ANSI/NFPA 68 An American National Standard December 2, 1987

NFPA 68
Venting of Deflagrations
1988 Edition

NFPA®

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

NOTICE

All questions or other communications relating to this document should be sent only to NFPA Headquarters, addressed to the attention of the Committee responsible for the document.

For information on the procedures for requesting Technical Committees to issue Formal Interpretations, proposing Tentative Interim Amendments, proposing amendments for Committee consideration, and appeals on matters relating to the content of the document, write to the Secretary, Standards Council, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

A statement, written or oral, that is not processed in accordance with Section 16 of the Regulations Governing Committee Projects shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Users of this document should consult applicable Federal, State and local laws and regulations. NFPA does not, by the publication of this document, intend to urge action which is not in compliance with applicable laws and this document may not be construed as doing so.

Policy Adopted by NFPA Board of Directors on December 3, 1982

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

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

Statement on NFPA Procedures

This material has been developed under the published procedures of the National Fire Protection Association, which are designed to assure the appointment of technically competent Committees having balanced representation. While these procedures assure the highest degree of care, neither the National Fire Protection Association, its members, nor those participating in its activities accepts any liability resulting from compliance or noncompliance with the provisions given herein, for any restrictions imposed on materials or processes, or for the completeness of the text.

NFPA has no power or authority to police or enforce compliance with the contents of this document and any certification of products stating compliance with requirements of this document is made at the peril of the certifier.

R.P G-AM-93

Join over 63,000 professionals like yourself. Belong to NFPA!

You can have impact on issues that affect the fire safety industry—How?

When you belong to NFPA you'll receive special membership benefits that help you make informed decisions and make your voice a stronger one in the fire safety community. Your benefits include:

1. **Voting privileges** on proposed changes to existing codes and standards, and on new codes and standards.
2. The ***NFPA Journal***, *Fire News* newsletter, and *NFPA Journal Reference Directory & Buyers' Guide*—your source for fire statistics, reports, investigations, manufacturers, and codes and standards references.
3. **10% discount** on all products and services.
4. **Special invitations** to Annual, Fall, and Regional Meetings—where you can compare notes with your colleagues and take a position on issues that affect you. All these benefits—plus the pride and confidence that comes with membership in an internationally acclaimed organization can be yours for annual dues of $95.00. Join today!

☐ **YES! Send me an application to join my colleagues at NFPA today!**

Name ______________________ Date ______________________

Address ______________________ Signature ______________________

City, State, Zip ______________________

Code PA1

You can't beat this value on NFPA codes and standards...

Stay up-to-date on fire codes with this super, money-saving service!

In the dynamic world of fire protection, you need to keep up with current fire code requirements, recent changes, and new developments. The *National Fire Codes® Subscription Service* makes that an easier job! This complete service delivers every NFPA code and standard directly to you—over 280 essential codes in all! As a subscriber, you automatically receive new and revised documents from NFPA's Annual and Fall Meetings—as soon as they are published. Plus, additional mailings keep you informed of changes as they happen, so you are always working with the latest requirements.

☐ **YES! Start my subscription today! (Item No. 2H-NFCSS) $600.00 (NFPA Members $540.00*)**

Total amount enclosed $ ______________________

Name ______________________

Address ______________________

City, State, Zip ______________________

NFPA Member No. ______________________

☐ I enclose a check (payable to NFPA).

☐ Please bill me.

For easy ordering, call toll-free
1-800-344-3555!
Monday–Friday, 8:30 AM–8:00 PM, ET

* *Prices subject to change.*

Thank you for your purchases!

NFPA listens to our customers. Please let us know what you think.

What types of products would you like to see more of?

☐ seminars
☐ code handbooks
☐ general reference books
☐ videos
☐ training packages
☐ informational brochures
☐ electronic media
☐ other ______________________

In what subject area(s) would you like to see more products?

☐ electrical
☐ Fire Prevention Week
☐ public education
☐ other ______________________
☐ life safety
☐ fire service
☐ hazardous materials

How can NFPA better serve your needs?

____

____

____

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 3376 BOSTON, MA

POSTAGE WILL BE PAID BY ADDRESSEE

NATIONAL FIRE PROTECTION ASSOCIATION
1 BATTERYMARCH PARK
PO BOX 9101
QUINCY MA 02269-9904

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 3376 BOSTON, MA

POSTAGE WILL BE PAID BY ADDRESSEE

NATIONAL FIRE PROTECTION ASSOCIATION
1 BATTERYMARCH PARK
PO BOX 9101
QUINCY MA 02269-9904

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 3376 BOSTON, MA

POSTAGE WILL BE PAID BY ADDRESSEE

NATIONAL FIRE PROTECTION ASSOCIATION
1 BATTERYMARCH PARK
PO BOX 9101
QUINCY MA 02269-9904
Attn: Product Development

NFPA 68

Guide for

Venting of Deflagrations

1988 Edition

This edition of NFPA 68, *Guide for Venting of Deflagrations*, was prepared by the Technical Committee on Explosion Protection Systems, and acted on by the National Fire Protection Association, Inc. at its Fall Meeting held November 9-11, 1987 in Portland, Oregon. It was issued by the Standards Council on December 2, 1987, with an effective date of December 22, 1987, and supersedes all previous editions.

The 1988 edition of this standard has been approved by the American National Standards Institute.

Origin and Development of NFPA 68

The Guide for Venting of Deflagrations was first adopted as a temporary standard in 1945. In 1954, the temporary standard was replaced with a guide 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 were used for many years. Some of the vents designed using these "rules of thumb" functioned well; perhaps it is well that some others were never put to the test.

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

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

In 1979, the Committee began a major effort to rewrite the Guide in order to incorporate the results of the most recent test work done in Germany. In addition, the entire text was rewritten to more clearly explain the various parameters that affect the venting of deflagrations.

Committee on Explosion Protection Systems

A. Richard Albrecht, *Chairman*
Dow Chemical Co.
Rep. Chemical Manufacturers Assn.

John V. Birtwistle, Monsanto Co.
William J. Bradford, Brookfield, CT
Laurence G. Britton, Union Carbide Corp.
George P. Garland, Crown Fire Protection
Rep. Fire Suppression Systems Assn.
Joseph P. Gillis, Fenwal Inc.
Stanley S. Grossel, Hoffmann-LaRoche Inc.
Walter B. Howard, St. Louis, MO
George A. Krabbe, Automatic Suppression Systems Inc.
Rep. National Assn. of Fire Equipment Distributors
R. A. Mancini, Amoco Oil Co.
Rep. American Petroleum Institute
Robert W. Nelson, Industrial Risk Insurers
John A. Noronha, Eastman Kodak Co.
Anthony Santos, Factory Mutual Research Corp.
R. F. Schwab, Allied Corp.
C. E. Scott, Kemper Group
Rep. Alliance of American Insurers
Ian Swift, Fike Corp.
Harry Verakis, Mine Safety & Health Admin.
Robert C. Worthington, Central Sprinkler Corp.
Rep. National Fire Sprinkler Assn.
(Vote Limited to NFPA 69)

Alternates

Robert L. DeGood, Fike Metal Products Corp.
(Alternate to I. Swift)
J. D. Dick, Kemper Group
(Alternate to C. E. Scott)
David C. Kirby, Union Carbide Corp.
(Alternate to L. G. Britton)
Edward D. Leedy, Industrial Risk Insurers
(Alternate to R. W. Nelson)
Arnold L. Mundt, BS&B Safety Systems
(Alternate to BS&B Safety Systems Rep.)
Gregory G. Noll, American Petroleum Institute
(Alternate to R. A. Mancini)
Thomas K. Palmer, Automatic Fire Protection Systems
(Alternate to G. A. Krabbe)
Parker Peterson, Fenwal Inc.
(Alternate to J. P. Gillis)
Robert G. Zalosh, Factory Mutual Research Corp.
(Alternate to A. Santos)

This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

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

Contents

Chapter 1 General 68- 5
1-1 Scope 68- 5
1-2 Purpose 68- 5
1-3 Definitions 68- 5
1-4 Conversion Factors 68- 6
1-5 Symbols 68- 6

Chapter 2 Fundamentals of Deflagration 68- 7
2-1 Prerequisites 68- 7
2-2 Fuel 68- 7
2-3 Oxidant 68- 9
2-4 Burning Velocity and Flame Speed 68- 9
2-5 Ignition Source 68- 9
2-6 Initial Temperature and Pressure 68- 9
2-7 Turbulence 68-10
2-8 Presence of Moisture 68-10
2-9 Presence of Inert Material 68-10

Chapter 3 Fundamentals of Venting of Deflagrations 68-11
3-1 Deflagration Vents 68-11
3-2 Consequences of a Deflagration 68-11
3-3 Maximum Rate of Pressure Rise and Maximum Pressure 68-11
3-4 Vent Variables 68-11
3-5 Basic Recommendations for Venting 68-12

Chapter 4 Venting of Deflagrations in Low-Strength Enclosures 68-13
4-1 Introduction 68-13
4-2 General 68-13
4-3 Calculating the Vent Area 68-13
4-4 Calculation of Internal Surface Area 68-14
4-5 Enclosure Strength 68-14
4-6 Vent Design 68-15
4-7 Sample Calculation 68-15

Chapter 5 Venting of Deflagrations in High-Strength Enclosures — General 68-17
5-1 Introduction 68-17
5-2 Basic Principles 68-17
5-3 Correlating Parameters for Deflagration Venting 68-18
5-4 Effects of Vent Ducts 68-18
5-5 Exposure from the Venting Process 68-19
5-6 Location of Deflagration Vents Relative to Air Intakes 68-19

Chapter 6 Venting of Deflagrations of Gas Mixtures and Mists in High-Strength Enclosures 68-19
6-1 Nomographs for Deflagration Venting 68-19
6-2 Deflagration Venting of Gases Other than Those Specified on the Nomographs 68-20
6-3 Effects of Initial Turbulence and Internal Vessel Appurtenances for Enclosures with Initial Pressure Near Atmospheric 68-25
6-4 Use of the Nomographs with Hydrogen 68-25
6-5 Effect of High Ignition Energy 68-25
6-6 Extrapolation of Nomographs 68-25
6-7 Effect of Initial Elevated Pressure 68-26
6-8 Effect of Initial Temperature 68-26
6-9 Effects of Combinations of Variables 68-26
6-10 Deflagration of Mists of Combustible Liquids 68-26
6-11 Deflagration of Foams of Combustible Liquids 68-26
6-12 Venting Deflagrations of Combustible Gases Evolved from Solids 68-26
6-13 Venting of Deflagrations in Conveying and Ventilating Ducts 68-26

Chapter 7 Venting of Deflagrations of Dust Mixtures in High-Strength Enclosures 68-26
7-1 Introduction 68-26
7-2 Use of Dust Nomographs 68-32
7-3 Extrapolation and Interpolation of Nomographs 68-36
7-4 Bins, Hoppers, and Silos 68-36
7-5 Effects of Vent Ducts 68-36
7-6 Venting of Enclosed Bag Dust Collectors 68-36
7-7 Flame Clouds from Dust Deflagrations 68-36
7-8 Hybrid Mixtures 68-36

Chapter 8 Venting of Deflagrations from Pipes, Ducts, and Elongated Vessels Operating At or Near Atmospheric Pressure 68-36
8-1 Scope 68-36
8-2 General 68-37
8-3 Design Guidelines 68-37
8-4 Determination of P_{red} for Pipes, Ducts, or Elongated Vessels that are Vented at One End Only 68-37
8-5 Explosion Vent Requirements When More Than One Vent Can Be Provided 68-39
8-6 Examples 68-40

Chapter 9 Description of Deflagration Vents and Vent Closures 68-42
9-1 General 68-42
9-2 Normally Open Vents 68-42
9-3 Normally Closed Vents for Rooms, Buildings, and Other Large Enclosures 68-42
9-4 Restraints for Large Area Panels 68-44
9-5 Equipment Vent Closures 68-45

Chapter 10 Inspection and Maintenance 68-46
10-1 General 68-46
10-2 Definitions 68-46
10-3 Inspection Frequency and Procedures 68-46
10-4 Maintenance 68-46
10-5 Recordkeeping 68-46

Appendix A Guidelines for Measuring Deflagration Indices of Dusts and Gases 68-46
A-1 General Comments on Dust Testing 68-46
A-2 Basic Principles 68-46
A-3 Gas Testing 68-48
A-4 Dust Testing 68-49
A-5 Classification as "Noncombustible" 68-51
A-6 Instrumentation Notes 68-51

Appendix B Fundamental Burning Velocities for Selected Combustible Gases in Air 68-52

Appendix C Deflagration Characteristics of Selected Combustible Gases 68-54

Appendix D Deflagration Characteristics of Selected Combustible Dusts 68-54

Appendix E Referenced Publications 68-56

Index 68-59

NFPA 68

Guide for

Venting of Deflagrations

1988 Edition

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

Chapter 1 General

1-1 Scope.

1-1.1 This Guide applies to the design and use of devices and systems that will vent the combustion gases and pressures resulting from a deflagration within an enclosure so that structural and mechanical damage is minimized. The enclosure may be a room, a building, a piece of equipment, or any other type of enclosure. The deflagration may result from the ignition of a combustible gas, mist, or dust.

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

1-1.3 This Guide does not apply to devices that are designed to protect storage vessels against excess internal pressure due to external fire exposure or to exposure from other heat sources. (*See NFPA 30, Flammable and Combustible Liquids Code.*)

1-1.4 This Guide does not apply to emergency vents for runaway exothermic reactions.

1-1.5 This Guide does not apply to pressure relief devices on equipment such as oil-insulated transformers. It also does not apply to pressure relief devices on tanks, pressure vessels, or domestic (residential) appliances.

1-1.6 Alternative methods for explosion control may be found in NFPA 69, *Standard on Explosion Prevention Systems*.

1-2 Purpose. The purpose of this Guide is to provide the user with criteria for venting of deflagrations. It is important to note that venting will not prevent a deflagration; venting will minimize the destructive effects of a deflagration.

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

Burning Velocity. The velocity at which a flame front propagates relative to the unburned material in a direction perpendicular to the flame front. Burning velocity varies with mixture composition, temperature, pressure, and the turbulence in the vicinity of the flame front.

Combustible. Capable of undergoing combustion.

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

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

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

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

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

Flame Speed. The speed of a flame front relative to a fixed reference point. Flame speed is dependent on turbulence and the equipment geometry and is not primarily a property of the fuel.

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

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

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

Fog. See mist.

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

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

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

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

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

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

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

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

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

Vapor. See gas.

Vent Ratio. The ratio of the free area of the vent to the volume of the enclosure protected by the vent.

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

Length	1 m	=	3.28 ft
		=	39.4 in.
		=	1.09 yd.
	1 in.	=	2.54 cm
	1 ft.	=	30.5 cm
	1 micron	=	1.00×10^{-6} m
Area	1 m^2	=	10.8 ft^2
	1 yd^2	=	0.836 m^2
	1 $in.^2$	=	6.45 cm^2
Volume	1 liter	=	61.0 $in.^3$
	1 ft^3	=	7.48 U.S. gal
	1 m^3	=	35.3 ft^3
		=	264 U.S. gal
	1 gal (U.S.)	=	3.78 liters
		=	231 $in.^3$
		=	0.134 ft^3
Pressure	1 atmosphere	=	760 millimeters Mercury (mm Hg)
		=	101 kiloPascals (kPa)
		=	14.7 psi
		=	1.01 bars
	1 psi	=	6.89 kPa
	1 Newton/m^2	=	1.00 Pascal
	1 bar	=	100 kPa
		=	14.5 psi
		=	0.987 atmosphere
	1 kilogram/cm^2	=	14.2 psi
	1 kilogram/m^2	=	0.205 lb/ft^2 (psf)
Energy	1 J	=	1.00 Watt-second
	1 Btu	=	1055 J
	1 J	=	0.738 ft-lb
Vent Ratio	1 ft^2/ft^3	=	3.28 m^2/m^3
	1 m^2/m^3	=	0.305 ft^2/ft^3
K_G and K_{St} Conversion Factors			
	$\frac{1 \text{ bar-meter}}{\text{sec}}$	=	$\frac{47.6 \text{ psi-ft}}{\text{sec}}$
	$\frac{1 \text{ psi-ft}}{\text{sec}}$	=	$\frac{0.021 \text{ bar-meter}}{\text{sec}}$
Concentration	1 oz. Avoir./ft^3	=	1000 g/m^3

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

A	—	Area, m^2 or ft^2 or $in.^2$
A_s	—	Internal Surface Area of Enclosure, ft^2 or m^2
A_v	—	Vent Area, m^2 or ft^2
C	—	Constants in Correlation Equations for Figures 7-1(d), 7-1(e), and 7-1(f) (*see 7-1.1.2*) or Constant in Venting Equation in Chapter 4.
C_g	—	Concentration of Gas in Mixture, percent by volume
dP/dt	—	Rate of Pressure Rise, bar/sec or psi/sec
F_r	—	Reaction Force, lb
K_G	—	Deflagration Index for Gases, bar-m/sec
K_r	—	Reaction Force Constant, lb
K_{St}	—	Deflagration Index for Dusts, bar-m/sec
L_n	—	Linear Dimension of Enclosure, m or ft (n = 1,2,3)
L_λ	—	Distance between adjacent vents
L/D	—	Length to diameter ratio, dimensionless
LFL	—	Lower Flammable Limit, percent by volume
p	—	Perimeter of Duct Cross-Section, m or ft
P	—	Pressure, bar (gage) or psig
P_{max}	—	Maximum Pressure Developed in an Unvented Vessel, bar (gage) or psig

P_{red} — Reduced Pressure (i.e., the maximum pressure actually developed during a vented deflagration), bar (gage) or psig
P_{stat} — Vent Closure Release Pressure, bar (gage) or psig
ΔP — Pressure Differential, bar or psi
S_u — Fundamental Burning Velocity, cm/sec
S_f — Flame Speed, cm/sec
S_t — Translational Flame Velocity, cm/sec
t_f — Duration of Pressure Pulse, sec
UFL — Upper Flammable Limit, percent by volume
V — Volume, m^3 or ft^3

NOTE: All pressures are gage pressure unless otherwise specified.

Chapter 2 Fundamentals of Deflagration

2-1 Prerequisites. The following are necessary for a deflagration to occur:

- fuel, in the proper concentration;
- an oxidant, in sufficient quantity to support the combustion;
- an ignition source strong enough to initiate combustion.

These factors are discussed individually in the following sections.

2-2 Fuel. The fuel involved in a deflagration may be a combustible gas (or vapor), a mist of a combustible liquid, a combustible dust, or some combination of these. The most common combination of two fuels is that of a combustible gas and a combustible dust, called a "hybrid mixture."

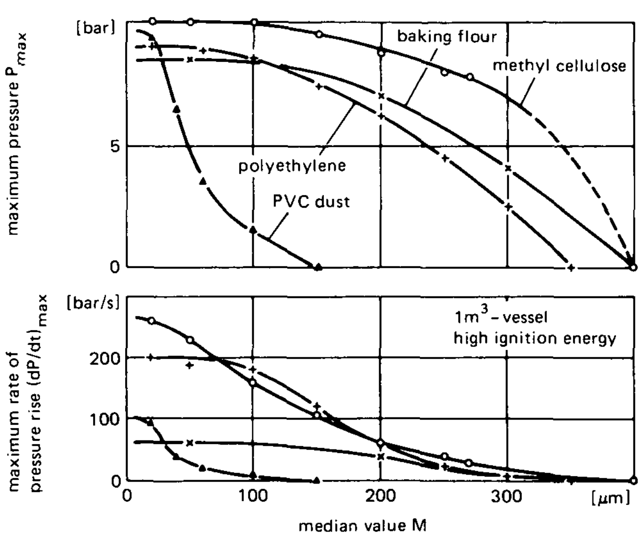

Figure 2-2(a) Effect of average particle diameter of dusts on the maximum pressure and the maximum rate of pressure rise developed by a deflagration in a 1 m³ vessel. (*See reference 3.*)

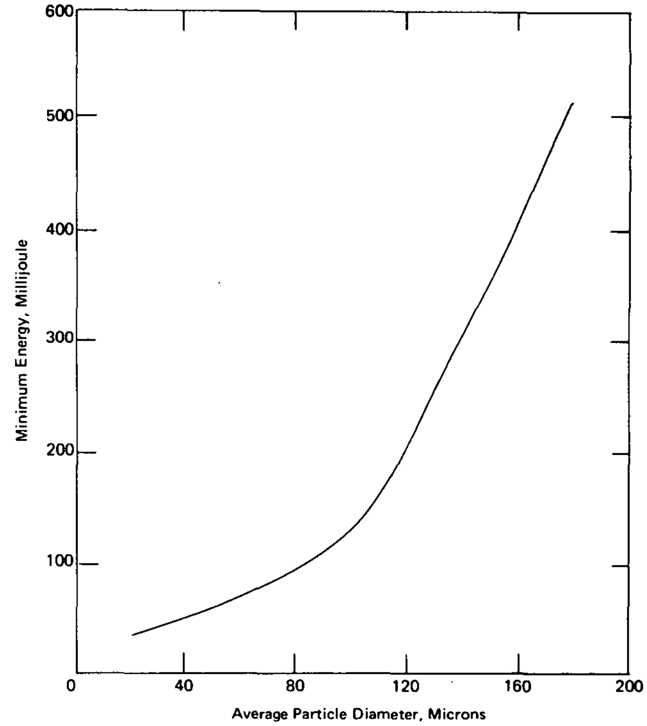

Figure 2-2(b) Effect of average particle diameter of a typical agricultural dust on the minimum ignition energy. (Unpublished data, courtesy of U.S. Mine Safety and Health Administration.)

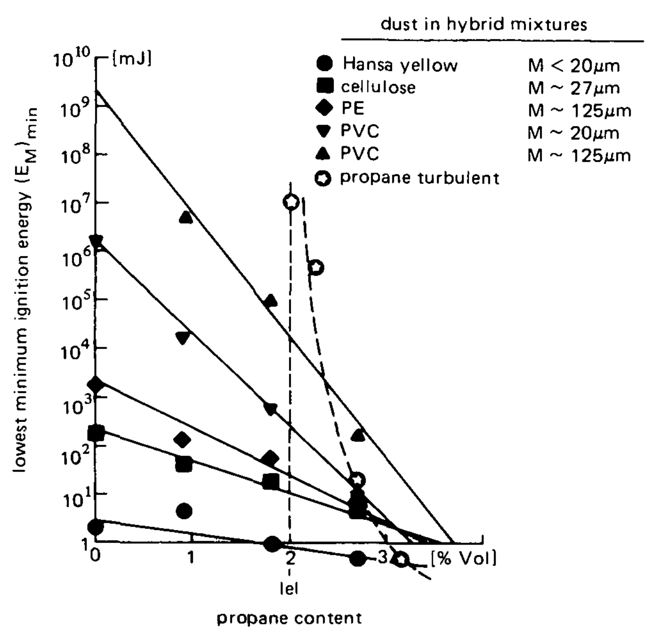

Figure 2-2(c) Lowest minimum ignition energy of hybrid mixtures versus propane content. (*See reference 3.*)

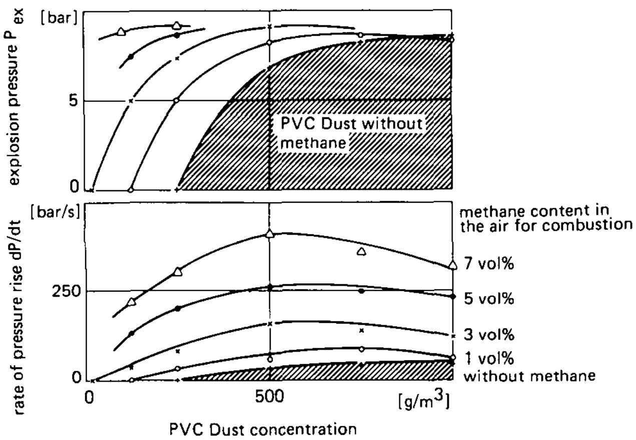

Figure 2-2(d) Combustion Data for Polyvinyl Chloride/Methane/Air Mixtures (1 m³ vessel; chemical detonator with an ignition energy of 10,000 J). (*See reference 4.*)

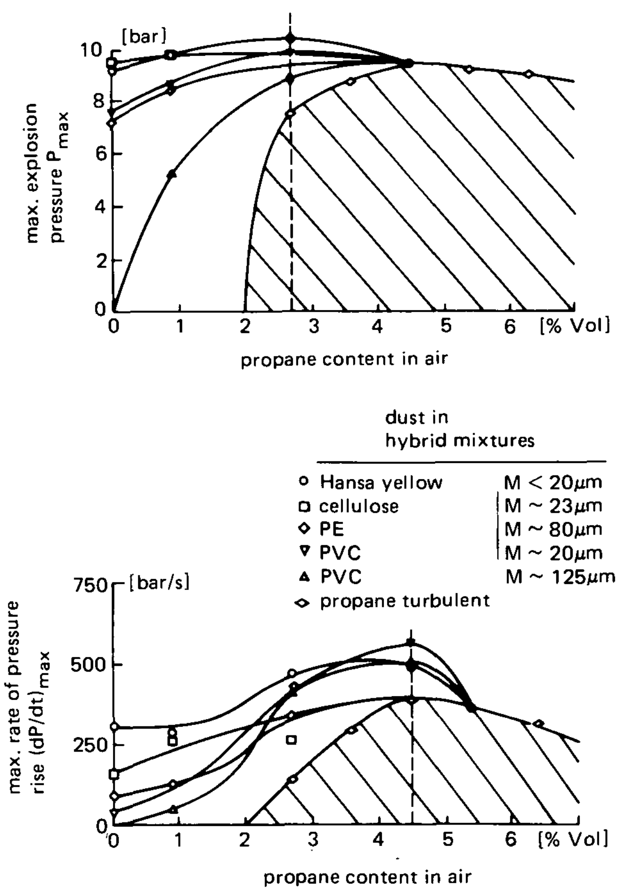

Figure 2-2(e) Combustion Data for Dust/Propane/Air Mixtures (1 m³ vessel; pyrotechnic igniter with an ignition energy of 10,000 J). (*See reference 4.*)

2-2.1 Fuel Concentration.

2-2.1.1 Gaseous fuels have a lower flammability limit (LFL) and an upper flammability limit (UFL). Between these limits, ignition is possible and combustion will take place. The optimum concentration usually occurs at slightly richer than the stoichiometric mixture.

2-2.1.2 Combustible dusts also have a lower flammability limit, often referred to as the minimum explosive concentration. For many dusts, this concentration is about 20 g/m³. Although this concentration can be experimentally determined, its practical value is somewhat limited because of the tendency for dust to fall out of suspension and settle on surfaces. However, such deposits can be thrown into suspension, thereby forming a dust cloud having an ignitible concentration. Therefore, the minimum explosive concentration can be used to determine the amount of such "static" dust that may be allowed to safely accumulate.

A maximum explosive concentration exists but is difficult to evaluate because of problems in achieving adequate dispersion of the dust during testing. Just as with gases, there exists an optimum concentration that yields the maximum rate of pressure rise during combustion.

Experiments show that a combustible dust cloud containing small particles (nominally less than 420 microns) may deflagrate. The maximum rate of pressure rise and the maximum pressure developed both increase as particle size is decreased. The maximum rate of pressure rise is more sensitive to particle size, and the sensitivity can be most pronounced for particle sizes below about 50 microns. The sensitivity of maximum pressure developed is most pronounced for the larger particle sizes in the size range of 200-420 microns. Minimum ignition energy is extremely sensitive to particle size (*see reference 1*). See Figures 2-2(a) and 2-2(b) for illustrations of these effects.

It should be noted that the average particle diameter is often reduced as a result of attrition during material handling and processing, and that certain process operations may cause separation of fine particles from coarse particles. This results in the formation of a "zone" of particles that has a smaller average particle diameter than the bulk of the material and that is no longer protected by the dilution effect of a sufficient concentration of coarse particles.

2-2.1.3 A mist of combustible liquid droplets can also deflagrate. This may happen not only at initial temperatures above the flash point, but also at any temperature below the flash point. In the extreme case, a cloud of frozen droplets may deflagrate in the same manner as a dust cloud.

The lower flammable limit (LFL) for dispersed liquid hydrocarbon mists varies from about 50 mg/liter to about 10 mg/liter as the representative droplet diameter increases from about 10 to 100 microns (*see references 58 and 61, and Figure 8*). Fifty mg/liter is roughly equal to the LFL for combustible hydrocarbon gases in air at room temperature.

Ease of ignition of liquid mists is related principally to the representative droplet diameter. The minimum ignition energy (MIE) increases in proportion to the cube of droplet diameter (*see reference 2*). The MIE is reduced dramatically as droplet diameter is reduced.

Foams of combustible liquids burn readily and, as a source of finely dispersed mist, they may exhibit a low MIE. Oxygen is more soluble than nitrogen in most combustible liquids and if a foam is produced by a degassing process the oxidant concentration may be enriched.

2-2.2 Hybrid Mixtures.

2-2.2.1 A mixture of a combustible gas and a combustible dust in an oxidant is referred to as a "hybrid mixture." The presence of the gas may have some effect on the combustion characteristics of the dust. This influence may be considerable and may occur even though the gas is below its lower flammable limit and the dust is below its minimum flammable concentration. For example, small amounts of combustible gas may lower the minimum ignition energy of a dust cloud, as illustrated in Figure 2-2(c). The maximum rate of pressure rise during a deflagration may increase considerably and the maximum pressure attained during the deflagration may also increase, as shown in Figures 2-2(d) and 2-2(e).

The minimum flammable concentration of the dust may be reduced and combination formulae have been suggested by both Bartknecht and Field to estimate this lower concentration (*see references 5 and 6*). Dusts that have low K_{St} values seem to be more sensitive to the presence of a combustible gas. Careful evaluation of the ignition and deflagration characteristics of these mixtures is required; specific testing is strongly recommended, since a hybrid mixture may require more vent area than would be required by either component alone.

2-2.2.2 Situations where hybrid mixtures may occur in industrial processes include: fluidized bed dryers in which combustible dusts wet with solvent are dried in a warm air stream, desorption of combustible solvent and monomer vapors from polymers, and coal pulverizing operations.

In many instances, the evolution of the gas may be completely unexpected or may be very slow. It has been shown that the introduction of a combustible gas into a cloud of dust that would normally be a minimal explosion hazard can result in a vigorous combustion of the hybrid mixture. An example of this phenomenon is the combustion of unplasticized polyvinyl chloride dust in an air/methane atmosphere.

2-3 Oxidant. The oxidant in a deflagration is normally the oxygen in air. Oxygen concentrations greater than 21 percent tend to intensify the combustion reaction and increase the probability of transition to detonation. Conversely, concentrations less than 21 percent tend to decrease the rate of reaction. There is for most fuels a limiting oxygen concentration below which combustion will not occur. (*See NFPA 69, Standard on Explosion Prevention Systems.*) Also, other oxidants, such as the halogens, may have to be considered.

2-4 Burning Velocity and Flame Speed. The flame speed is the local velocity of a freely propagating flame relative to a fixed point. It is the sum of the burning velocity and the translational velocity of the flame front. This is expressed by the equation:

$$S_f = S_u + S_t$$

S_f = flame speed, cm/sec;

S_u = burning velocity, cm/sec;

S_t = translational velocity, cm/sec.

The burning velocity is the velocity at which a plane reaction front moves into the unburned mixture as it chemically transforms the fuel and oxidant into combustion products. It is only a fraction of the flame speed. The translational velocity is the sum of the velocity of the flame front caused by the volume expansion of the combustion products due to the increase in temperature and any increase in the number of moles and any flow velocity due to motion of the gas mixture prior to ignition. The burning velocity of the flame front can be calculated from the fundamental burning velocity, which is reported at standardized conditions of temperature, pressure, and composition of unburned gas.

2-5 Ignition Source.

2-5.1 Both the maximum pressure and the maximum rate of pressure rise developed during a deflagration in vessels much smaller than 1 m^3 increase as the energy of the ignition source increases. In larger vessels these increases only occur with powerful sources of ignition, such as jet flames. Thus, the energy released by a point source of ignition in a relatively large vessel will have little effect on the course of the deflagration. This is because turbulence is induced in the flame front by the deflagration and this turbulence will outweigh any effects of the ignition source.

2-5.2 Ignition at the geometric center of an enclosure will usually result in the most destructive effects. Of course, the energy of the ignition source must be above some minimum value. Values of these minimum ignition energies have been reported for gases and for dust clouds (*see references 7 through 13*). Usually minimum ignition energies of gases are much lower than those of dust clouds. However, some recent work has been reported that indicates that dust clouds can be ignited by sources releasing much less energy than has been previously reported (*see reference 14*).

2-5.3 Ignition can result from external energy sources such as an electrical arc, a flame, a mechanically produced spark (impact or friction), or a hot surface. Ignition can also result from slow exothermic reactions that may produce spontaneous heating. Simultaneous multiple ignition sources may produce turbulence in the fuel/oxidant mixture that will intensify deflagration. An ignition source may travel from one zone to another; e.g., a mechanical spark may be transported from a grinding mill to a dust collector via ductwork. Similarly, a flame produced by an ignition source in one enclosure may itself become a much larger ignition source if it propagates to another enclosure.

2-6 Initial Temperature and Pressure. Any change in the initial (absolute) pressure of the fuel/oxidant mixture at a given initial temperature, will produce a proportionate change in the maximum pressure developed by a deflagration of the mixture in a closed vessel. Conversely, any change in the initial (absolute) temperature at a given initial pressure will produce an inverse change in the maximum pressure attained. (*See Figure 2-6.*) However, an increase in temperature usually results in an increase in the maximum rate of pressure rise.

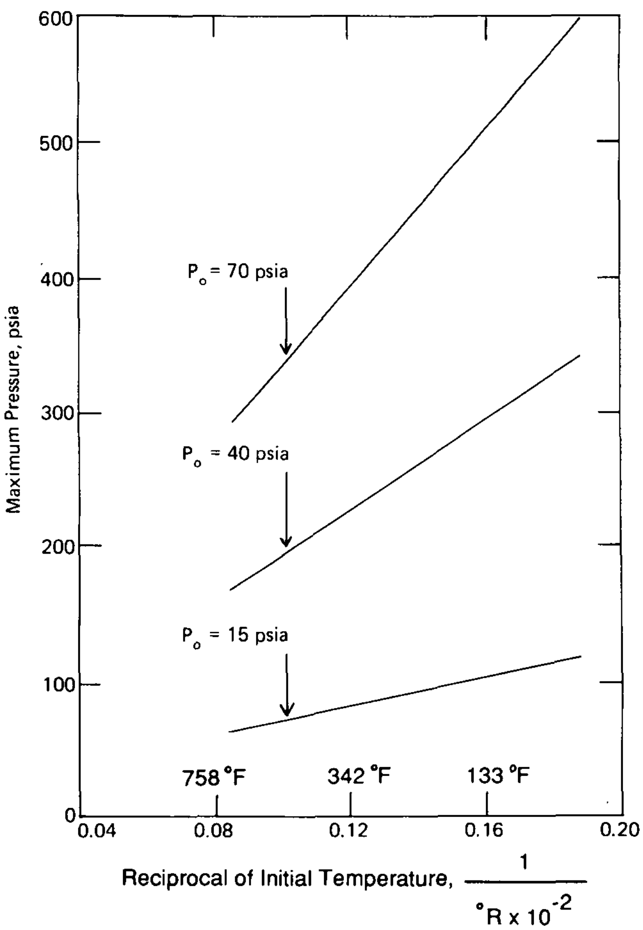

Figure 2-6 Effect of initial temperature on the maximum pressure developed in a closed vessel for deflagrations of 9.9 percent methane/air mixtures at several initial pressures. (*See reference 15.*)

2-7 Turbulence. Initial turbulence in closed vessels results in both higher maximum pressures and higher maximum rates of pressure rise than would be obtained if the fuel/oxidant mixture were at initially quiescent conditions. This is shown in Figure 2-7.

2-8 Presence of Moisture.

2-8.1 Moisture absorbed on the surface of dust particles will usually raise the ignition temperature of the dust because of the energy absorbed in vaporizing the moisture. However, the moisture in the air (humidity) surrounding a dust particle has no significant effect on a deflagration once ignition has occurred.

2-8.2 In many cases, there are direct relationships between moisture content and the minimum energy required for ignition, the minimum flammable concentration, the maximum pressure developed during a deflagration, and the maximum rate of pressure rise. For example, the minimum ignition temperature of cornstarch dust may increase by as much as 50 °C when the moisture content increases from 1.6 to 12.5 percent by weight.

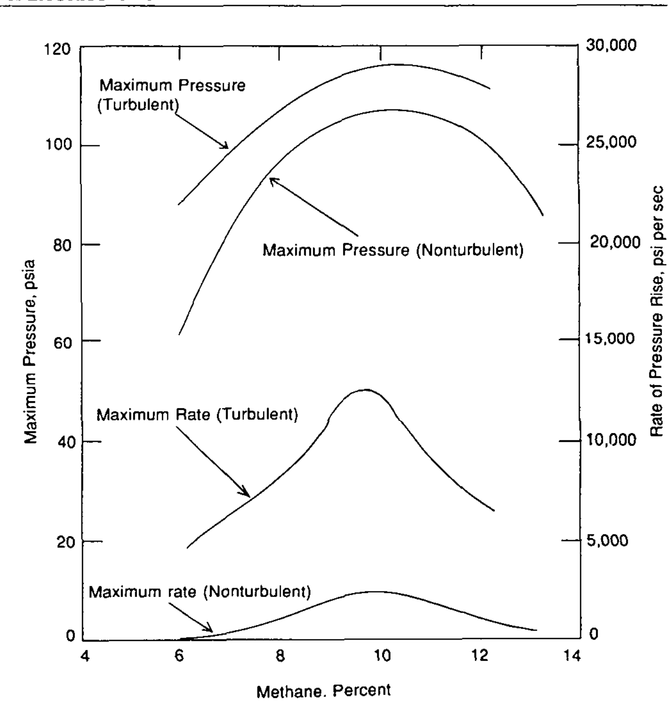

Figure 2-7 Maximum pressure and rate of pressure rise for turbulent and nonturbulent methane/air mixtures in a 1 cubic foot closed vessel. (*See reference 16.*)

2-8.3 As a practical matter, moisture cannot be considered an effective means of preventing a deflagration since most ignition sources will provide more than enough energy to vaporize the moisture and to ignite the dust. For moisture to prevent ignition of a dust by most common sources (such as hot pieces of slag from cutting operations, hot bearing surfaces, etc.), the dust would have to be so damp that a cloud would not readily form. Unfortunately, material containing this much moisture will usually cause processing difficulties.

2-9 Presence of Inert Material.

2-9.1 Inert gases such as nitrogen or carbon dioxide are often used to prevent ignition of gases and dusts. The use of inert gases is discussed in NFPA 69, *Standard on Explosion Prevention Systems.*

2-9.2 Inert powder can reduce the combustibility of a dust for the same reason that moisture does: the powder will absorb heat. Unfortunately, the amount of inert powder necessary to prevent a deflagration is considerably greater than the concentration that can usually be tolerated as foreign material. Some inert powders such as silica can be harmful because they increase the dispersibility of the combustible dust.

2-9.3 Addition of inert powder to a combustible dust/oxidant mixture, when practical, will reduce the maximum rate of pressure rise and will increase the minimum concentration of combustible dust necessary for ignition. Rock dusting of coal mines is one practical application of the use of inert dust to prevent a deflagration. However, enough rock dust is usually added to provide a concentration of at least 65 percent inert dust. See Figure 2-9 for an example of the effect of admixed inert powder.

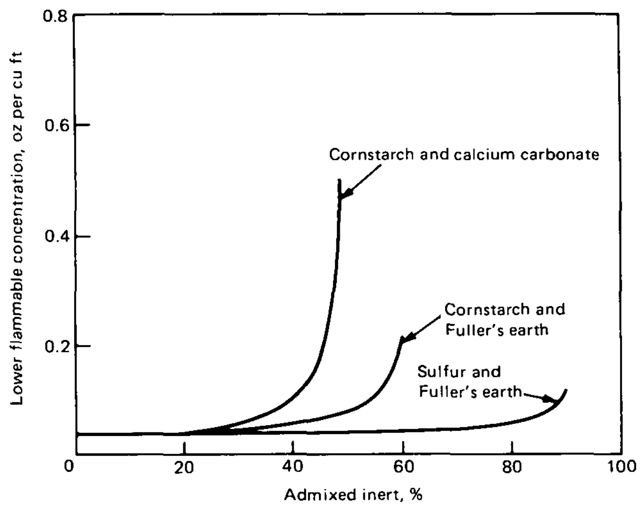

Figure 2-9 Effect of admixed inert powder on the minimum explosive concentration of several dusts. (*See reference 17.*)

Chapter 3 Fundamentals of Venting of Deflagrations

3-1 Deflagration Vents. A deflagration vent is an opening in an enclosure through which combustion-generated gases may expand and flow. The purpose of the vent is to limit the deflagration pressure so that damage to the enclosure is limited to an acceptable level or is eliminated entirely. The vent may or may not be equipped with a cover. In the case of uncovered vents, the maximum pressure attained during venting will exceed atmospheric pressure, but will be lower than the pressure developed in an unvented enclosure. In the case of covered vents, the maximum pressure developed during venting will be greater than for the case of the uncovered vents (all other factors being equal) because of the pressure required to open the vent by bursting the cover or pushing it out of the way.

3-2 Consequences of a Deflagration.

3-2.1 In any enclosure that is too weak to withstand the overpressure from an expected deflagration, extensive damage will occur should there actually be a deflagration. For example, an ordinary masonry wall (8 in. brick or concrete block, 10 ft high) cannot withstand a sustained overpressure of much more than 0.5 psi. Unless an enclosure is designed to withstand the maximum expected overpressure from a deflagration, venting should be considered to minimize damage. The area of the vent must be great enough to limit the deflagration pressure to some predetermined safe level.

3-2.2 Venting of a deflagration implies the need to relieve internal pressure fast enough to maintain a low enough overpressure within the enclosure so that significant damage does not occur. The peak overpressure allowed is normally chosen to be less than the rupture pressure of the weakest significant structural element. In buildings, this may be a wall, floor, roof, column, or beam; in equipment, the weakest element may be a joint or seam.

Few data are available on the actual forces experienced by the structural elements of an enclosure during a deflagration. Therefore, designs must be based on the type of enclosure (vessel, equipment, room, building), its material of construction, its resistance to mechanical shock, the effects of vents (including consequent thrust forces), and the level and duration of overpressure. In practice, the vent design should be based on withstanding the maximum overpressure attained during venting of the deflagration. If no venting is provided, the (maximum) overpressures developed during a deflagration will typically be between 8 and 12 times the initial absolute pressure, assuming complete combustion. In many cases it is impractical and economically prohibitive to construct an enclosure that will withstand or contain such pressures. In some cases, however, it is possible to design for containment of a deflagration. (*See NFPA 69, Standard on Explosion Prevention Systems.*) If adequate venting can be provided, the enclosure need not be constructed so robustly.

3-3 Maximum Rate of Pressure Rise and Maximum Pressure.

3-3.1 The rate of pressure rise is an important parameter in the venting of a deflagration; it determines the time available for products of combustion to escape from the enclosure and for pressure to dissipate. A rapid rate of rise means that only a short period of time is available for successful venting. Conversely, a slower rate of rise permits the venting to proceed more slowly, yet still be effective. In terms of required vent area, the more rapid the rate of rise, the greater the area needed for venting to be effective, all other factors being equal.

3-3.2 The effect of a deflagration depends on the maximum pressure attained, the maximum rate of pressure rise, and the duration of the peak overpressure. The total impulse imparted to the enclosure (i.e., the integral of the pressure vs. time curve) is reduced as the ratio of vent area to enclosure volume increases. (*See Figure 3-3.*) However, total impulse is not a useful design basis. The stress developed on the enclosure should be calculated on the basis of the static force that is equivalent to the dynamic force developed at the peak pressure reached during venting.

3-4 Vent Variables.

3-4.1 Vent Size and Shape. The maximum pressure developed in a vented enclosure decreases as the available vent area increases. If the enclosure is relatively small and symmetrical, one large vent may be just as effective as several small vents of equal combined area. As an enclosure increases in size, this probably ceases to be true. Rectangular vents are almost as effective as square or cir-

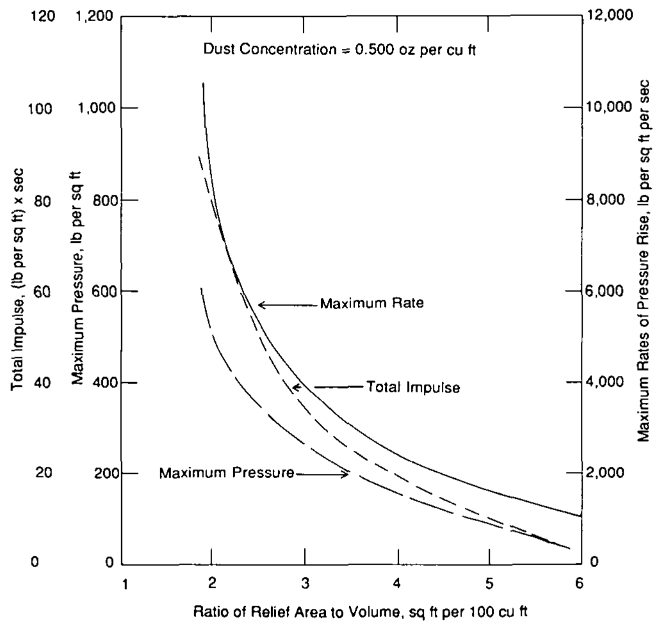

Figure 3-3 Variation of pressures, rates, and impulses with vent ratios in magnesium deflagrations in a vented vessel. (*See reference 18.*)

cular vents of equal area; thus, vent shape has minimal effect on the successful application of venting.

3-4.2 Vent Type. Open or unrestricted vents are the most effective in relieving deflagration overpressures. Vents covered with a diaphragm, rupture disc, swinging or hinged cover, or other type of cover present inertia and a mechanical attachment that must be overcome. Such vents are inherently less effective. Chapter 9 describes various types of vents and vent closures.

3-4.3 Inertia of Vent Closure. The free area of a vent does not become fully effective in relieving the deflagration pressure until the vent closure moves completely out of the way of the vent opening. Until this occurs, the closure obstructs the combustion gases issuing from the vent. The closure has mass and this mass represents inertia that must be overcome by the force of the deflagration. Some finite period of time is needed for the combustion gases to push the closure completely out of the way.

Since the acceleration of the closure is inversely proportional to its mass, the greater the mass of the closure, the longer the closure takes to completely clear the vent opening for a given vent opening pressure. Conversely, closures of low mass move away from the vent opening more quickly and venting is more effective.

Experience has shown that the inertia of the vent closure is usually not significant if the closure weighs less than 2.5 lb per sq ft of free vent area.

3-4.4 Vent Operation. Vents must function dependably. Closures must not be hindered by deposits of snow, ice, or debris; neither must they be hindered by buildup of deposits on their inside surfaces. Adequate clear space must be maintained on both sides of the vent to enable operation without restriction and without impeding the free flow of vented gases.

3-5 Basic Recommendations for Venting. Since venting of deflagrations is a complex subject of many variables on which information is limited, the following provides only general guidelines.

3-5.1 Venting is usually required in buildings, rooms, or equipment that contain an operation or process that may release combustible material in amounts sufficient to create an ignitible mixture with air or other available oxidant.

3-5.2 The required vent area will depend on the strength of the enclosure, the maximum rate of pressure rise, maximum pressure developed for the fuel/oxidant mixture in question, and the design of the vent itself, including the presence or absence of a closure device. Empirical methods are presented in later chapters to determine the required vent area.

3-5.3 Vents should be evenly distributed over the surface area of the enclosure to the greatest practical extent.

3-5.4 The gases vented from an enclosure during a deflagration must be directed to a safe location to avoid injury to personnel and to minimize property damage. It may be necessary to install guardrails immediately in front of vent panels in building walls and around vent panels in roofs to prevent personnel from falling against or through the panels. Suitable warning signs should also be posted. It may also be necessary to provide restraining devices to keep vent panels or closures from becoming missile hazards. An alternative means of protection is to provide a missile barrier close enough to the vent to intercept any missiles, but far enough from the vent so as not to impede its operation. Suitable warning signs should be posted on the inside and outside of the enclosure to provide warning to fire or emergency services of the possibility of a deflagration venting.

3-5.4.1 When a deflagration is vented, a tongue of flame of brief duration issues from the vent. If the fuel is a dust, this tongue of flame will usually contain some unburned dust, along with the gaseous products of combustion. This is because the amount of dust present initially is usually greater than that which the oxidant in the container can burn. This unburned dust will be ignited as it flows out the vent and can produce a large fireball that will extend not only outward and upward, but also downward from the vent. This has been shown in numerous tests conducted with full-scale equipment.

3-5.5 If vents are fitted with closure devices, they should be designed so that they do not allow the development of a vacuum in the enclosure after heated gases have cooled.

3-5.6 Interconnections between separate pieces of equipment should be avoided. Where such interconnections are necessary, flashback prevention devices should be considered to prevent propagation of the deflagration from one piece of equipment through the interconnection to other equipment. Such devices may be mechanical or chemical in operation.

3-5.7 Structural damage can also be minimized by locating vented equipment either outside buildings or in isolated areas.

3-5.8 Ducts used to direct vented gases from the vent to the outside of a building must be strong enough to withstand the maximum expected deflagration overpressure and must be able to withstand the maximum anticipated temperature during venting. Ducts should be as short as possible and should preferably not have any bends.

3-5.9 Wind may cause a vent to operate falsely or may hinder its operation. Vent design must anticipate the problems created by prevailing wind patterns.

3-5.10 Situations may occur in which it is not possible to provide adequate deflagration venting as described in Chapters 4 through 7 of this Guide. This is not justification for providing no venting at all. It is suggested that the "maximum practical" amount of venting be provided, since some venting will reduce the resulting damage to a limited degree. In addition, consideration should be given to other protection and prevention methods. (*See NFPA 69, Standard on Explosion Prevention Systems.*)

3-5.11 Reaction forces resulting from venting should also be considered in the design of the equipment and their supports. (*See 5-2.9.*)

Chapter 4 Venting of Deflagrations in Low-Strength Enclosures

4-1 Introduction.

4-1.1 This chapter is applicable to the design of deflagration vents for low-strength enclosures capable of withstanding not more than 1.5 psig (0.1 bar ga), such as rooms, buildings, and certain equipment enclosures.

4-1.2 The proper design of deflagration vents depends on many variables, only some of which have been investigated in depth. The simplest techniques use one or more empirical factors that allow a simplified expression for vent area to be adjusted so as to envelop available data. These data are the result of analyses of actual explosion incidents and experimental tests.

4-1.3 Tests and analyses conducted to date have allowed certain generalizations to be made. The calculation techniques presented in this Guide are based on these generalizations. The techniques must, therefore, be recognized as approximate only. The user of this Guide is urged to give special attention to all precautionary statements.

4-2 General.

4-2.1 The reason for providing deflagration venting for an enclosure is to minimize or eliminate structural damage to the enclosure itself and to reduce the probability of damage to other structures. In some cases, people within buildings with deflagration venting may not be protected from flame, heat, and pressure damage.

4-2.2 Most enclosures of the type covered by this chapter cannot be subjected to high internal overpressures without serious damage. Adequate venting can minimize the damage from a deflagration. However, the venting must be sufficient to prevent the maximum pressure developed within the enclosure from exceeding the breaking point of the weakest structural element, which may be a wall, the floor, the roof, a column, or a beam.

4-2.3 Care must be taken to ensure that the weakest structural element is recognized. All structural elements must be considered — walls, windows, doors, floors, ceilings, roofs, and structural supports. For example, it must be recognized that floors and roofs are not usually designed for much structural loading from beneath. Furthermore, the structural analysis must be based on the actual design and the existing condition of the enclosure.

4-3 Calculating the Vent Area.

4-3.1 Numerous methods have been proposed for calculating the vent area for an enclosure (*see references 19 through 23*). Some venting models (*see references 24 and 25*) have used the surface area of the enclosure as a basis for determining vent area. Analysis of available data (*see references 26 through 41*) shows that such methods overcome certain deficiencies of previous methods of calculating vent area. The recommended venting equation is as follows:

$$A_v = \frac{CA_s}{(P_{red})^{1/2}}$$

where A_v = vent area (ft² or m²)
C = venting equation constant (*see Table 4-3*)
A_s = internal surface area of enclosure (ft² or m²)
P_{red} = maximum internal overpressure that can be withstood by the weakest structural element (psi or kPa)

4-3.2 Applicable Dimensions. The form of the venting equation is such that there are no dimensional constraints (such as a maximum length-to-diameter ratio) *provided* that the vent area is not applied solely to one end of an elongated enclosure. For elongated enclosures, the vent area should be applied as evenly as possible with respect to the longest dimension. If the available vent area is restricted to one end of an elongated enclosure, for example the top of a silo or the end wall of a building, the ratio of length to diameter should not exceed 3. (For larger ratios of length to diameter or higher allowable overpressures, see Chapters 6 through 8.) For cross-sections other than circular or square, the effective diameter can be taken as the hydraulic diameter. The hydraulic diameter is given by 4A/p, where A is the cross-sectional area and p is the perimeter of the cross-section. Therefore, if the vent area is restricted to one end of an elongated enclosure, the venting equation is constrained as follows:

$$L_3 \leqslant 12\ A/p \text{ (ft or m)}$$

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

If the vent area is restricted to one end of an elongated enclosure containing a highly turbulent gas mixture, the ratio of length to diameter should not exceed 2, or:

$$L_3 \leqslant 8\ A/p\ (\text{ft or m})$$

Where the above constraints on L_3 are violated, investigate alternate methods in Chapters 6 through 8 for possible solutions.

It should also be noted that these constraints apply only to the use of the recommended fuel characteristics constants given in Table 4-3.

4-3.3 Venting Equation Constant. The value of C in the venting equation serves two purposes: it characterizes the fuel and it clears the dimensional units. Also, two sets of C values have been derived so that the venting equation can be used with either English or SI units. Table 4-3 gives some recommended values of C.

Table 4-3 Fuel Characteristic Constant for Venting Equation

Fuel	$C(psi)^{1/2}$	$C(kPa)^{1/2}$
Anhydrous Ammonia	0.05	0.13
Methane	0.14	0.37
Gases with fundamental burning velocity less than 1.3 times that of propane	0.17	0.45
St-1 dusts	0.10	0.26
St-2 dusts	0.12	0.30
St-3 dusts	0.20	0.51

Supporting material on explosion protection methods against dust explosions is available for review at NFPA Headquarters, Batterymarch Park, Quincy, MA 02269.

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

4-3.3.2 The available database includes references 24 and 26 through 41. Most data are for aliphatic gases. It is believed that liquid mists can be treated as aliphatic gases provided that the fundamental burning velocity of the vapor is less than 1.3 times that of propane. No recommendations can presently be given for fast-burning gases such as hydrogen, certain alkenes, alkynes, dienes, and epoxides. This is because the recommended method allows for initial turbulence and turbulence-generating internals, and no venting data have been generated to address such conditions for fast-burning gases. Expert opinion should be sought in such cases. Unusually high rates of combustion (including detonation) have been observed in actual practice during turbulent hydrogen combustion; as conditions become severe, combustion rates may approach those of detonation for other fast-burning fuels. In addition, as rates of pressure rise increase, the inertia of vent closures becomes more critical (*see 9-3.3*). Even if detonation does not occur, it may be impossible to successfully vent fast deflagrations in some cases.

4-4 Calculation of Internal Surface Area. The enclosure is defined by the structural elements that are capable of withstanding the expected overpressure. The surface area of any equipment within the enclosure is excluded. Nonstructural partitions that cannot withstand the expected overpressure (e.g., suspended ceilings) are not considered to be part of the enclosure's internal surface area, A_s. The internal surface area, A_s, in the venting equation, includes roof or ceilings, walls, and floor and may be based on simple geometric figures. Thus, surface corrugations are neglected. Minor deviations from the simplest shape (parallelepiped, prism, cone, etc.) are also neglected. Regular geometrical deviations such as "saw-toothed" roofs may be "averaged" by adding the contributed volume to that of the major structure and calculating A_s for the basic geometry of the major structure. However, while the surface area of equipment and contained structures should be neglected, the internal surface area of any adjoining rooms *must* be included and the vent area distributed as symmetrically and evenly as possible in proportion to the contribution of each volume to A_s.

4-5 Enclosure Strength.

4-5.1 The term P in the equation is defined as the "maximum internal overpressure that can be resisted by the weakest structural element." Since one side of the vent is always assumed to be atmospheric, the gage pressure within the enclosure can be used.

4-5.2 Theoretically, the force exerted on an enclosure by an internal deflagration is dynamic. However, recent work by Howard and Karabinis (*see reference 26*) indicates that the enclosure may be assumed to respond as if the peak deflagration pressure is applied as a static loading, provided some inelastic deformation (but *not* catastrophic failure) can be accepted. Therefore, if a structural member must not be permanently damaged or deformed by the deflagration, it must be designed to withstand the maximum internal overpressure, P, without catastrophic failure.

4-5.3 In designing an enclosure to prevent catastrophic failure while still allowing some inelastic deformation, the normal dead and live loads should not be relied upon to provide adequate restraint. For example, walls should be fastened along top and bottom edges, as well as at all corners.

4-5.4 In all cases, except as noted in 4-5.5, the maximum allowable design stress should not exceed two-thirds of the ultimate strength.

4-5.5 Ductile design practices should be used. For materials subject to brittle failure, such as cast iron, special reinforcing should be considered. If such reinforcing is not used, the maximum allowable design stress should not exceed 25 percent of the ultimate strength.

4-5.6 In all cases, the strength of the enclosure should exceed the vent relief pressure by at least 0.35 psi (50 psf or 2.4 kPa).

4-6 Vent Design.

4-6.1 Where inclement weather, environmental contamination, or loss of material is not a consideration, open vents may be used and are recommended. In most cases, however, vents will be covered by some type of lightweight closure or panel. The panel must be designed, constructed, installed, and maintained so that it will readily release and move out of the path of the combustion gases. The panel must also not become a missile hazard when it operates.

4-6.2 The total weight of the panel assembly, including any insulation and permanently mounted hardware, should be as low as practical, but in no case should it exceed 2.5 lb/ft^2. The purpose of this limitation is to keep the inertia of the assembly as low as possible so that the vent opens as rapidly as possible.

4-6.3 The material of construction of the panel should be suitable for the environment to which it will be exposed. Brittle materials will fragment, producing potentially lethal missiles. Some panels, because of their configuration, may travel some distance from the enclosure. Each installation must be evaluated to determine the extent of the hazard to personnel from such missiles.

4-6.4 Vent panels must release at as low an internal pressure as practical, yet stay in place when subjected to external wind forces. The suction effects of wind passing around and over the structure and across the surface of the panel must be considered. In most cases, the vent panel release pressure can be about 20 lb per sq ft (psf). In areas subject to severe windstorms, the release pressure may have to be as great as 30 psf.

4-6.5 Under the dynamic conditions of deflagration venting, magnetic, spring-loaded, or diaphragm-type panels will release at overpressures reasonably close to their design values. Release devices that fail under tension or shear may require unusually higher forces for operation under dynamic condition than under the static conditions at which they are usually tested. These higher forces may not be compatible with the design requirements of the vent system.

4-6.6 The panel(s) must provide the required vent area for the volume of the enclosure being protected. If the enclosure itself is subdivided into compartments by walls, partitions, floors, or ceilings, then each compartment that contains a deflagration hazard must be provided with its own vent.

4-6.7 A single large vent should not provide the required vent area for more than one enclosure. This restriction ensures that the pressure developed by a deflagration must only move the mass of vent panel required for venting that enclosure only.

4-6.8 Each panel must be designed and installed to move freely without interference by obstructions such as ductwork, piping, etc. This ensures that the flow of combustion gases is not impeded by a "hung-up" vent panel.

4-6.9 An explosion relief panel may open if personnel fall or lean on it. If injury could result from this event, guardrails must be provided.

4-6.10 A restraining device may be needed to keep the panel from tearing completely free of the enclosure and becoming a missile (*see Chapter 9*).

4-6.11 The criteria for the design of roof panels are basically the same as for wall panels. Since the panels will not likely be safe to step or sit on, access to the roof should be prohibited or guardrails should be installed around each panel. In climates subject to snow and ice accumulation, the panels should not be insulated, thus allowing building heat to thaw any snow and ice. If building heat alone is not adequate, special heating may have to be provided.

4-7 Sample Calculation.

4-7.1 Consider the building illustrated in Figure 4-7(a) for which deflagration venting is required. The building is to be protected against a deflagration of a hydrocarbon vapor, having the burning characteristics of propane. The maximum internal overpressure that this building can withstand has been determined by structural analysis to be 0.5 psi (3.45 kPa).

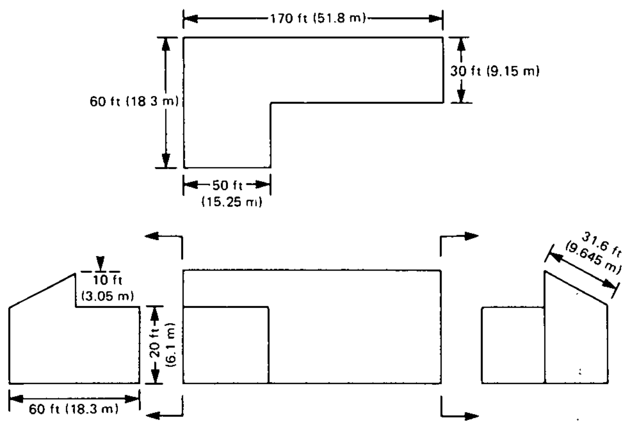

Figure 4-7(a) Not to Scale.

4-7.2 Divide the building into sensible geometric parts (parts 1 and 2) shown in Figure 4-7(b).

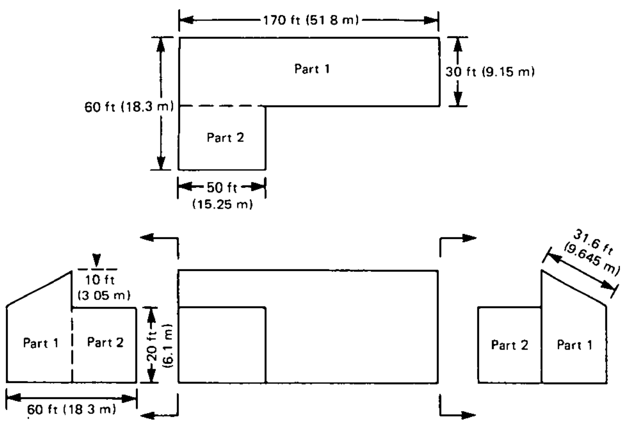

Figure 4-7(b) Building Used in Sample Calculation (Not to Scale).

4-7.3 Calculate the total internal surface area of each part of the building.

Part 1 Surface Area

Floor = 170 × 30 = 5100 ft²

Roof = 170 × 31.6 = 5372 ft²

Rear Wall = 170 × 20 = 3400 ft²

Front Wall = 120 × 30 + 50 × 10 = 4100 ft²

Side Walls = 2 × 30 × 20 = 1200 ft²
(Rectangular Part)

Side Walls = 30 × 10 = 300 ft²
(Triangular Part)

Total internal surface of Part 1 (A_{s1}) = 19,472 ft²

Part 2 Surface Area

Floor = 50 × 30 = 1500 ft²

Roof = 50 × 30 = 1500 ft²

Front Wall = 50 × 20 = 1000 ft²

Side Walls = 2 × 30 × 20 = 1200 ft²

Total internal surface of Part 2 (A_{s2}) = 5200 ft²

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

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

4-7.4 Calculate the total vent area requirement using:

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

Where, A_s = 24,672 ft²
P_{red} = 0.5 psi
C = 0.17 (psig)$^{1/2}$ (from Table 4-3)

Substituting,

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

The total vent area requirement of 5932 ft² should be divided evenly over the outer surface of the building and should be apportioned between the parts in the same ratio as their surface area. Thus,

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

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

4-7.5 Check to determine whether sufficient external surface area on the building is available for venting.

In Part 1, the required vent area (4406 ft²) can be obtained by using parts of the front, rear, and side walls or the building roof.

In Part 2, the required vent area (1177 ft²) can be obtained by using parts of the front and side walls or the building roof. Note: Only the outer "skin" of the building may be used for vent locations; a deflagration cannot be vented into other parts of the building.

4-7.6 An irregularly shaped building may be squared off to give a building of regular geometry whose internal surface area can be easily calculated. This is particularly applicable to buildings with "saw-toothed" roofs or other such architectural features.

4-7.7 Situations may arise in which the roof area or one or more of the wall areas cannot be used for vents, either because of the placement of equipment, or exposure to other buildings or to areas normally occupied by personnel. In such cases it is necessary to strengthen the structural members of the compartment so that the reduced vent area available is matched to the vent area required. The minimum pressure requirement for the weakest structural member is obtained by substituting into the equation the available area, the internal surface area, the appropriate C value, and calculating P_{red}, the maximum allowable overpressure. The vent area must still be distributed as evenly as possible over the building's "skin."

4-7.8 If the only available vent area is located in an end wall of an elongated building or structure, such as a silo, a check must be made to determine whether the equation can be validly applied (*see 4-3.2*).

Chapter 5 Venting of Deflagrations in High-Strength Enclosures — General

5-1 Introduction.

5-1.1 This chapter and Chapters 6 and 7 apply to vessels and equipment capable of withstanding more than 1.5 psig (0.1 bar ga).

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

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

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

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

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

5-2.2 Vent closures must open dependably. Their proper operation must not be hindered by deposits of snow, ice, tarry or sticky materials, polymers, etc. Their operation must not be prevented by corrosion or by objects that obstruct the opening of the vent closure. Allowance should be made for the restriction to flow caused by any objects in the path of the gas flow.

5-2.3 Vent closures must have a low mass per unit area to minimize inertia in order to reduce opening time. The total mass of the closure divided by the area of the vent opening should not exceed 2.5 lb/ft^2 (12.5 kg/m^2). Greater mass per unit area results in higher maximum overpressure during venting. The vent closure should have no counterweights; counterweights add more inertia.

5-2.4 Vent closures should not become missile hazards as a result of their operation. For example, vent panels made of frangible material like glass fiber-reinforced plastic, or cement/inorganic fiber can readily break when they operate. The broken pieces will constitute missile hazards. In most cases, the vent closure should be restrained so that it will not fly away from the vessel when it operates. (*See Section 9-4 for two suitable methods for restraining vent closures.*)

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

5-2.6 Vent closures must release at overpressures reasonably close to their design release pressures. Therefore, release mechanisms must be properly designed and installed. Magnetic or spring-loaded closures will satisfy this criterion. Release devices that fail in tension or shear may require much greater forces to break under dynamic conditions than under static test conditions.

5-2.7 Vent closures must reliably withstand fluctuating pressure differentials that are below the design release pressure. They must also withstand any vibration or other mechanical forces to which they may be subjected.

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

5-2.9 The supporting structure for the enclosure must be strong enough to withstand any reaction forces developed as a result of operation of the vent. The equation for these reaction forces has been established from test results (*see reference 42*) as follows:

$$F_r = 1.2\,(A)\,(P_{red})$$

where

F_r = reaction force resulting from combustion venting, lb;

A = vent area, in.^{2};

P_{red} = maximum pressure developed during venting, psig

The total thrust force can be considered equivalent to a force applied at the geometric center of the vent. Installation of vents of equal area on opposite sides of a vessel cannot be depended upon to prevent thrust in one direction only. It is always possible for one vent to open before another. Such imbalance should be considered when designing vessel or enclosure restraints for resisting thrust forces.

Reference 42 contains a rule-of-thumb equation that roughly approximates the duration of the thrust force of a dust deflagration. Knowing this duration can aid in the design of certain support structures for vessels with deflagration vents. The duration calculated by the following equation will be quite conservative:

$$t_F = \frac{(10^{-2})\,(K_{St})\,(V^{1/3})}{(P_{red})\,(A)}$$

where t_F = duration of pressure pulse, sec;

K_{St} = Deflagration Index for dust (*see Chapter 7*);

V = vessel volume, m^3;

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

A = Area of vent (without vent duct), m^2

5-3 Correlating Parameters for Deflagration Venting.

5-3.1 The technical literature reports extensive experimental work on venting of deflagrations in vessels up to 100 m^3 in volume (*see references 3 and 43 through 48*). From this experimental work, Bartknecht and Donat have developed a series of nomographs, Figures 6-2(a) through (d) in Chapter 6 and Figures 7-2(a) through (f) in Chapter 7, that can be used for determining the necessary vent areas for vessels and equipment.

5-3.2 The nomographs differ from earlier techniques in that they are not based on a linear relationship of vent area to vessel volume.

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

5-3.4 The nomographs may not exactly predict the vent area required for different volumes of vessels. Certain data (*see reference 40*) indicate that the gas venting nomographs may not be conservative in every case. For the present, however, the use of the venting nomographs is recommended on the basis of successful industrial experience. Also, tests in a full-scale mock-up of a large refuse shredding hammermill have shown that the extreme levels of turbulence inherent in its operation caused pressures to exceed those indicated by nomograph recommendations for turbulent propane-air deflagrations (*see references 38 and 83*).

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

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

5-4 Effects of Vent Ducts.

5-4.1 Normally, equipment to be vented is placed in a safe outside location and is vented directly outdoors.

5-4.2 In some situations, equipment or vessels that require deflagration vents must be located inside buildings. In these cases, the vents preferably should not discharge within the buildings. Flames emerging from the vessel during the venting process may seriously injure personnel and may damage other equipment or the building itself. Gases discharging from the vent may also cause appreciable overpressure within the building and lead to additional damage. Therefore, vent ducts should be used to direct vented material from the equipment to the outdoors.

5-4.3 Vent ducts will significantly increase the pressure developed in the equipment during venting. The vent ducts must have a cross-section at least as great as that of the vent itself. The increase in overpressure due to the use of vent ducts as a function of duct length is shown in Figures 5-4(a) for gases, and 5-4(b) for dusts. The same phenomenon, as a function of flow velocity through the duct, is shown for both gases and dusts in Figures 5-4(c) and 5-4(d), respectively.

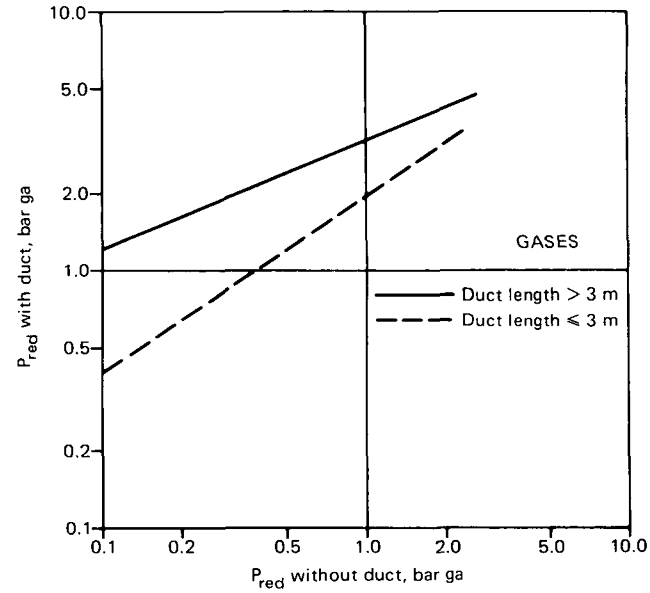

Figure 5-4(a) Maximum pressure developed during venting of gases, with and without vent ducts. (*See reference 49.*)

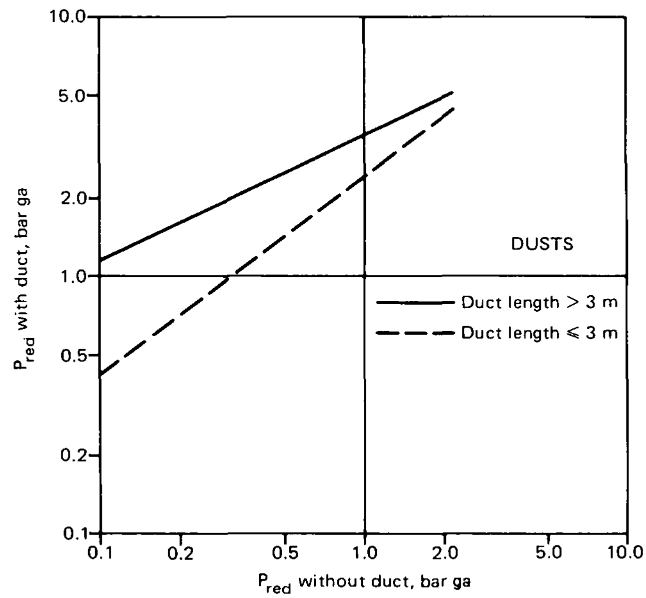

Figure 5-4(b) Maximum pressure developed during venting of dusts, with and without vent ducts. (*See reference 62.*)

5-4.3.1 The use of vent ducts of larger cross-section than the vent will result in a smaller increase in the maximum pressure developed during venting (P_{red}) than will vent ducts of equivalent cross-section. Figure 5-4(e) shows this trend, based on tests in a 1 ft^3 vessel, but should not be used for design.

5-4.4 If vented equipment must be located within buildings, it should be placed close to exterior walls so that the vent ducts will be as short as possible, preferably not more than 3 m long.

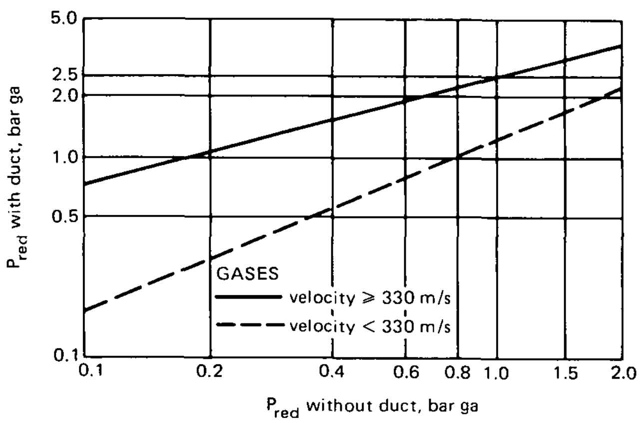

Figure 5-4(c) Maximum pressure developed during venting of gases, with and without vent ducts. (*See reference 3.*)

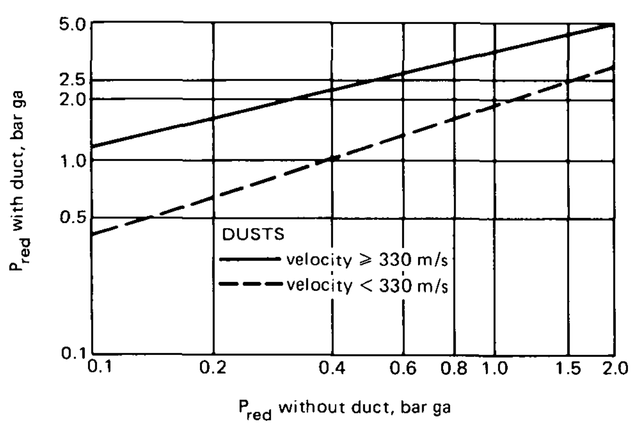

Figure 5-4(d) Maximum pressure developed during venting of dusts, with and without vent ducts. (*See reference 3.*)

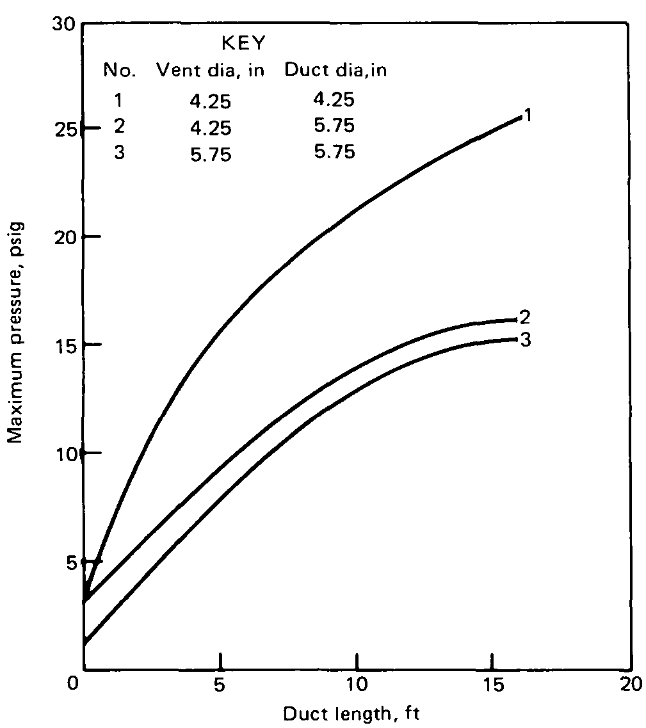

Figure 5-4(e) Maximum pressure developed during venting of explosion of cornstarch through various sized ducts. (*See reference 17.*)

5-4.5 Vent ducts should be as straight as possible. Any bends will cause increases in the overpressure developed during venting. If bends are unavoidable, they should be as shallow-angled (i.e., have as long a radius) as practical.

5-5 Exposure from the Venting Process. Flames emerging from the vessel or equipment during the venting process can seriously injure personnel, ignite other combustibles in the vicinity, result in ensuing fires or secondary explosions, and result in overpressure damage to adjacent buildings or equipment. For a given quantity of combustible mixture, the amount that will be expelled from the vent and the thermal and overpressure damage that results outside of the equipment will depend on the volume of the equipment and the vent opening pressure. For a given volume of equipment and a given quantity of combustible mixture, a lower vent opening pressure relative to the internal operating pressure will result in more unburned material being discharged through the vent, resulting in a larger fireball outside the equipment. A higher vent opening pressure relative to internal operating pressure will result in more combustion taking place inside the equipment prior to the vent opening, higher velocity through the vent, and the potential for more overpressure damage.

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

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

6-1 Nomographs for Deflagration Venting.

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

- no initial turbulence in the vessel at the time of ignition,
- no turbulence-producing internal appurtenances,
- a low ignition energy of 10 J or less, and
- atmospheric pressure.

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

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

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

where

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

		a=	b=	c=	d=
and for:	Methane	0.105	0.770	1.230	−0.823
	Propane	0.148	0.703	0.942	−0.671
	Coke Gas	0.150	0.695	1.380	−0.707
	Hydrogen	0.279	0.680	0.755	−0.393

Since this equation is derived from the nomographs, it is no more accurate than the nomographs themselves. The equation is subject to the same limitations as the nomographs and therefore should not be used for indiscriminate extrapolation; serious errors in the value of A_v will occur if this is done.

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

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

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

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

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

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

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

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

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

Using the propane and hydrogen nomographs [Figures 6-2(b) and (d)], the required vent area to protect the vessel specified will be 10.1 m^2 and 11.0 m^2, respectively. The maximum rates of pressure rise for propane and hydrogen are 369 and 2029 bar/sec, respectively, in the same test vessel. By linear interpolation, the required vent area for this vessel and this specific gas is:

$$10.1 + \left(\frac{730 - 369}{2029 - 369}\right) \times (11.0 - 10.1) = 10.3 \text{ m}^2$$

6-2.5 K_G Values. The maximum rate of pressure rise can be normalized to give the K_G value (*see equation 1 in Appendix A*). It should, however, be noted that the K_G value is not constant and will vary depending on test conditions. In particular, increasing the volume of the test vessel and increasing the ignition energy can result in increased K_G values. Although the K_G value provides a means of comparing the maximum rates of pressure rise of various gases, it should only be used as a basis for deflagration vent sizing if the tests are performed in vessels of approximately the same shape, and size, and with the same kind of igniter having the same ignition energy. (*See Appendix C for examples of K_G values.*)

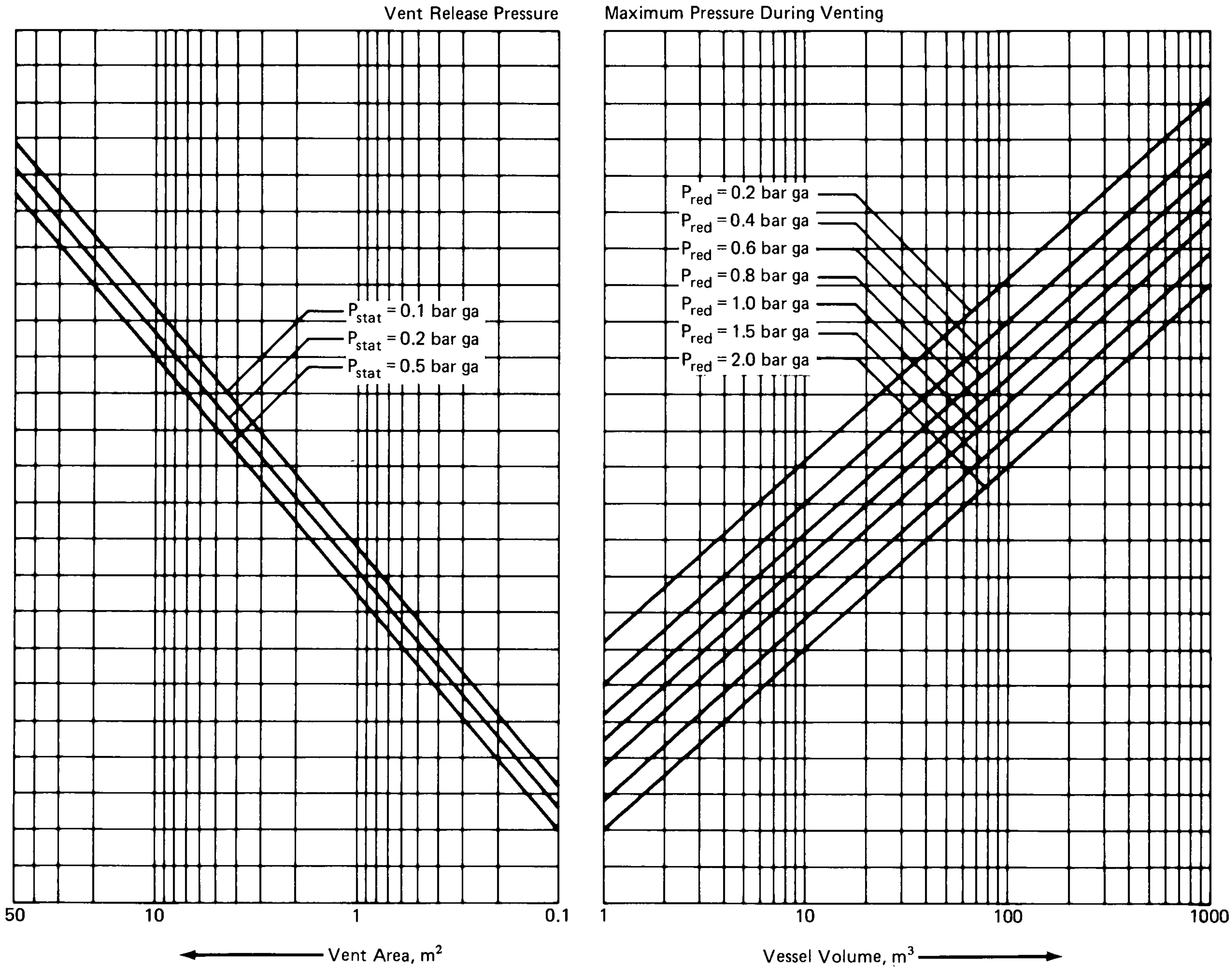

Figure 6-2(a) Venting Nomograph for Methane.

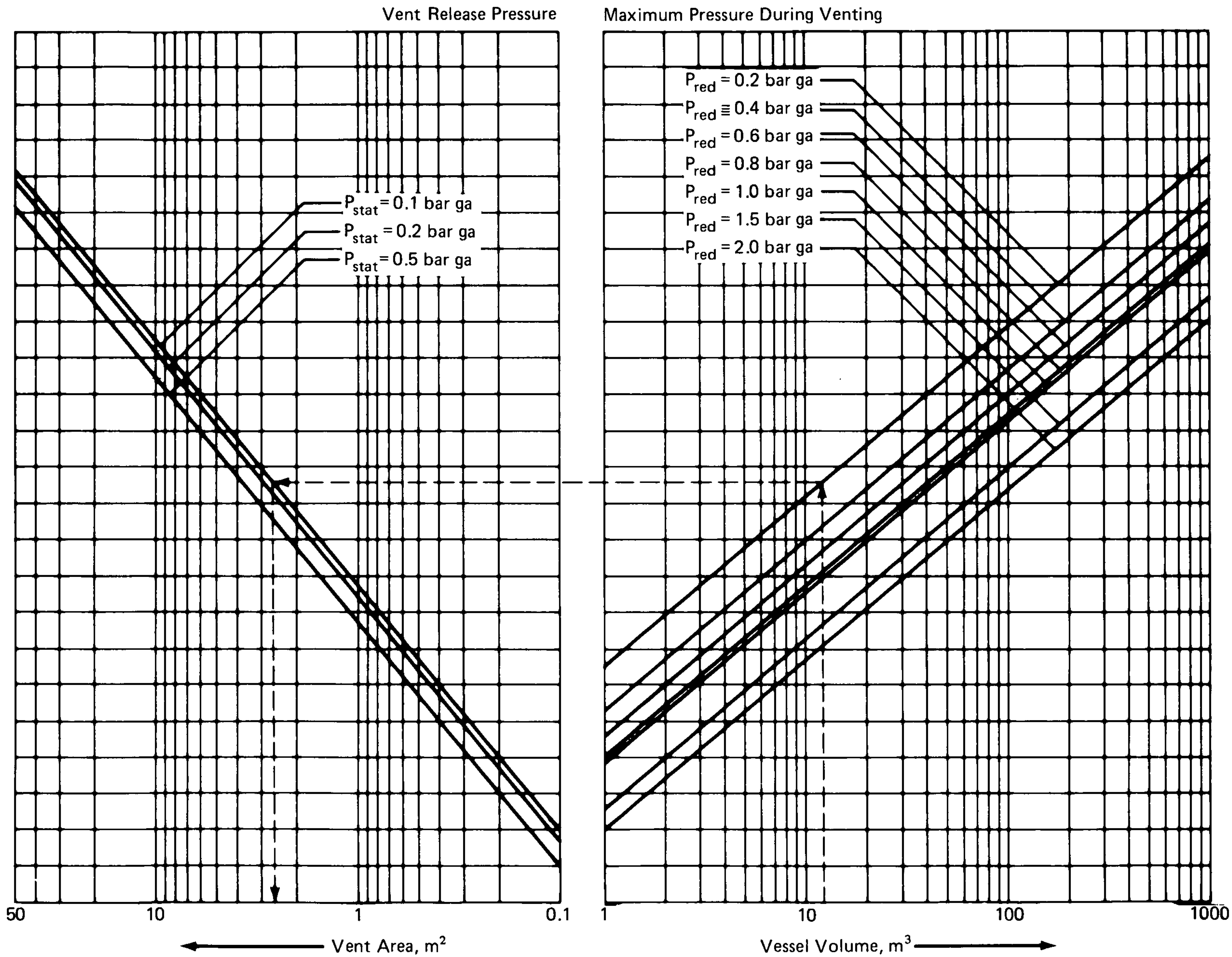

Figure 6-2(b) Venting Nomograph for Propane.

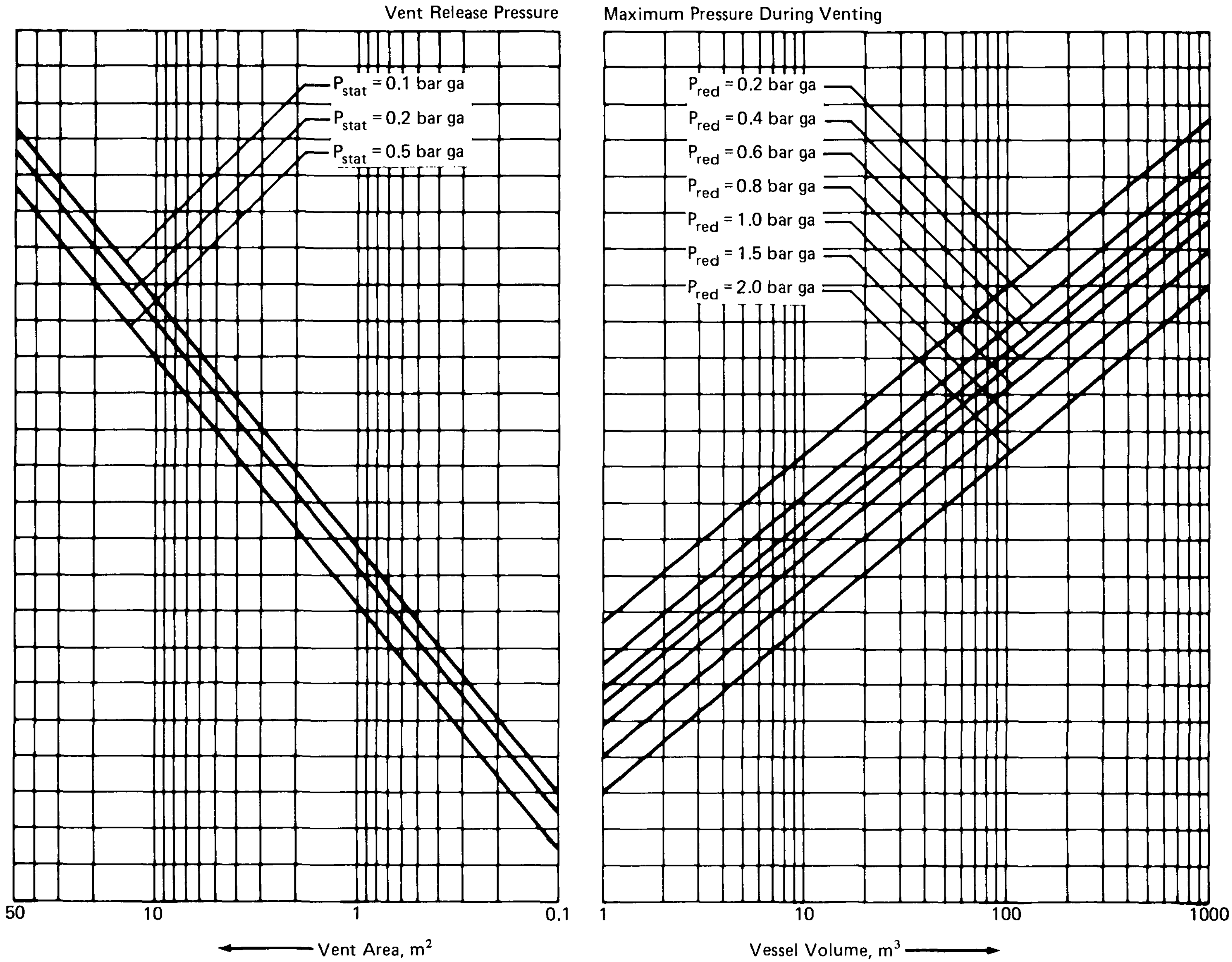

Figure 6-2(c) Venting Nomograph for Coke Gas.

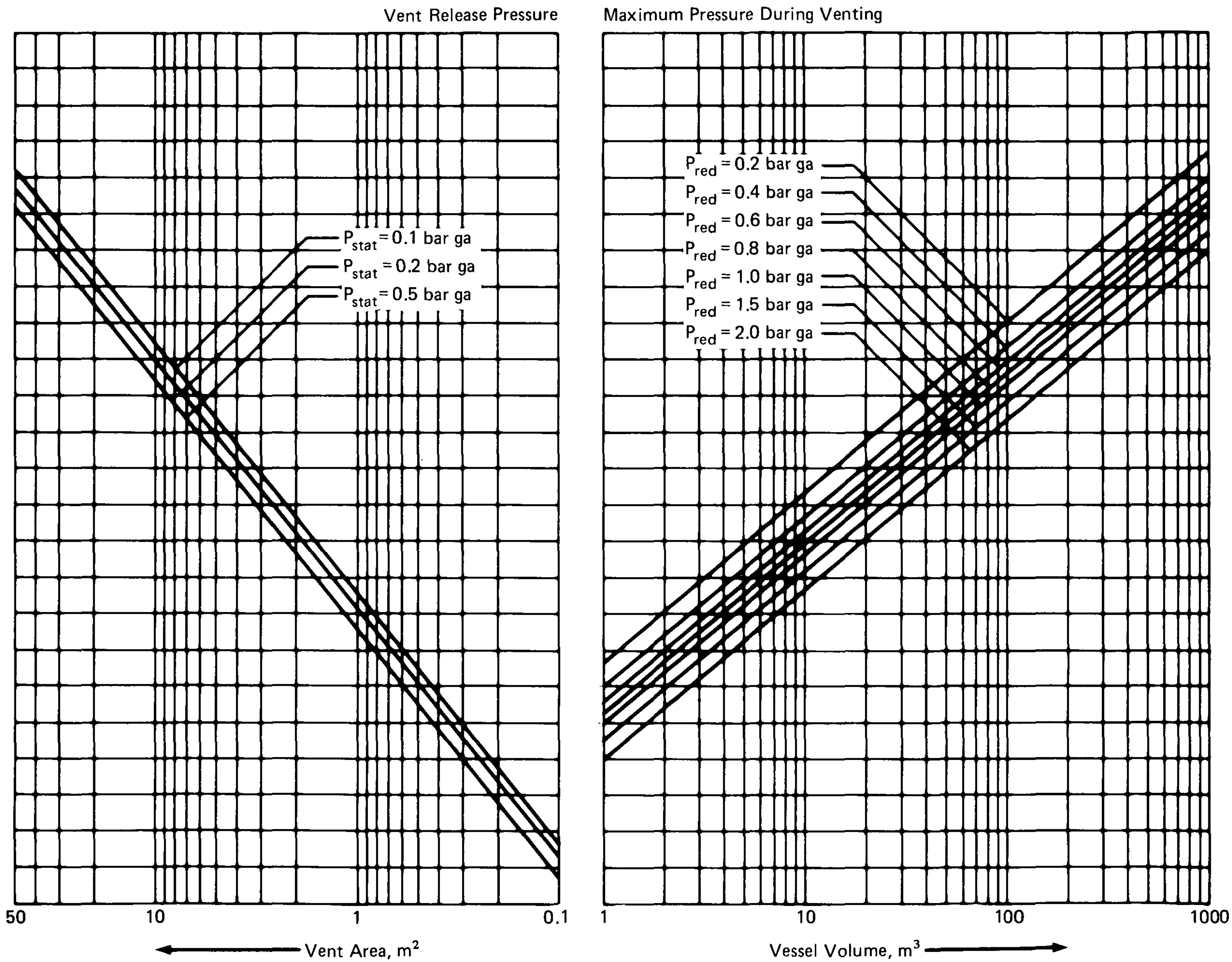

Figure 6-2(d) Venting Nomograph for Hydrogen.

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

6-3.1 Initial Turbulence. In many items of industrial equipment, the gas phase is present in a turbulent condition. An example is the continuous feed of a combustible gas/oxidant mixture to a catalytic partial oxidation reactor. Normally this mixture enters the reactor head as a high-velocity turbulent flow through a pipe. As the gas enters the reactor head, still more turbulence develops due to the sudden enlargement of the flow cross-section.

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

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

6-3.2 Vessel Appurtenances. The presence of internal appurtenances within vented equipment can result in turbulence which may result in transition from deflagration to detonation. When the equipment contains internal appurtenances, an expert should be consulted to determine if the potential exists for a detonation to occur. (*See reference 51 for further information.*)

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

6-5 Effect of High Ignition Energy.

6-5.1 The amount and type of ignition energy can affect the effective flame speed and the venting. The exact amount of ignition energy that may occur in vessels or equipment cannot normally be predicted. In many industrial cases, however, the ignition energy can be quite large.

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

6-6 Extrapolation of Nomographs.

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

6-6.2 In Figure 6-6, the vent areas for a 10 m³ vessel were taken from the four gas nomographs at constant P_{red}, but for different values of P_{stat}. Similar graphs can be constructed for various values of P_{red}. This graph allows interpolation and extrapolation, thus extending the utility of the basic nomographs.

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

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

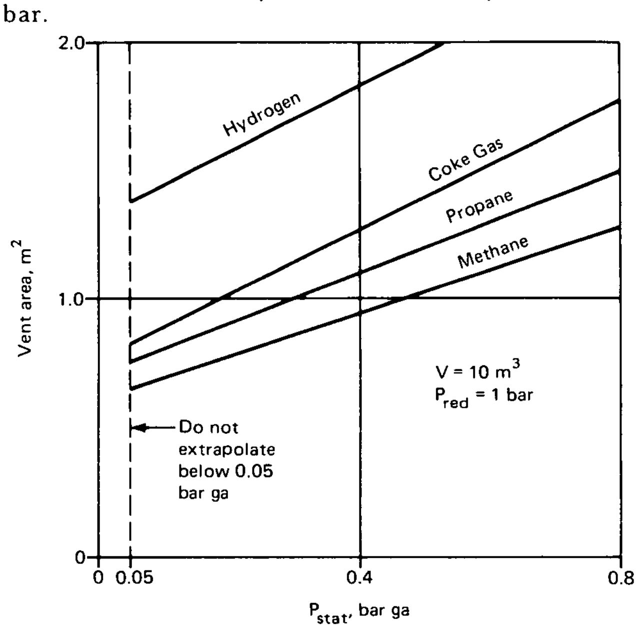

Figure 6-6 Extrapolation of Nomographs. (*See reference 54.*)

6-7 Effect of Initial Elevated Pressure.

6-7.1 The effect of initial pressure must be correlated on the basis of absolute pressures. The data from reference 55 serve as a basis for correlating pressures developed during venting as a function of the initial absolute pressure of gases in the vessel and as a function of the absolute pressure at which the vent opens. If the ratio of vent bursting pressure to initial gas pressure is kept constant and if vessel size and vent size are kept constant, the pressure developed during the venting of propane combustion will vary approximately as the 1.5 power of the initial pressure. The power exponent for propane varies from about 1.2 for larger vent ratios ($A/V^{2/3} = 0.3$) to about 1.5 for smaller vent ratios ($A/V^{2/3} = 0.1$). For hydrogen, the exponent ranges from 1.1 to 1.2.

6-7.2 It is recommended that the 1.5 power be used in extrapolating from the nomograph for gases having K_G values close to that of propane. For hydrogen, the recommended exponent for increased initial pressure is 1.2; for ethylene, 1.4. The latter value has not been validated by test. The correlation may apply to initial pressures up to 4 atmospheres absolute, but this also is untested.

6-7.3 Based on his extensive experimentation, Bartknecht (*see reference 3*) maintains: "The nomographs are based on an operating pressure of 1 bar (absolute), but they may be used without correction for operating pressures up to 1.2 bar (absolute). For higher operating pressures, sufficient experience is not yet available. For the time being it should be assumed that when the operating pressure is raised above normal (atmospheric) pressure, the reduced explosion pressure (P_{red}) will show a proportional increase for a given constant relief venting area."

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

6-9 Effects of Combinations of Variables. There are insufficient data to determine precisely how combinations of variables may affect the maximum pressure developed during venting (P_{red}). On the basis of test work recently conducted (*see reference 57*), it appears that the effects of initial turbulence, (i.e., prior to ignition) may not be significant when the initial pressure is above 1.0 bar ga. In such cases, an allowance would only be made for the initial pressure above atmospheric, but not for turbulence.

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

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

6-12 Venting Deflagrations of Combustible Gases Evolved from Solids. In certain processes, combustible gases may evolve from solid materials. These gases may form combustible mixtures with any oxidant present. If the solid is itself combustible and is dispersed in the gas/oxidant mixture, as might be the case in a fluidized bed dryer, a "hybrid" mixture results. For hybrid mixtures, use the nomograph that applies to the component that requires the larger vent area, which is usually the gas. See also Section 7-8 for more detail.

6-13 Venting of Deflagrations in Conveying and Ventilating Ducts. Most deflagrations of combustible gas mixtures inside ducts occur at initial internal pressures of nearly atmospheric. The venting of deflagrations in such ducts is discussed in Chapter 8.

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

7-1 Introduction.

7-1.1 The most comprehensive design bases for venting of dust deflagrations are contained in VDI Richtlinie 3673, published in Germany (*see reference 62*). This work is based on data obtained from an extensive test program involving four dusts and four vessel sizes: 1, 10, 30, and 60 m³. The nomographs developed from the test data are reproduced here as Figures 7-1(a) through 7-1(f). The nomographs apply to vessels of an L/D ratio of not over 5.

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

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

Where
$a = 0.000571\ e^{(2)\,(P_{stat})}$
$b = 0.978\ e^{(-0.105)\,(P_{stat})}$
$c = -0.687\ e^{(0.226)\,(P_{stat})}$

and
A_v = vent area, m^2
V = enclosure volume, m^3.
e = 2.718 (base of natural logarithm)
P_{red} = maximum pressure developed during venting, bar ga
P_{stat} = vent closure release pressure, bar ga
K_{St} = deflagration index for dust, $\frac{\text{bar-m}}{\text{sec}}$

Since this equation is derived from the nomographs, it is no more accurate than the nomographs themselves. The equation is subject to the same limitations as the nomographs and, therefore, should not be used for indiscriminate extrapolation; serious errors in the value of A_v will occur if this is done.

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

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

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

where
A_v = vent area, m^2
V = enclosure volume, m^3
P_{red} = maximum pressure developed during venting, bar ga
C = 1.88854 for St-1 dusts
= 1.69846 for St-2 dusts
= 1.50821 for St-3 dusts

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

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

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

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

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

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

Since these equations are derived from the nomographs, they are no more accurate than the nomographs themselves. They are subject to the same limitations as the nomographs and, therefore, should not be used for indiscriminate extrapolation; serious errors in the value of A_v will occur if this is done.

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

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

Hazard Class	K_{St},[3] bar m/sec
St-1	≤ 200
St-2	201 – 300
St-3	> 300

[1]The application of the nomographs is limited to an upper K_{St} value of 600.

[2]See Appendix D for examples of K_{St} values.

[3]K_{St} values were determined in approximately spherical calibrated test vessels of at least 20 liter capacity.

7-1.3 Combustion venting characteristics of dusts of the same chemical composition vary with the physical properties such as size and shape of dust particle, moisture content, and others. See 2-2.1.2 and Appendix A for more information on this subject.

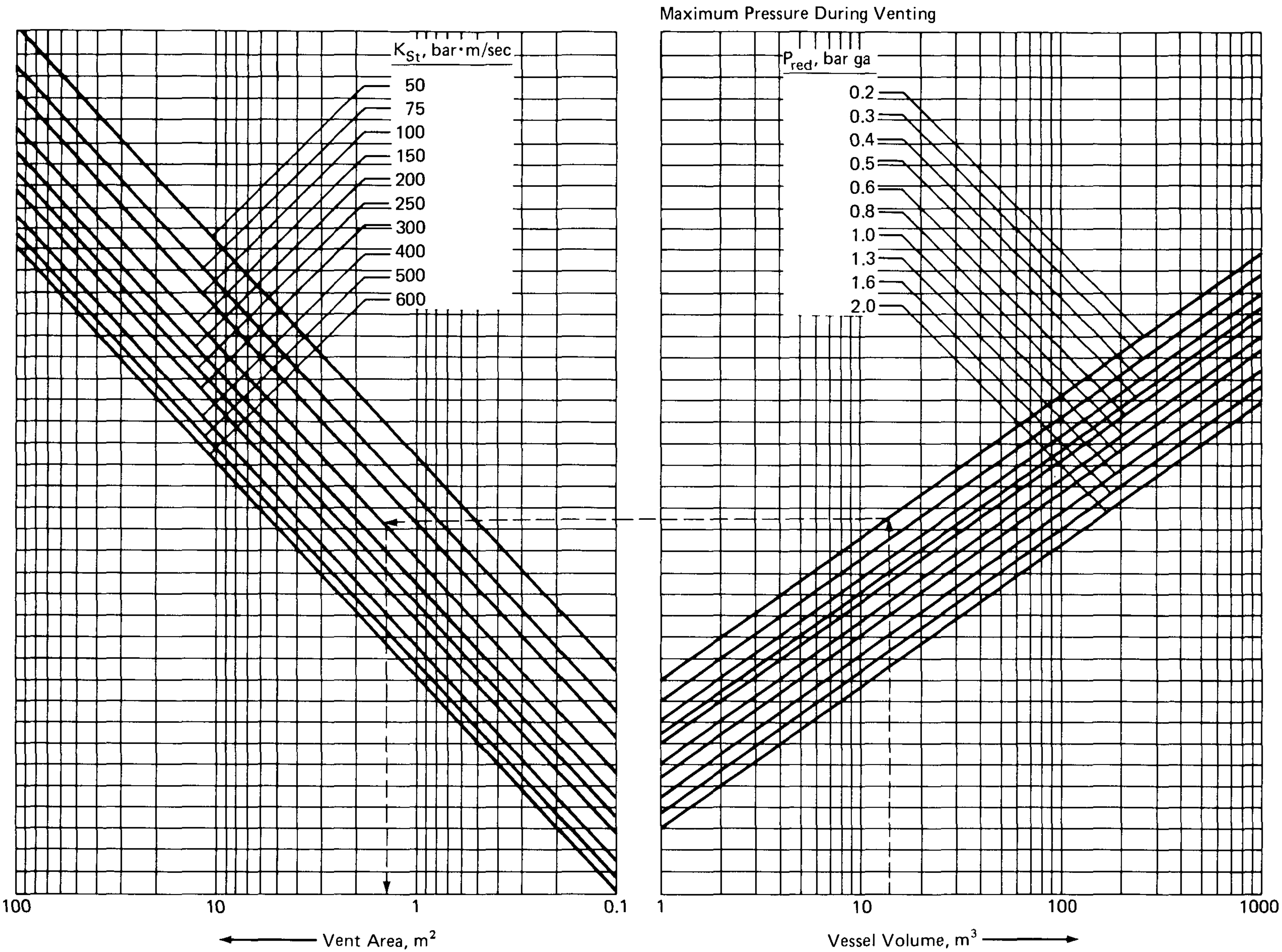

Figure 7-1(a) Venting Nomograph for Dusts—P_{stat} = 0.1 bar ga

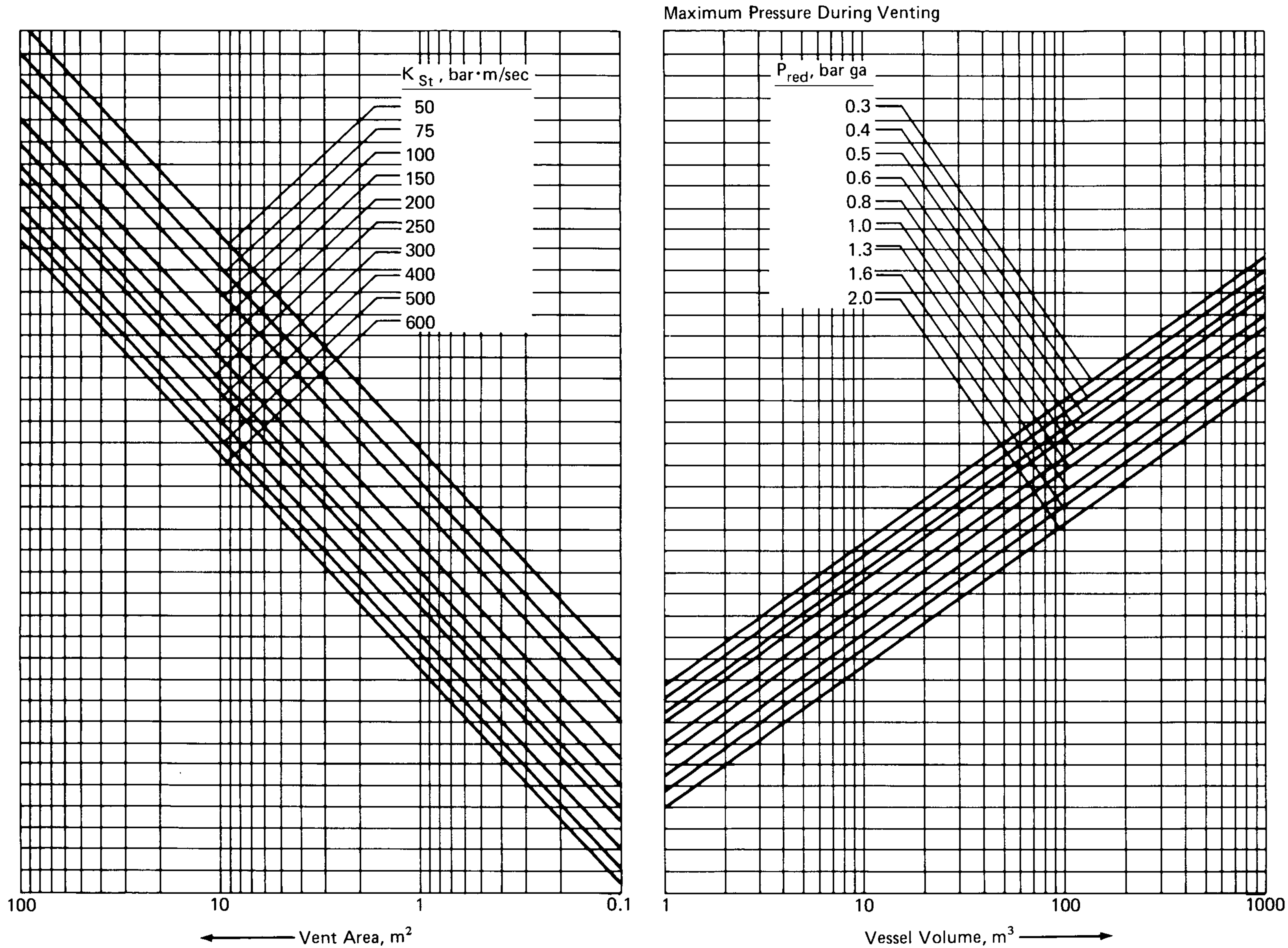

Figure 7-1(b) Venting Nomograph for Dusts—P_{stat} = 0.2 bar ga

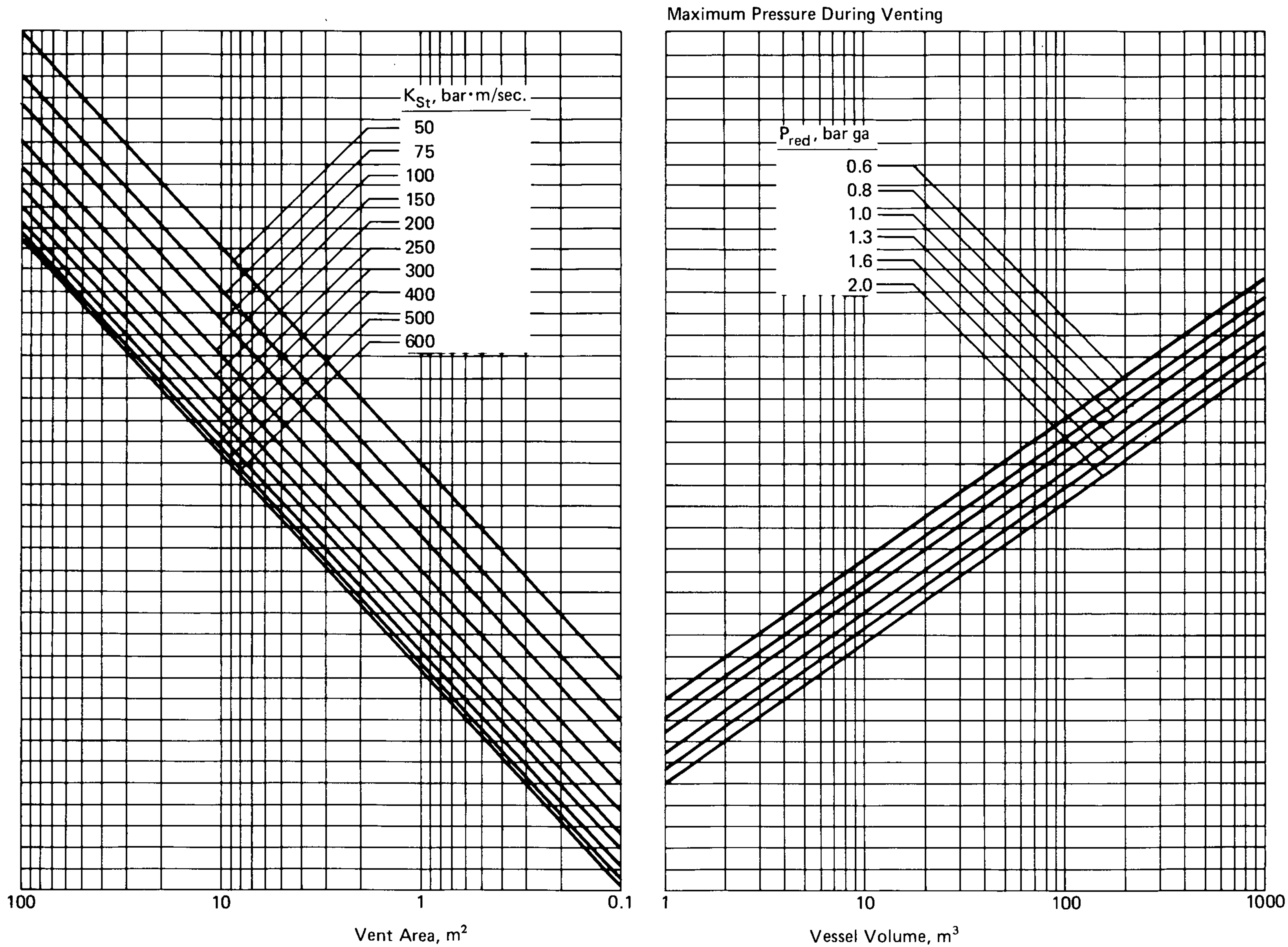

Figure 7-1(c) Venting Nomograph for Dusts—P_{stat} = 0.5 bar ga

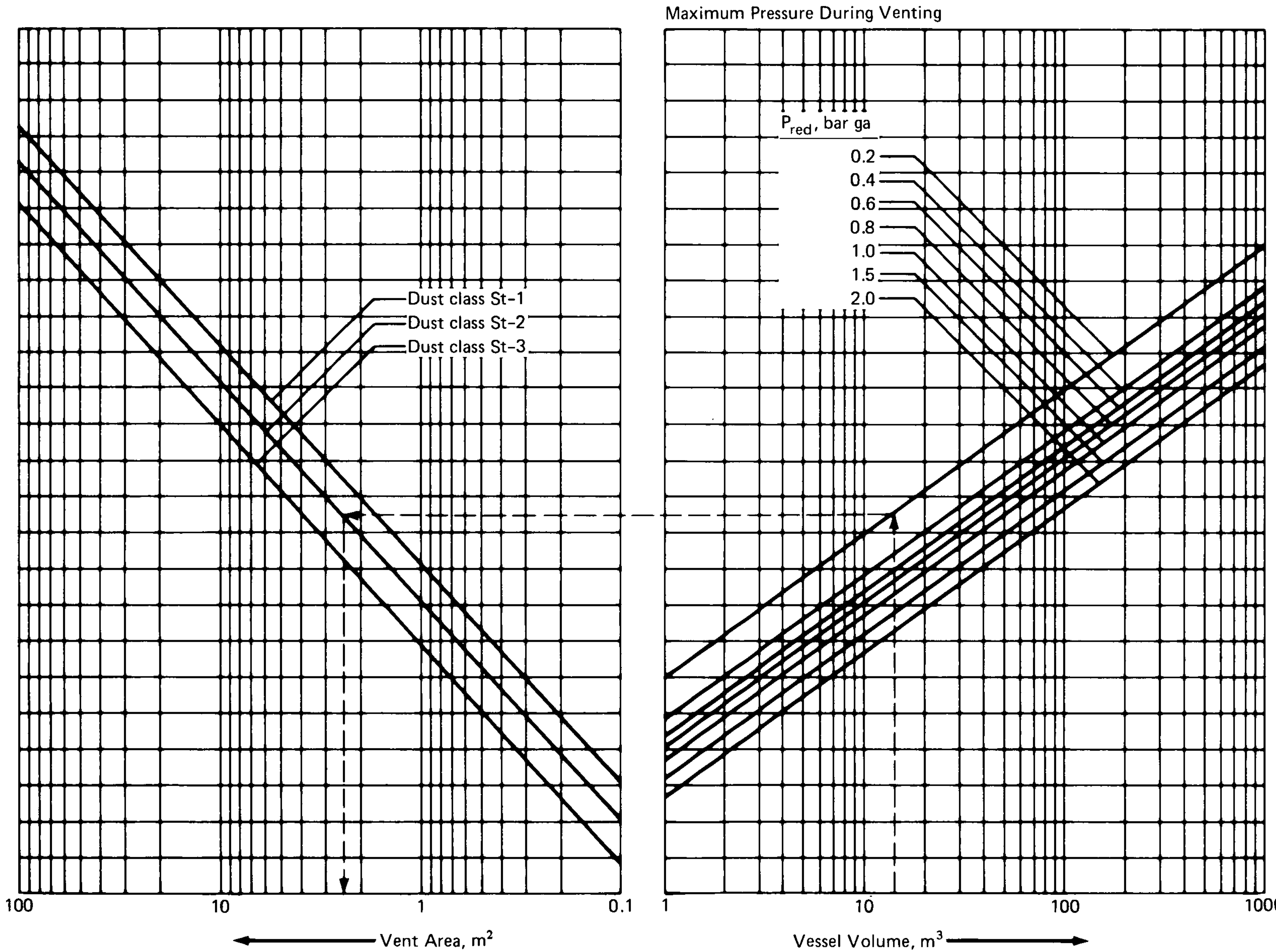

Figure 7-1(d) Venting Nomograph for Classes of Dusts—P_{stat} = 0.1 bar ga

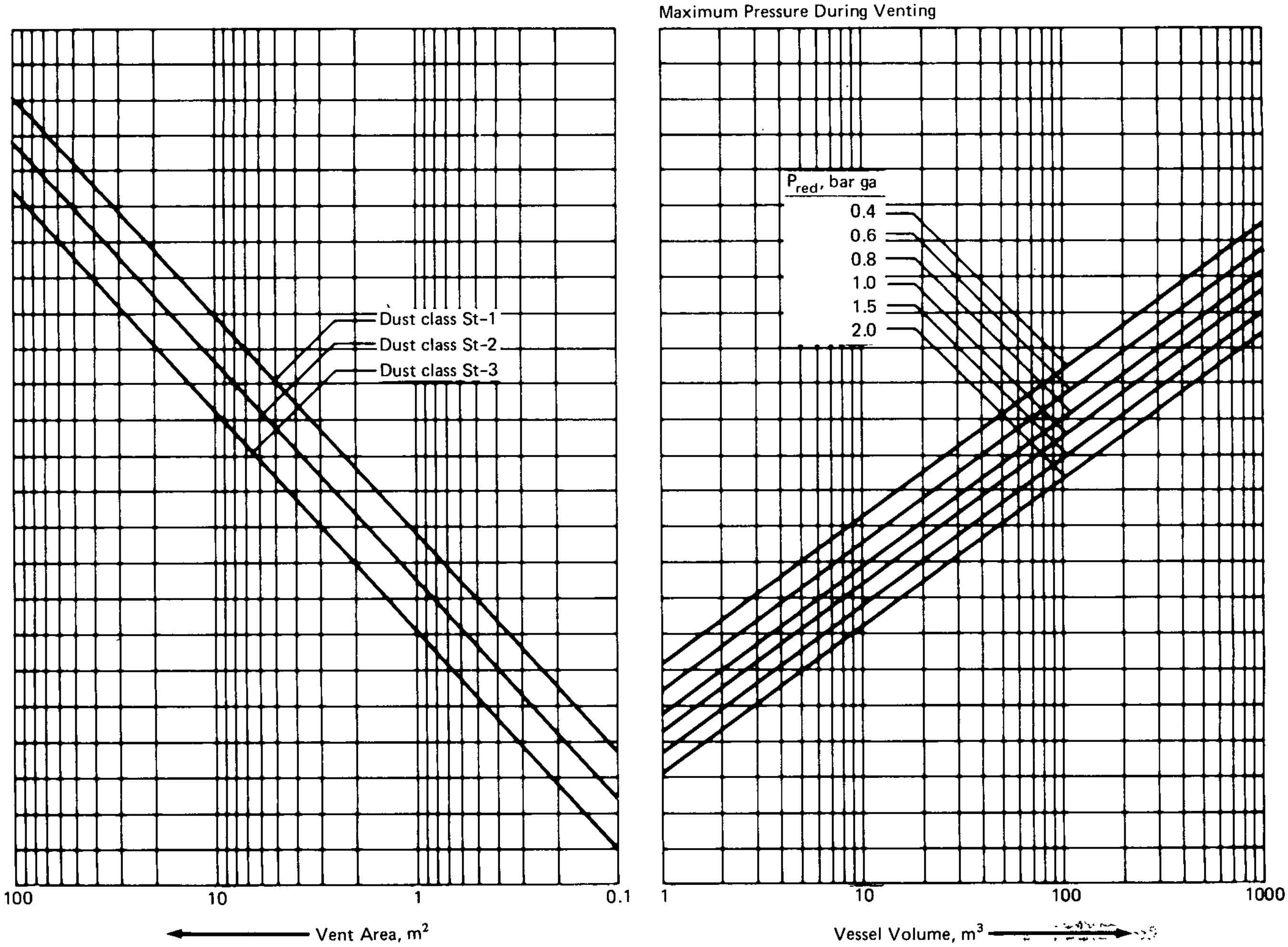

Figure 7-1(e) Venting Nomograph for Classes of Dusts—P_{stat} = 0.2 bar ga

7-2 Use of Dust Nomographs.

7-2.1 The necessary vent area for a dust can be determined from the nomographs as a function of the K_{St} value or the dust hazard class, the vessel volume and strength, and the relieving pressure of the vent closure.

7-2.2 The vent areas predicted by the two sets of nomographs described in 7-1.2 may not completely agree. The agreement is, however, sufficiently close for practical applications. When experimental values of K_{St} are available, Figures 7-1(a) through 7-1(c) should preferably be used to establish the minimum vent area required. The nomographs themselves are not exact and the determination of K_{St} can introduce additional errors. However, the nomographs have been shown to predict the required vent area with sufficient accuracy for dependable use in industry.

7-2.3 Dusts of the same hazard class that have maximum deflagration pressures not greater than 9 bar ga require less vent area than those that have a maximum deflagration pressure greater than 9 bar ga. The nomographs in Figures 7-2(a) and 7-2(b), based on test work reported in reference 84, are limited to dusts whose maximum deflagration pressure in closed vessel tests (*see Appendix A*) is not greater than 9 bar ga and only for vent opening pressures not exceeding 0.1 bar ga. The limitations stated in 7-2.2 apply to these nomographs as

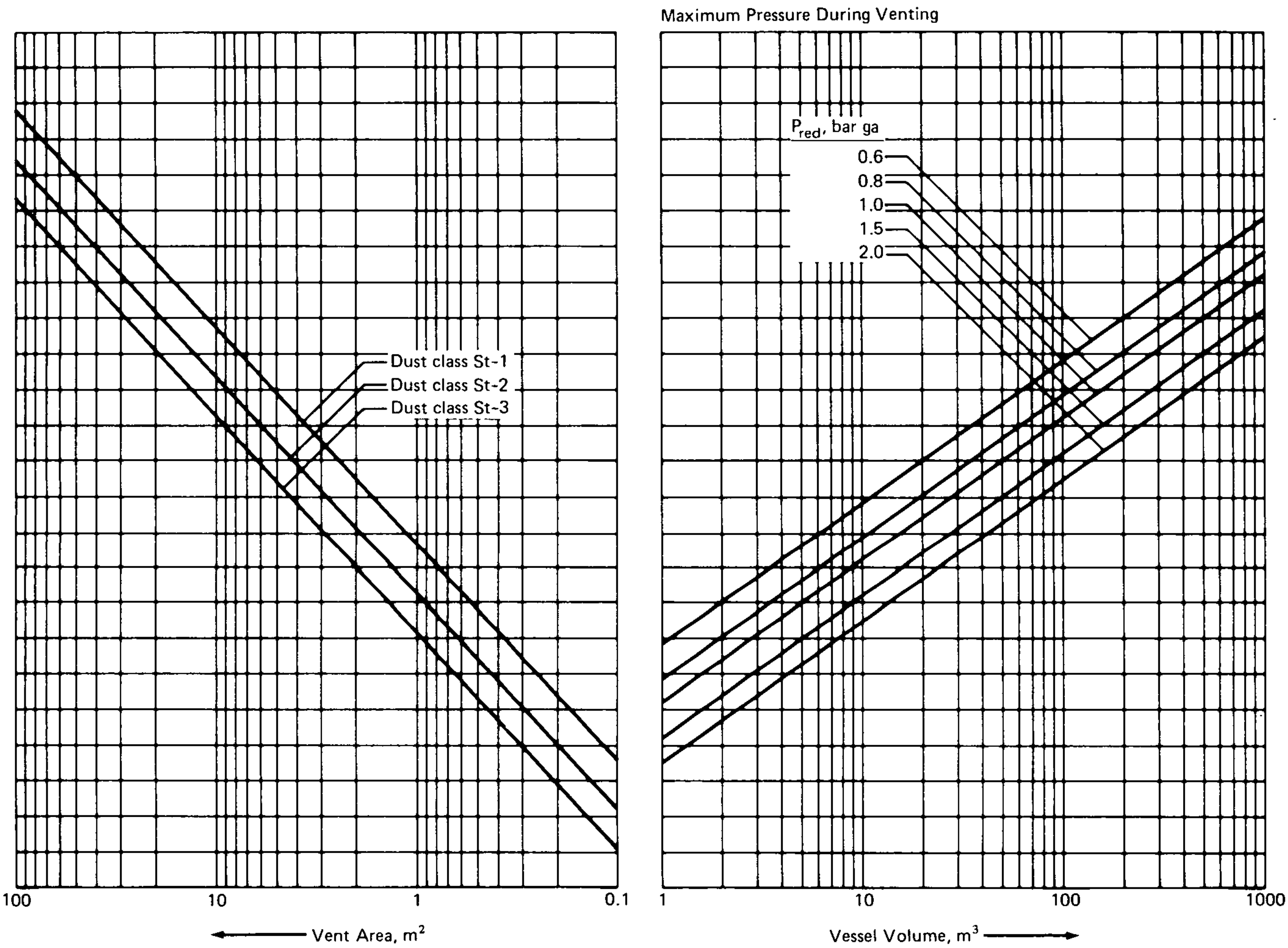

Figure 7-1(f) Venting Nomograph for Classes of Dusts—P_{stat} = 0.5 bar ga

well. Also, none of the equations in 7-1.1.1 or 7-1.1.2 are applicable to these two nomographs.

As an alternate to Figure 7-2(a), the following equation may be used to determine the necessary vent area for Class St-1 dusts that do not develop pressures in closed vessel tests of greater than 9 bar. P_{stat} = 0.1 bar.

$$\text{Log } A_v = 0.77957 \text{ Log } V - 0.42945 \text{ Log } P_{red} - 1.24669.$$

As an alternate to Figure 7-2(b), the following equations may be used to determine the necessary vent area for Class St-2 dusts that do not develop pressures in closed vessel tests of greater than 9 bar. P_{stat} = 0.1 bar.

For V = 1 - 10 m^3

$\text{Log } A_v = 0.64256 \text{ Log } V - 0.46527 \text{ Log } P_{red} - 0.99461$

Equation for Pressure Venting of Dust Deflagrations. St-2

P_{stat} = 0.1 bar

For Vessel Volume (V)m^3 = 10 m^3 - 1000 m^3

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

Supporting material on the comparisons between the nomographs and the equations is available for review at NFPA Headquarters.

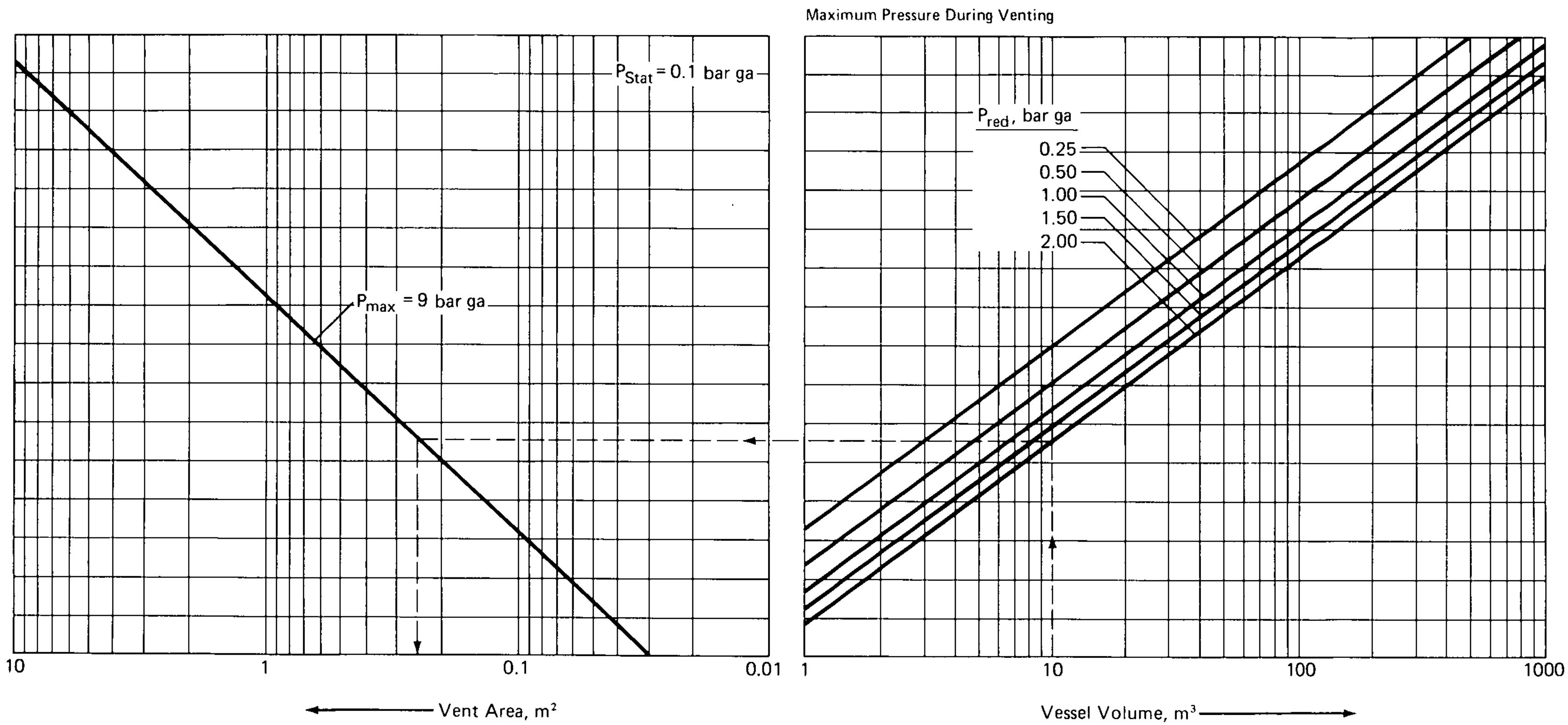

Figure 7-2(a) Alternate Venting Nomograph for Dusts of Class St-1 whose Maximum Deflagration Pressure Does Not Exceed 9 bar ga

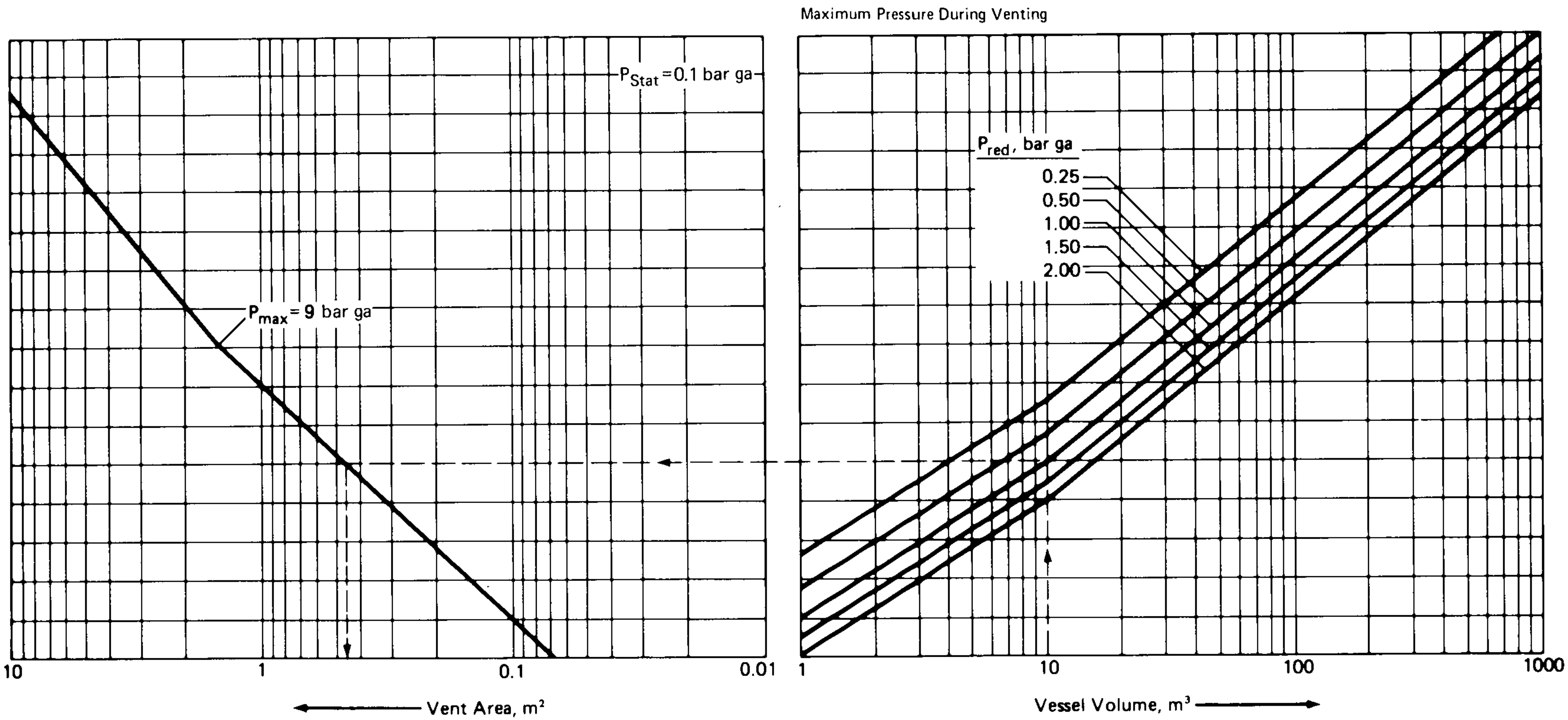

Figure 7-2(b) Alternate Venting Nomograph for Dusts of Class St-2 whose Maximum Deflagration Pressure Does Not Exceed 9 bar ga

7-3 Extrapolation and Interpolation of Nomographs.

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

7-3.2 The user is cautioned not to extrapolate the nomographs below 0.05 bar ga for P_{stat} nor below 0.1 bar ga for P_{red}. For values below these, use the calculation procedure in Chapter 4. Furthermore, P_{red} should not be extrapolated above 2.0 bar ga, the upper limit in the nomographs. Although P_{stat} may be extrapolated upward, it must always be less than P_{red} by at least 0.05 bar. The venting nomographs are to be taken as the final authority within their applicable ranges of P_{stat} and P_{red}.

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

7-4 Bins, Hoppers, and Silos.

7-4.1 Deflagration venting for bins, hoppers, and silos must be from the top or the upper side, above the maximum level of the material contained and must be directed to a safe outside location (*see Sections 5-5 and 7-7*). In some instances, the required vent area may be as large as the vessel cross-section. In these cases, the entire vessel top can be made to vent. Space must be available above the top to allow it to open sufficiently. The top should be as lightweight as possible. (*See 3-4.3 for effects of vent mass.*) Large-diameter tops of this type cannot be made self-supporting and will require internal supports. Panels that make up the top must not be welded or otherwise attached to the internal roof supports. As an alternative, individual vent closures may be located on the top or the side (above the maximum level of solids). When vent closures are located on the side and top of the vessel, the maximum useful area for venting will correspond to the cross-sectional area of the vessel. The reader is cautioned that deflagration venting of these vessels can result in higher pressures than expected from the venting nomographs (*see reference 85*).

7-4.2 The vent area required is determined by the strength of the vessel. If this vent area is larger than the vessel cross-section, the vessel needs to be strengthened to contain a pressure consistent with the available vent area. In all cases, the total volume of the vessel should be assumed to contain a suspension of the combustible dust in question. That is, no credit should be taken for the vessel being partly full of settled material.

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

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

7-6 Venting of Enclosed Bag Dust Collectors. It is desirable to design bag filter vent panels in such a way as to minimize the potential for bags and cages to interfere with the venting process. The filter medium may not adequately segregate the clean and dirty sections of the collector during the deflagration. Therefore, the entire volume of each section should be used when calculating the vent area for that section. If the volume of the clean section above the tube sheet is relatively small, the vent area required may be achieved by placing the vents on the dirty section.

7-7 Flame Clouds from Dust Deflagrations. Normally when dust deflagrations occur, there is far more dust present than there is oxidant to burn it completely. When venting takes place, large amounts of unburned dust are vented from the vessel. Burning continues as the dust mixes with additional air from the surrounding atmosphere. Hence, a very large and long fireball of burning dust develops, which can extend downward as well as upward. The size of the fireball depends on many factors. In one deflagration venting test, a dust fireball extended at least 4 m below the level of the vent and about 15 m horizontally. Personnel enveloped by such a fireball would likely not survive. The potentially large size of the fireball extending from the dust deflagration vent should be considered when locating vents and vent ducts so as to avoid hazards to adjacent equipment and personnel.

7-8 Hybrid Mixtures.

7-8.1 A mixture of a combustible gas and a combustible dust constitutes a hybrid mixture. Such a mixture may be ignitible even if both constituents are below their respective lower flammable limits. The properties of hybrid mixtures are extensively discussed by Bartknecht (*see reference 3*). Certain dusts that do not form combustible mixtures by themselves may do so if a combustible gas is added, even if the latter is at a concentration below its lower flammable limit. The lower flammable limit concentrations of most combustible dusts are decreased by addition of combustible gases, even when the concentrations of the latter are below their lower flammable limits. The minimum ignition energy is also reduced below that for the dust alone (*see 2-2.2.1*).

7-8.2 The effective K_{St} value of most combustible dusts is raised by the admixture of a combustible gas, even if the gas concentration is below the lower flammable limit. This, in turn, leads to an increase in the required vent area. For hybrid mixtures, use the nomograph for the component that requires the greater vent area. This is usually the gas.

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

8-1 Scope. This chapter applies to systems operating at pressures up to 1.2 bar absolute.

8-2 General.

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

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

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

(c) Turbulence-producing appurtenances such as valves, elbows, and other fittings are frequently present. The turbulence produced can generate sudden flame acceleration and a consequent rapid increase in pressure.

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

(e) Conversely, when a flame front propagates through an inadequately vented pipe or duct and then enters an enclosure or vessel containing a mixture in the flammable range, the resulting jet of flame is such a massive ignition source that any deflagration venting in the vessel may be rendered inadequate.

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

8-3 Design Guidelines.

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

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

8-3.3 Any pipes or ducts connected to a vessel in which a deflagration can occur may also require deflagration venting. For gases and Class St-3 dusts, a deflagration vent whose area is equal to the cross-sectional area of the pipe or duct should be provided at a location on the pipe or duct that is no more than two diameters distant from the point of connection to the vessel. For Class St-2 and St-1 dusts, evaluations should be made to determine the need for any additional venting on a case by case basis.

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

8-3.5 For systems handling gases, unless appropriate tests indicate otherwise, pipes and ducts containing obstacles should be provided with deflagration vents on each side of the obstacle. When designing for a P_{red} of 0.2 bar ga or less, two vents, each of which has an area equal to the cross-sectional area of the duct or pipe, should be placed on each side of the obstacle at distances from the obstacle of 3 diameters and 6 diameters, respectively. When designing for a P_{red} of greater than 0.2 bar ga, one vent on each side of the obstacle at distances of 3 diameters should be sufficient. At the present time, there is not sufficient information available for venting of dusts. An obstacle is defined here as an elbow, tee, flow splitter, orifice, valve, or any appurtenance that blocks more than 5 percent of the cross-sectional area of the pipe or duct.

8-3.6 The weight of deflagration vent closures should not exceed 2.5 lb/sq ft for each square foot of free vent area.

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

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

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

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

8-4.1 The curves in Figure 8-4(a) should be used to determine the maximum allowable length of a smooth, straight pipe, duct, or vessel that is closed on one end and vented on the other when no additional deflagration vents are provided. If L/D ratios greater than those shown in the figure are present, there is a risk that detonation may occur. In these cases, the container should be designed to resist detonation pressures, provided with additional vents, or provided with explosion prevention measures such as those described in NFPA 69, *Standard on Explosion Prevention Systems*. Class St-1 dusts are an exception in that there is no evidence that large L/D ratios can lead to a detonation of these dusts.

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

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

8-4.4 Initial Velocity Greater than 2 m/sec. Flame acceleration and peak pressures can be greatly enhanced when the flammable mixture is initially flowing at velocities greater than 2 m/sec. Consequently, pipes, ducts, or elongated vessels that are vented only at one end should be constructed to withstand detonation, provided with additional explosion vents, or provided with explosion protection measures such as those described in NFPA 69, *Standard on Explosion Prevention Systems.* In lieu of designing for detonation pressures, Class St-1 dusts may be handled in systems designed to withstand 10 bar without bursting.

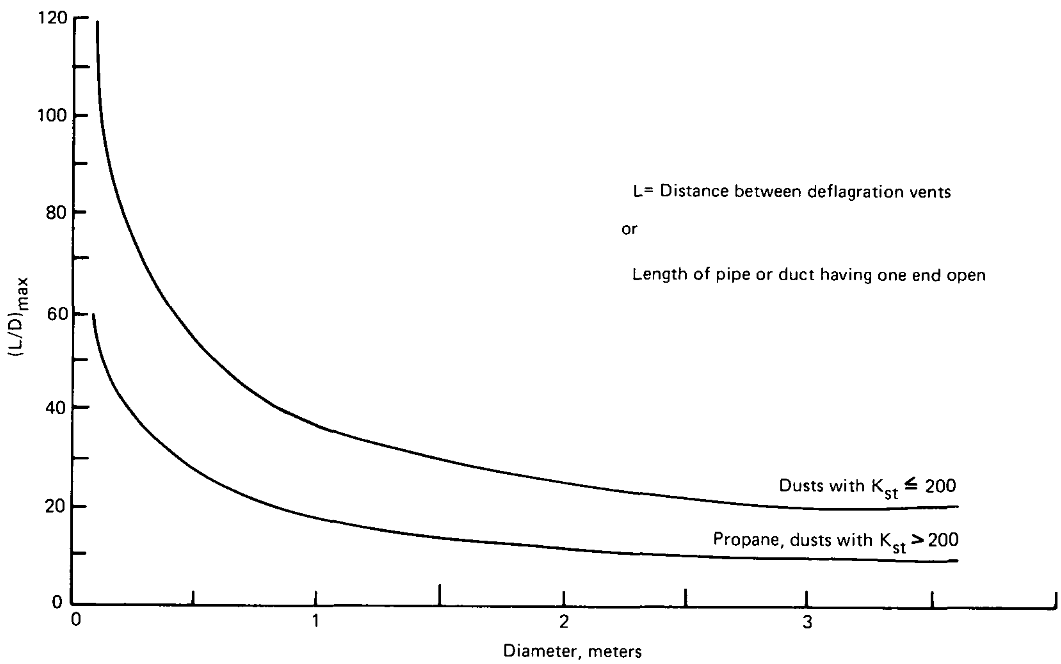

Figure 8-4(a) Maximum allowable distance, expressed as length-to-diameter ratio, for a smooth straight pipe or duct.

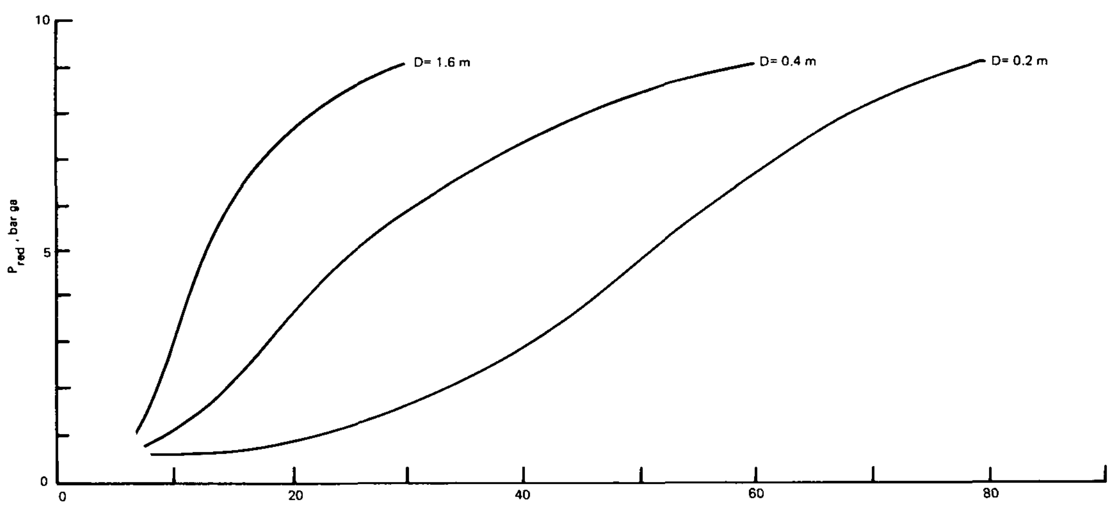

Figure 8-4(b) Maximum pressure developed during deflagration of propane/air mixtures flowing at 2 m/s or less in a smooth, straight pipe closed at one end.

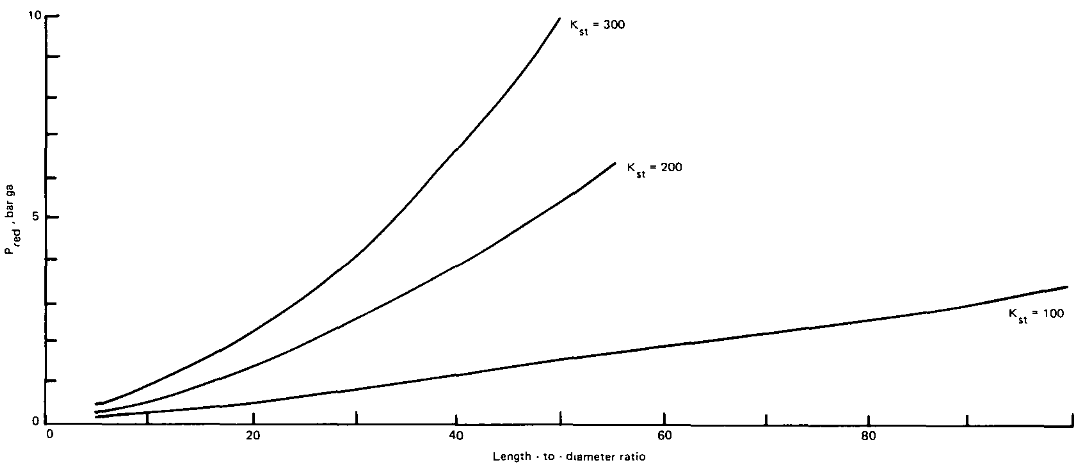

Figure 8-4(c) Maximum pressure developed during deflagration of dust/air mixtures flowing at 2 m/s or less in a smooth, straight pipe closed at one end.

8-5 Explosion Vent Requirements When More Than One Vent Can Be Provided.

8-5.1 Maximum Distance Between Vents. The curves shown in Figure 8-4(a) should be used to determine the maximum allowable distance between vents. If distances in excess of those indicated are used, the pipe or duct should be designed to withstand a detonation, or explosion prevention measures such as those described in NFPA 69, *Standard on Explosion Prevention Systems*, should be used. This limitation does not apply to Class St-1 dusts, since there is no evidence that large L/D ratios can lead to a detonation of these dusts.

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

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

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

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

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

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

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

8-5.5 Initial Velocity Greater than 20 m/sec, *or* Gases Having Burning Velocities More than 1.3 Times that of Propane, or Dusts With $K_{St} > 300$. For these situations, vents should be placed no more than 1 to 2 m apart, or the pipe or duct should have a design pressure capable of withstanding a detonation or explosion protection measures, such as those described in NFPA 69, *Standard on Explosion Prevention Systems*, should be employed.

8-5.6 Obstacles. For ducts or pipes containing obstacles as previously described, vents should be placed as specified in 8-3.5. Additional vents, as specified elsewhere in Section 8-5, may also be required.

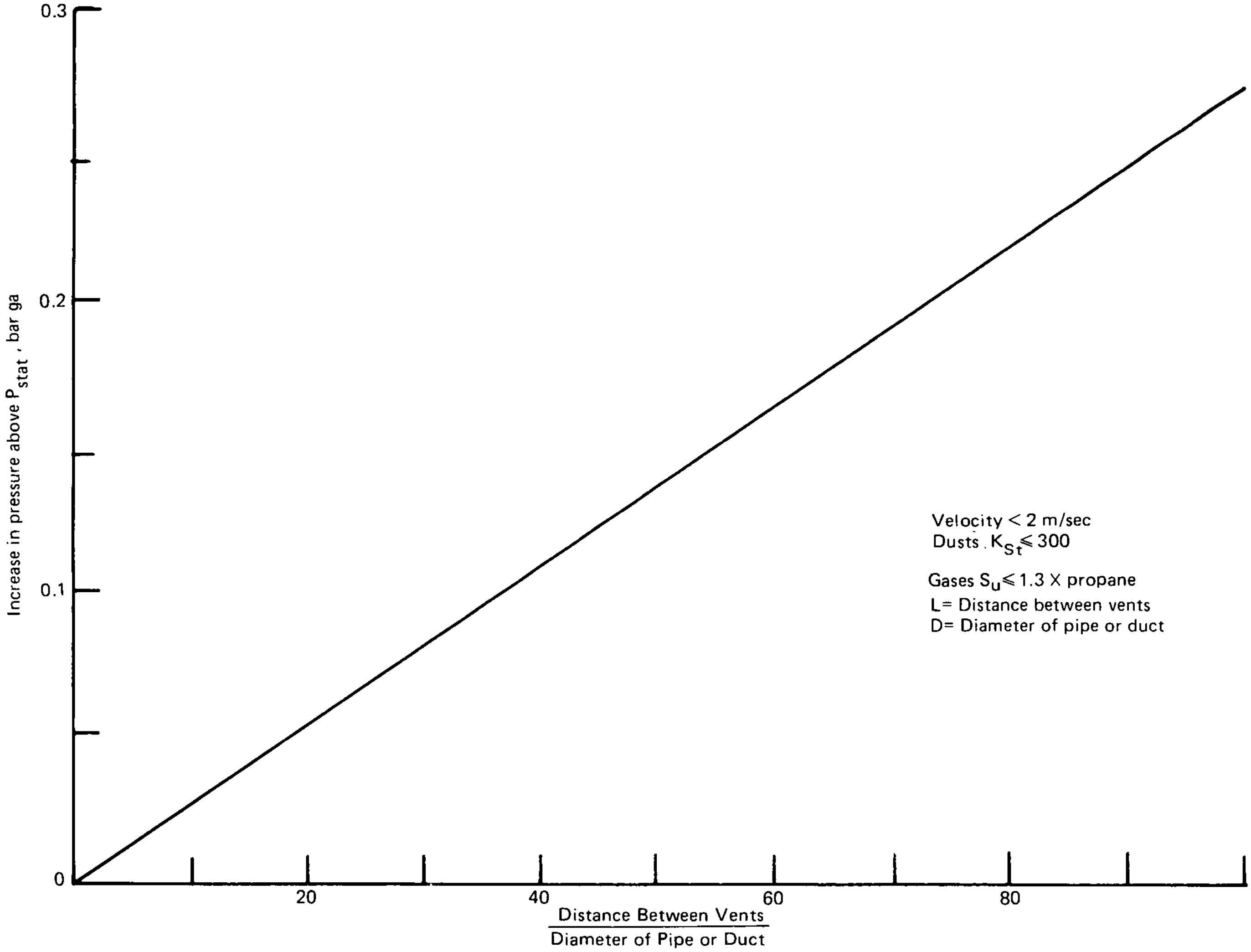

Figure 8-5(a) Maximum pressure developed during deflagration of gases or dusts in a pipe or duct when more than one vent is provided.

8-6 Examples.

8-6.1 A dryer handling a dust whose K_{St} is 190 is 2 m in diameter and 20 m long and is designed so that one end functions as an explosion vent. What pressure will be developed during a vented explosion?

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

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

8-6.2 A flare stack is 0.4 m in diameter by 40 m tall and is equipped with a water seal at its base. What must its design pressure be in order to protect it from the pressure developed by ignition of a fuel/air mixture having properties similar to those of propane?

(a) Check maximum allowable length: From Figure 8-4(a), a maximum L/D of 28 is allowed. This stack has an L/D equal to 100. Therefore, it must be designed to withstand a detonation or must be protected by some other means.

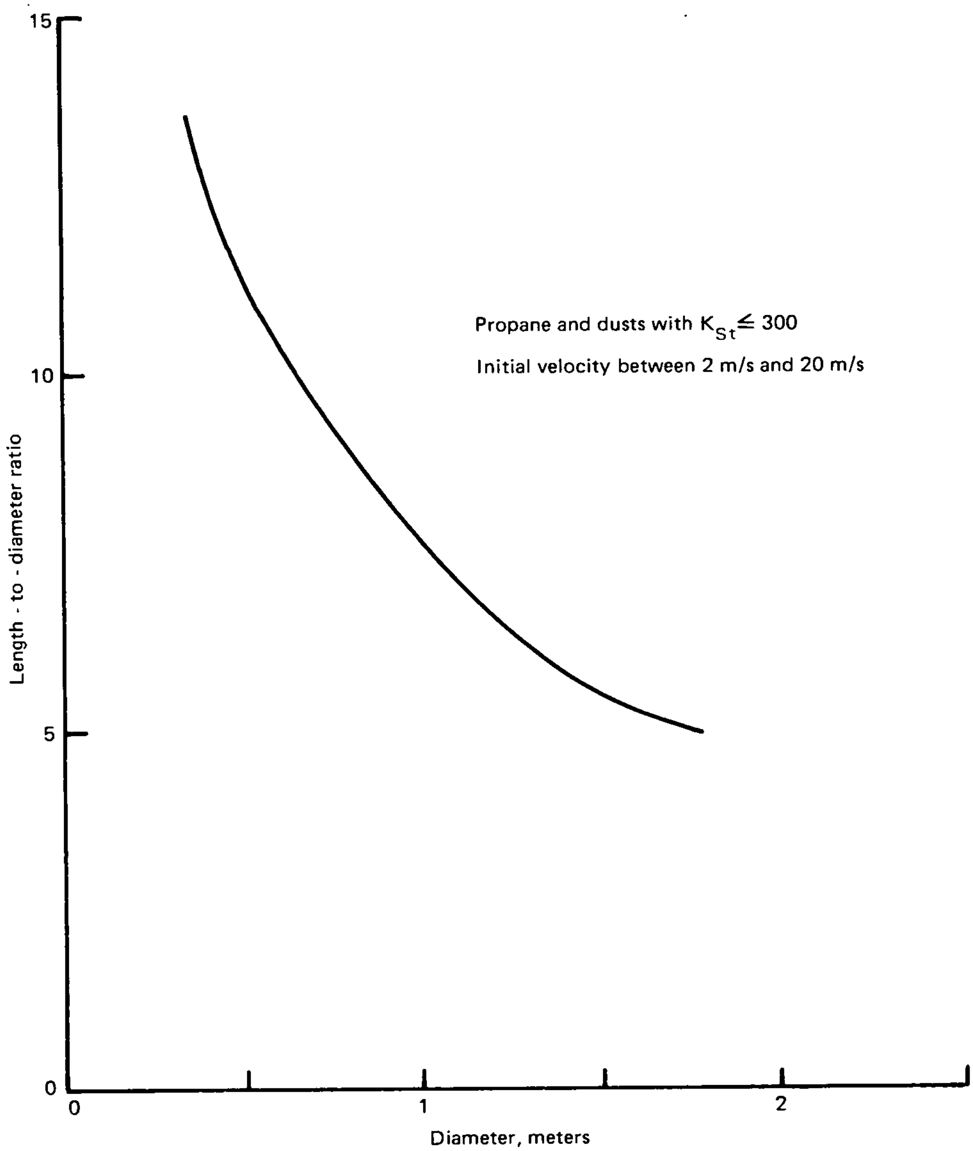

Figure 8-5(b) **Vent spacing required to keep P_{red} from exceeding 0.2 bar ga.**

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

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

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

8-6.4 Provide deflagration vents for the ducts in the system shown in Figure 8-6.4. The gas flow through the system is 100 m³/min, and all ducts are 0.6 m diameter. The maximum allowable working pressure for the ducts and equipment is 0.2 bar ga and the maximum operating pressure in the system is 0.05 bar ga. The system handles a Class St-2 dust. It is further assumed that the dryer and dust collector are equipped with adequate deflagration vents.

According to the provisions in 8-3.3 and 8-3.5, the following vents are required:

- A and B must be located no greater than 6 and 3 diameters, respectively, upstream of the first elbow as required by 8-3.5. 8-3.3 may require a vent in the duct leaving the dryer, but allows it to be located on a "case by case basis." Locating duct "A" 6 diameters upstream of the first bend places it 2.3 diameters downstream of the dryer. This is acceptable.
- C and D located 3 and 6 diameters distance, respectively, downstream from the first elbow.
- G located at a position approximately 2 diameters upstream of the dust collector inlet based on the "case by case" criteria in 8-3.3.
- H, I, and J located at the midpoints respectively of the three 1.5 m sections. Since these sections are less than 3 diameters in length, the second vents specified in 8-3.5 (i.e., the vents to be located 6 diameters and downstream of an obstruction) are not required.
- K and L located 3 and 6 diameters distance, respectively, after the last elbow.

Additional venting is required for the 20 m section. The flow of 100 m^3/min corresponds to a velocity of 6 m/sec. Hence Figure 8-5(b) should be used. According to this figure, the vents should be placed at intervals no greater than 11 diameters, or approximately 6.5 m apart. The distance between vents D and G is 15.2 m, therefore, two additional vents (E and F) at approximately equal spacing would meet the requirement.

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

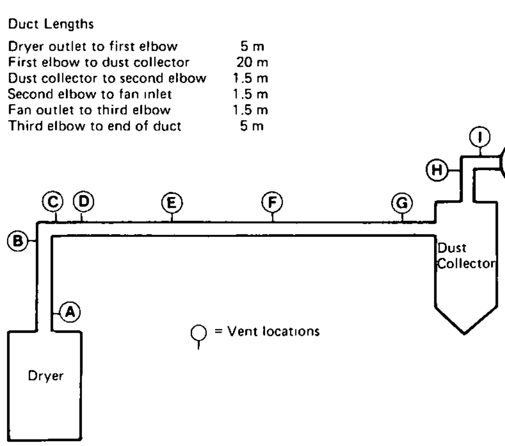

Figure 8-6.4 Diagram for example in 8-6.4.

Chapter 9 Description of Deflagration Vents and Vent Closures

9-1 General.

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

9-1.2 Some types of vent and closure assemblies are commercially available and may be purchased ready to install. Others must be custom fabricated on site by the user. The following descriptions may be used as a basis for the selection or design of suitable vent and closure assemblies.

9-2 Normally Open Vents.

9-2.1 The most effective deflagration vent is an unobstructed opening that has no closure. Open vents are an option wherever equipment or rooms do not need to be totally closed. However, there are comparatively few situations where operations with an inherent deflagration hazard can be conducted in open equipment.

9-2.2 Louvered Openings. Openings fitted with fixed louvers may be considered as open vents. However, the construction of the louvers partially obstructs the opening, thus reducing the net free vent area. The obstruction presented by the louvers decreases the flow rate of gases passing through the vent and increases the pressure drop across the vent. These factors must be considered when choosing louvered vents.

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

9-3 Normally Closed Vents for Rooms, Buildings, and Other Large Enclosures.

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

9-3.2 The vent closure must be designed to function at as low a pressure as practical and must be suitable for the service conditions to which it will be exposed. The static release pressure, P_{stat}, must be identified, ideally by test, and it must correlate with the calculations used to determine the vent area versus the maximum pressure developed during venting, P_{red}. If the enclosure will be exposed to temperatures that may affect the release pressure, this must be taken into consideration in determining P_{stat}.

9-3.2.1 The closure should be permanently marked with the release pressure.

9-3.3 The vent closure must be designed to function as rapidly as is practical. Thus, the mass of the closure should be as low as possible to reduce the effects of inertia. The total weight of the movable part of the closure assembly should not exceed 2.5 lb/ft^2. (The effect of inertia is illustrated in Table 9-3.3.) Counterweights should not be used because they add to the inertia of the closure. The closure must also be designed to withstand natural forces such as wind or snow loads, operating conditions such as internal pressure fluctuations and internal temperature, and effects of corrosion.

Table 9-3.3 Maximum Pressure Developed by Deflagration in Enclosures having Unrestricted Vents and Different Vent Closures. (*See reference 72*).

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

9-3.4 Types of Building or Room Vent Closures. The following types of vent closures are intended for use primarily with relatively large, relatively low-strength enclosures such as those covered by Chapter 4.

9-3.4.1 Hinged Doors, Windows, and Panels. These closures are designed to swing outward and normally have latches or similar hardware that automatically release when influenced by slight internal pressure. Friction, spring-loaded, or magnetic latches of the type used for doors on industrial ovens are the usual type of hardware. For personnel safety, the door or panel should be designed to remain intact and to stay attached. Materials that tend to fragment, such as glass or mineral/cement boards must not be used. Also, special attention must be given to maintenance of operating mechanisms to ensure proper function.

9-3.4.2 Shear and Pull-Through Fasteners. Specially designed fasteners that will fail under relatively low mechanical stress to release a vent closure are commercially available. The shear-type fastener is designed to break from the shear stress that develops in the fastener when the overpressure from a deflagration pushes laterally on the vent closure. The pull-through type of fastener uses a collapsible or deformable washer to hold the closure panel in place. The force of the deflagration on the panel causes the washer to be pulled through the mounting hole and the panel can then be pushed away from the vent opening. Since these fasteners can be applied to a variety of types and configurations of vent and closure assemblies, the response of a given fastener to a pressure differential cannot be predicted for any given application based on fastener test data alone. Dynamic testing should be carried out to establish the P_{stat} for any given fastener/vent/closure combination.

Shear and pull-through fasteners are suitable for applications where the vent design calls for very large vent areas, such as the entire side wall of a room.

9-3.4.3 Friction-Held Closures. Some commercially available vent and closure assemblies use a flexible diaphragm held around its edges in a restraining frame. When a deflagration occurs, the pressure deforms the diaphragm, pushing it from its frame. [*See Figures 9-3.4(a) and (b).*] This type of vent and closure assembly is well suited for large structures such as rooms, buildings, conveyor enclosures, silos, dust collectors and baghouses, and other large enclosures. It is also particularly suited to ductwork operating at or close to atmospheric pressure.

In locations where personnel or equipment might be damaged by flying diaphragms, tethering of the diaphragm to its frame or other safety measures may be necessary.

The material used for the diaphragm should be durable, nonshattering, and should not exceed 2.5 lb/ft^2. The diaphragm should be appropriately dimensioned and attached.

These vent and closure assemblies are capable of being tested by static methods and by simulated deflagrations corresponding to the intended application. It is recommended that both static and dynamic tests be conducted.

9-3.4.4 "Weak" Roof or Wall Construction. A portion of a roof or wall may be deliberately designed to fail under slight overpressure. In this type of venting, suitable lightweight panels may be located between strong partition walls. In some cases, the entire roof area is constructed as a blowout panel. In all cases, the weak wall or roof must be adequately anchored to prevent wind lift.

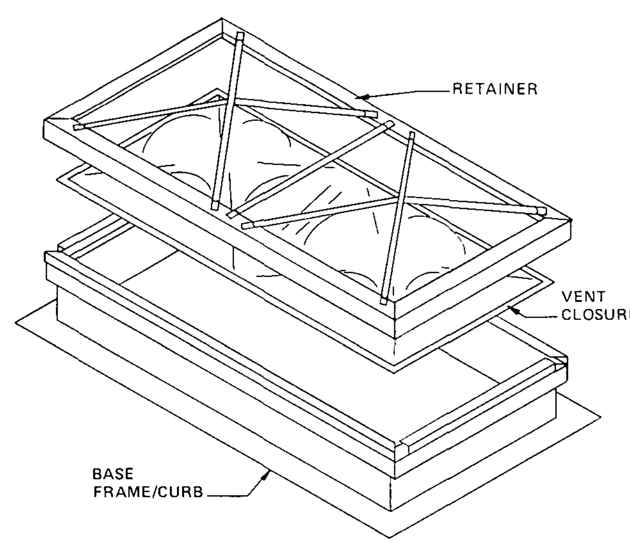

Figure 9-3.4(a) Exploded view of manufactured vent closure.

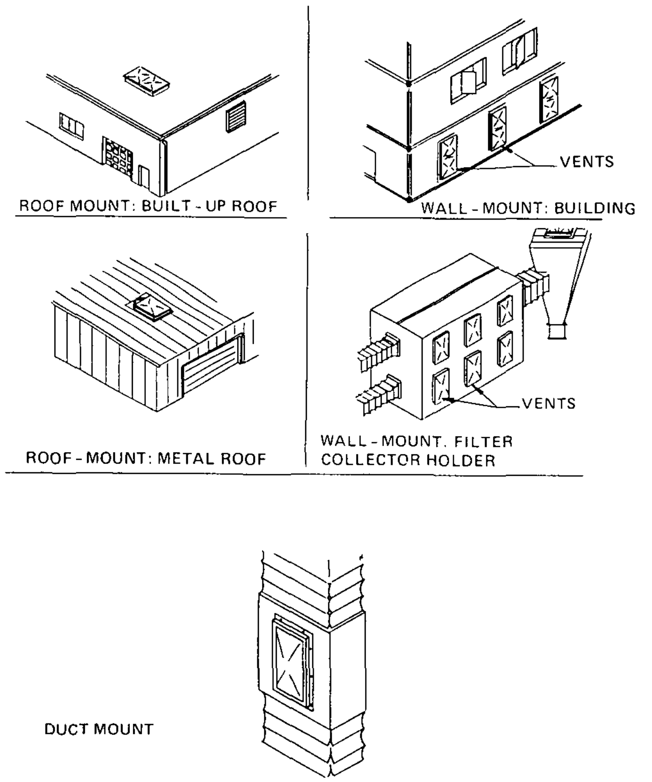

Figure 9-3.4(b) Typical applications for manufactured vent closures.

9-4 Restraints for Large Area Panels.

9-4.1 When large, lightweight panels are used as vent closures (usually over entire wall areas), it is usually necessary to tether the panels so they do not become missile hazards. The restraining method shown in Figure 9-4.1 illustrates one method that is particularly suited for conventional single-wall metal panels. The key features of the system include a permanent anchor between the panel and the building structural frame using a 2 in. wide, 10 gage bar washer. The length of the bar is equal to the panel width, less 2 in. and less any overlap between panels. The bar washer/vent panel assembly is secured to the building structural frame using at least three ⅜ in. diameter through-bolts. Shear fasteners or collapsible washers are used at the opposite end of the panel.

9-4.1.1 "Pop" rivets have been used successfully as the failure fastener. During deflagration tests using this design, the pop rivets failed within acceptable design limits to allow rotation of the panel about the plastic hinge formed by the attachment of the panel to the building structural frame.

9-4.1.2 Precautionary Measures for Aluminum Vent Panels. In tests of 21 gage corrugated aluminum panels, a tendency for the panels to tear out in the vicinity of the through-bolts (*see Figure 9-4.1*) has been observed. This may be controlled by maintaining at least 3 in. distance between the edge of the panel and the bar washer and by hinging the panels to the lowest building structural member. This limits the amount of rotation that can occur, thus reducing the chance of tear-out.

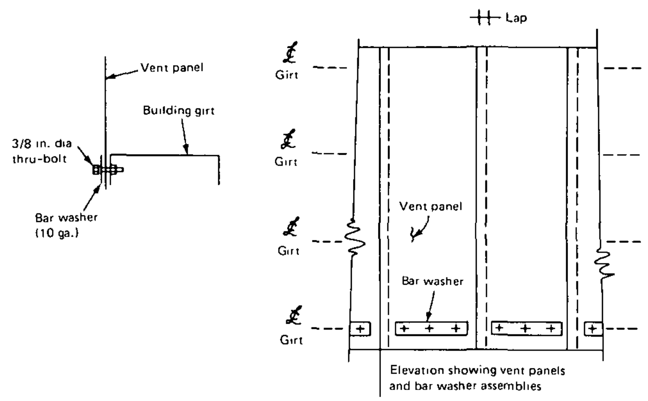

Figure 9-4.1 Panel restraint system for single-wall metal vent panels.

9-4.2 When the vent closure panel is a double-wall type (such as insulated sandwich panels), the restraint system described in 9-4.1 is not recommended. The stiffness of the double-wall panel is much greater than that of a single-wall panel. The formation of the plastic hinge will occur more slowly and rotation of the panel may be incomplete. Both factors will tend to delay or impede venting during a deflagration.

The restraint system shown in Figure 9-4.2 is recommended for double-wall panels. For successful functioning, the panel area is limited to 33 ft^2 and its mass to 2.5 lb/ft^2.

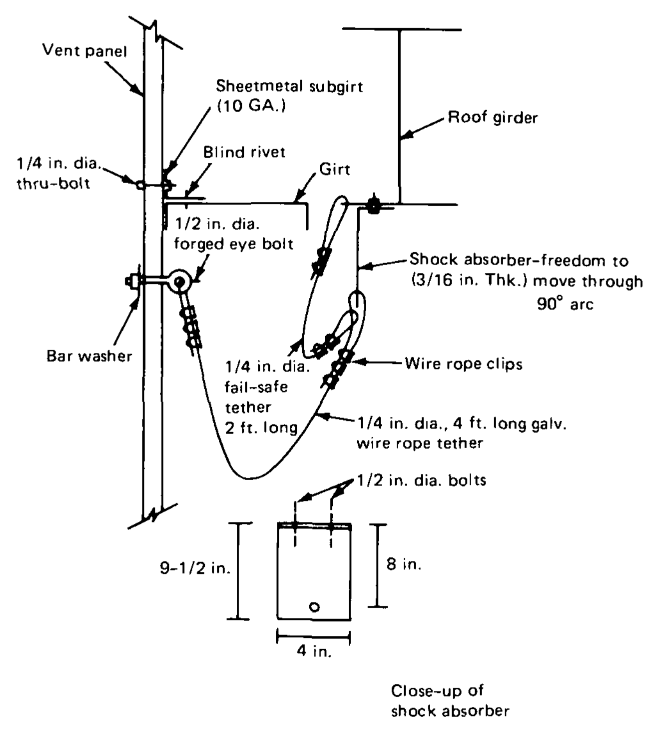

Figure 9-4.2 Panel restraint system for double-wall insulated metal vent panel.

9-4.2.1 Tests employing fewer than three rope clips have in some instances resulted in slippage of the tether through the rope clips, thus permitting the vent panel to become a free projectile.

9-4.2.2 Forged eyebolts are necessary. Alternatively, a 0.5 in. "U" bolt may be substituted for the forged eyebolt.

9-4.2.3 A "shock absorber" device with a fail-safe tether is provided. The shock absorber is a 4 in. wide, $^3/_{16}$ in. thick, L-shaped piece of steel plate to which the tether is attached. During venting, the shock absorber will form a plastic hinge at the juncture in the "L" as the outstanding leg of the "L" rotates in an effort to follow the movement of the panel away from the structure. The rotation of this leg provides additional distance and time over which the panel is decelerated while simultaneously dissipating some of the panel's kinetic energy.

9-5 Equipment Vent Closures.

9-5.1 Hinged Devices. Hinged doors or covers may be designed to function as vent closures for many kinds of equipment. The hinge should be designed to offer minimum frictional resistance and to ensure that the closure device remains intact during venting. Closures held shut with spring, magnetic, or friction latches are most frequently used for this form of protection. Hinged devices can be used on totally enclosed mixers, blenders, driers, and similar equipment. It is difficult to vent equipment of this type if the shell, drum, or enclosure revolves, turns, or vibrates. Charging doors or inspection ports can be designed to serve this purpose when their action does not endanger personnel. Special attention should be given to the regular maintenance of hinge and spring-loaded mechanisms to ensure proper operation.

9-5.2 Rupture Diaphragm Devices. Rupture diaphragms may be designed in round, square, rectangular, or other shapes to effectively provide vent relief area to fit the available mounting space. (*See Figure 9-5.2.*)

9-5.3 Static Release Pressure. As in all vent closure designs, the static vent release pressure, P_{stat}, must be identified. P_{stat} is a function of vent design and materials of construction, and may vary from lot to lot during manufacture. Therefore, a minimum of two samples from each lot manufactured must be destructively tested. The average of the test values is to be considered the static vent release pressure.

9-5.4 Effects of Temperature. Most materials used for rupture diaphragms will be affected by elevated or reduced operating temperatures. If the operating temperature at the vent closure device is other than ambient, the static release pressure should be rated at the coincident operating temperature. This may be done by performing the two required tests of the lot manufactured at the coincident temperature or by using a temperature versus pressure curve, established specifically for the material or materials of the rupture diaphragm, which is then applied to the average of the destructive tests performed at the ambient temperature.

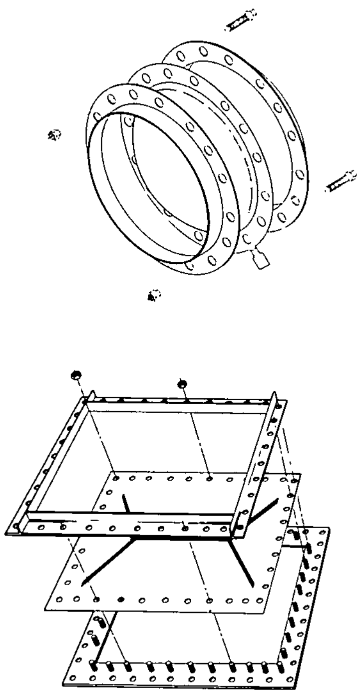

Figure 9-5.2 Typical rupture diaphragm.

9-5.5 Opening Characteristics. Some materials used as rupture diaphragms may balloon, tear away from the mounting frame, or otherwise open randomly, leaving the vent opening partially blocked on initial rupture. Although such restrictions may be momentary, delays of only a few milliseconds in relieving deflagrations of dusts or gases having high rates of pressure rise may cause extensive damage to equipment. For these reasons, only rupture diaphragms with controlled opening patterns that ensure full opening on initial rupture should be utilized.

9-5.6 Blow-out panels may be held in place by special rubber clamps. Pressures developed by a deflagration will push the panel out of the rubber clamp, providing an unrestricted vent opening.

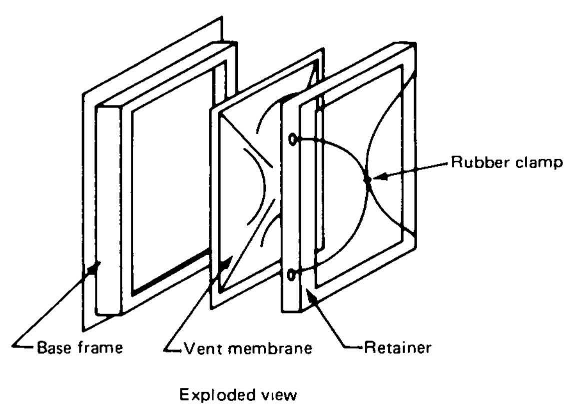

Figure 9-5.6 Typical blow-out panel.

9-5.6.1 The panel must be secured to avoid missile hazards. Such restraints should be carefully designed and tested for the type of application.

9-5.6.2 Because the weight of the panel will have a marked effect on its performance, any replacement panels must be manufactured from the same material and material thickness as the original design.

9-5.6.3 Aging, corrosion, or embrittlement of rubber clamps may cause the P_{stat} of such vent closure devices to change. Scheduled replacement of the rubber clamp may be necessary to maintain the desired performance.

Chapter 10 Inspection and Maintenance

10-1 General.

10-1.1 This chapter covers the inspection and maintenance procedures necessary to ensure proper function and operation of devices for venting deflagrations.

10-1.2 The occupant of the property in which the deflagration vents are located is responsible for inspecting and maintaining such devices.

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

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

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

Maintenance. Repair of any defects noted during inspection and periodic testing, performance of procedures recommended by the manufacturer of the device, or replacement of the device or its components.

10-3 Inspection Frequency and Procedures.

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

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

10-3.3 The recommendations of the manufacturer regarding inspection procedures and frequency should be followed.

10-3.4 Inspection procedures and frequency should be in written form and should include provisions for periodic testing, where practical.

10-3.5 To facilitate inspection, access to and visibility of venting devices should not be obstructed.

10-3.6 Any seals or tamper indicators that are found to be broken, any obvious physical damage or corrosion, and any other defects found during inspection should be immediately corrected.

10-3.7 Any structural changes or additions that might interfere with operation of venting devices should be immediately reported.

10-4 Maintenance.

10-4.1 Venting devices should receive appropriate preventive maintenance as recommended by the manufacturer.

10-4.2 Any defects noted during inspection should receive immediate corrective action.

10-5 Recordkeeping. A record should be maintained showing the date and the results of each inspection, and the date and description of each maintenance activity. The record should be kept at least until the completion of the next inspection.

Appendix A Guidelines for Measuring Deflagration Indices of Dusts and Gases

A-1 General Comments on Dust Testing. At the time of the writing of this Guide, work was progressing by standards-setting organizations (such as Committee E27 on Hazard Potential of Chemicals of the American Society for Testing and Materials) toward a standard method of measuring deflagration properties of dusts. This Appendix does not discuss formal procedures but is a general discussion of test procedures already in use that rely on the same basic principles.

A-1-1 Purpose. The purpose of these measurements is to predict the effect of the deflagration of a particular material (dust or gas) in a large enclosure without carrying out full-scale test work.

A-2 Basic Principles. The nomographs presented in this Guide and those in VDI 3673 (*see reference 62*) are based on large-scale tests carried out in vented vessels using a variety of test materials and vessel sizes (*see references 3, 43*). For each test material and vessel volume, the maximum reduced deflagration pressure (P_{red}) was found for a series of vents with various areas (A_v) and opening pressures (P_{stat}). Use of the nomographs requires only that a single material classification (the K_G or K_{St} index) be experimentally obtained by the user. Knowing the volume and mechanical constraints of the enclosure to be protected, the user can then determine the venting requirements from the nomographs.

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

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

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

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

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

where P = pressure (bar)
t = time (s)
V = Volume (m^3)
K = Normalized K_G or K_{St} Index (bar·m/s)

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

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

A-2-4 Effect of Volume on K_G and K_{St}. In the case of many initially quiescent gases, the normalized index K_G is found not to be constant but to increase with vessel volume. Figure A-1 shows the variation of K_G with vessel volume for methane, propane, and pentane as measured in spherical test vessels (*see reference 73*). The increase of K_G is related to various flame acceleration effects as described in references 40, 74, and 75. It is for this reason that K_G values measured in vessels of different sizes cannot be directly compared, even if all other factors affecting K_G are held constant. Any K_G measurement should be made in a spherical vessel at least 5 liters in volume and the values obtained should be used only to interpolate between the venting requirements of gases identified in the nomographs (Section A-3).

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

A-2-5 Effect of Initial Pressure. The initial pressure for deflagration testing is one standard atmosphere (14.7 psia or 760 mmHg). Alternatively, a standard pressure of 1 bar could be used with negligible error. If initial pressures are not of standard value, they must be reported and correction methods applied. P_{max} is proportional to initial test pressure and any difference between initial test pressure and one standard atmosphere will be multiplied by the deflagration pressure ratio (usually between 7 and 12) in the measured P_{max} value. Measured $(dP/dt)_{max}$ values will be affected to a smaller degree. The effect of initial pressure is most important where tests are conducted at ambient pressure. Ambient pressure can vary from extremes of 12.9 to 15.6 psia, even at sea level, and decreases with elevation. For example, at an elevation of 2 km (1.25 miles), the average pressure in latitude 50°N is 11.5 psia. It is readily seen that a P_{max} value measured at such an elevation would be about 20 percent lower

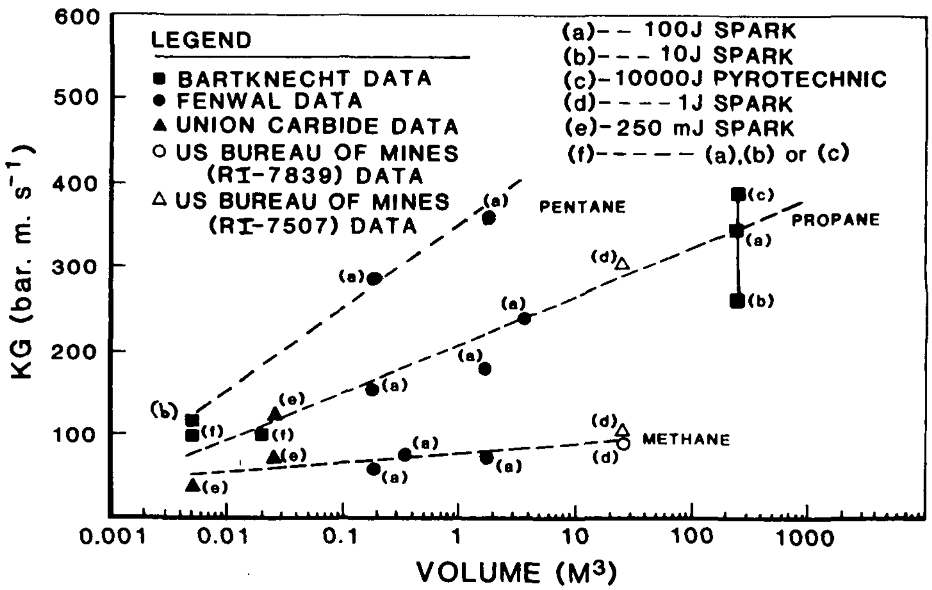

Figure A-1 Effect of Test Volume on K_G Measured in Spherical Vessels.

than would be measured at one standard atmosphere, assuming a 10:1 deflagration pressure ratio. It is always preferable to conduct tests under standard conditions rather than to correct the measured values.

A-3 Gas Testing. The test vessel used for gas testing should be spherical with a volume of at least 5 liters and preferably 20 liters or greater. Since the only source of initial turbulence is the ignition source employed, an important consideration is that the flame front not be unduly distorted by the ignition process. The ignition source should be centrally placed and should approximate a point source. A discrete capacitor discharge carrying no great excess of energy above that needed to ignite the mixture is recommended. Fused-wire and chemical igniters may cause multipoint ignition and should not be used for routine K_G measurements in small vessels.

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

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

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

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

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

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

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

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

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

A-4-1 Obtaining Samples for Standardization. Samples should be obtained having established K_{St} values in Dust Classes St-1, St-2, and St-3. At the time of the writing of this Guide, suitable standard samples were not generally available.

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

- the mass of sample dispersed, or concentration;
- the uniformity of the dispersion;
- the turbulence at ignition;
- the ignition strength.

The concentration is not subject to standardization since this must be varied for each sample tested until the maximum K_{St} has been found. The maximum K_{St} usually corresponds to a concentration several times greater than stoichiometric. A useful series of test concentrations are (in g/m^3): 250, 375, 500, 625, 750, 1000. A plot of measured K_{St} is made against concentration, and tests are continued until the maximum has been found. By testing progressively leaner mixtures, the minimum explosive concentration (lean limit or LFL) may similarly be determined. This limit may be affected by ignition energy.

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

A number of dust dispersion methods exist. For small vessels, the most common types are the perforated ring and the "whipping hose." The perforated ring (Figure A-3) fits around the inside surface of the test vessel and is designed to disperse the dust in many directions. A ring

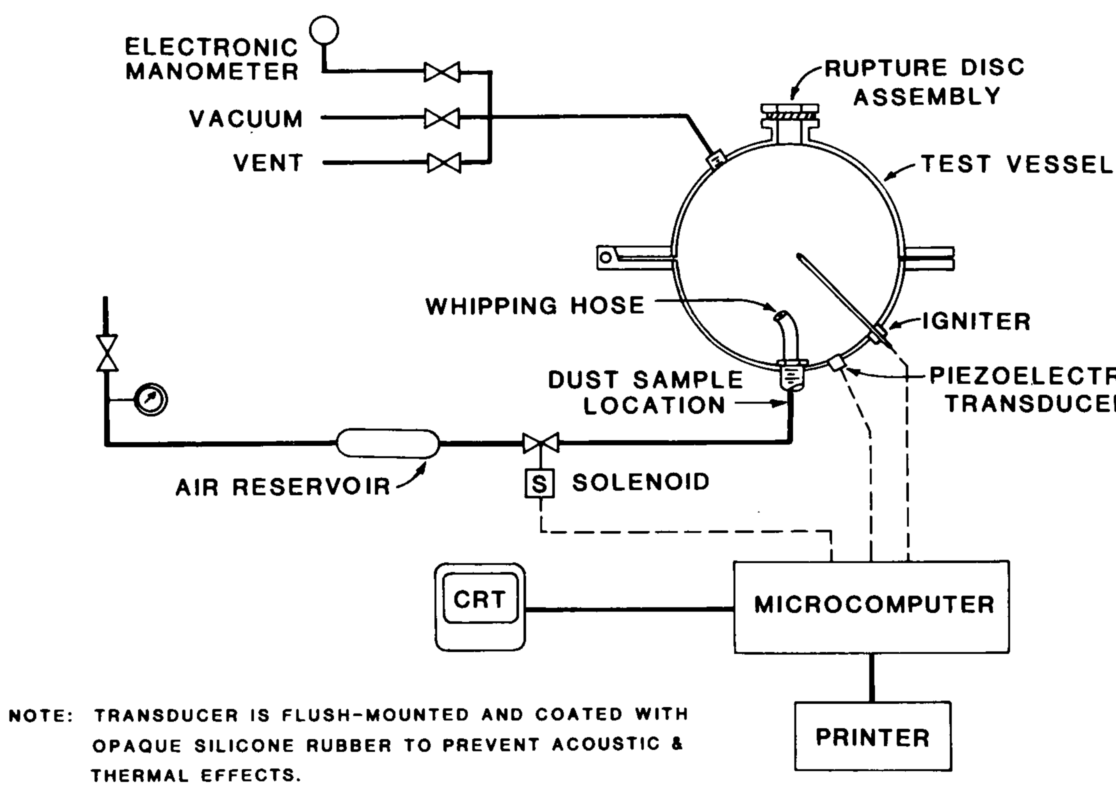

Figure A-2 Typical Dust Testing Apparatus.