes turbulent and one of the consequences of this is that the rate of combustion at the flame front is increased. This process may result in the continued acceleration of the flame to very high speeds. Shock waves associated with the acceleration of the flame may also give rise to a large increase in pressure both in front and behind the flame and may also play a vital part in the eventual transition to a detonating combustion. Under the latter conditions, flame speeds of the order of 6,000 ft/s and pressures of several hundred lbf/in.^{2} may be obtained.