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# NFPA 69
# Explosion Prevention Systems
# 1986

NFPA

National Fire Protection Association Batterymarch Park, Quincy, MA 02269

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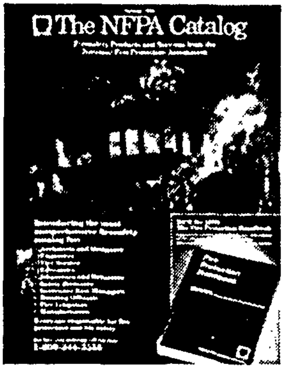

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## NFPA 69

### Standard on

# Explosion Prevention Systems

### 1986 Edition

This edition of NFPA 69, *Standard on Explosion Prevention Systems*, was prepared by the Technical Committee on Explosion Protection Systems and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 19-22, 1986, in Atlanta, Georgia. It was issued by the Standards Council on June 11, 1986, with an effective date of July 1, 1986, and supersedes all previous editions.

The 1986 edition of this standard has been approved by the American National Standards Institute.

## Origin and Development of NFPA 69

In 1965, an NFPA Committee was appointed to develop standards for explosion protection systems. These standards would include information on inerting to prevent explosions and venting to minimize damage from an explosion.

A tentative draft on explosion prevention systems was presented at the NFPA Annual Meeting in New York City in May 1969. This tentative document was officially adopted in May 1970. NFPA 69 was revised in 1973 and reconfirmed in 1978.

In 1982, the Committee on Explosion Protection Systems began a thorough review of NFPA 69, including the development of a chapter on the technique of deflagration pressure containment. This 1986 edition of NFPA 69 is the result of that effort.

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

## Contents

# NFPA 69

## Standard on

# Explosion Prevention Systems

## 1986 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Information on referenced publications can be found in Chapter 7 and Appendix E.

## Chapter 1 General

### 1-1 Scope.

1-1.1 This standard shall apply to the design, construction, operation, maintenance, and testing of systems for the prevention of deflagration explosions by means of the following methods:

(a) control of oxidant concentration;

(b) control of combustible concentration;

(c) explosion suppression;

(d) deflagration pressure containment;

(e) spark extinguishing systems.

1-1.2 This standard shall not apply to devices or systems designed to protect against overpressure due to phenomena other than internal deflagrations.

1-1.3 This standard shall not apply to the design, construction, and installation of deflagration vents, as covered by NFPA 68, *Guide for Explosion Venting*.

1-1.4 This standard shall not apply to:

(a) the preparation of tanks, piping, or other enclosures for hot work such as cutting and welding (*see NFPA 327, Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers*);

(b) the general use of inert gas for fire extinguishment;

(c) rock dusting of coal mines, as covered by Title 30, *Code of Federal Regulations*, Part 75;

(d) unconfined deflagrations such as open-air or vapor cloud explosions.

1-1.5 This standard shall not apply to ovens or furnaces handling flammable or combustible atmospheres, as covered by NFPA 86, *Standard for Ovens and Furnaces*, NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*, and NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*.

**1-2 Purpose.** This standard outlines the minimum requirements for installing systems for the prevention of explosions of enclosures that contain flammable concentrations of combustible gases, vapors, mists, dusts, or hybrid mixtures. Basic information is provided for design engineers, operating personnel, and authorities having jurisdiction.

**1-3* Techniques.** There are five techniques recognized in this standard; they are grouped into two classes. One class is based on preventing combustion; the other is based on preventing or limiting damage after combustion occurs. (Deflagration venting is not addressed in this standard; *see NFPA 68, Guide for Explosion Venting.)*

**1-3.1 Methods Based on Preventing Combustion:**

(a) oxidant concentration reduction;

(b) combustible concentration reduction.

**1-3.2 Methods Based on Limiting or Preventing Damage:**

(a) explosion suppression;

(b) deflagration pressure containment;

(c) spark extinguishing systems.

**1-4 Limitations.** The limitations specific to each method are addressed in the chapter on that method.

**1-5 Factors to be Considered.** The following factors must be considered in the selection of one of the methods and the design of the system:

(a) effectiveness of each method;

(b) reliability of the system;

(c) personnel hazards inherent in each method.

1-5.1 The reliability of the system chosen shall be assessed on the system's design basis, the possibility of electrical and mechanical malfunction, dependence on sophisticated activating systems, and the need for special installation, training, operating, and maintenance procedures.

1-5.2 In general, explosion prevention systems are used to protect processing, storage, and materials handling equipment. When explosion prevention techniques are applied to rooms, buildings, or other enclosures where personnel may be present, consideration shall be given to the safety of the personnel.

### 1-6 Plans.

1-6.1 Plans and system specifications shall be reviewed by the authority having jurisdiction.

1-6.2 Plans shall contain sufficient detail to enable the authority having jurisdiction to evaluate the explosion hazard and the effectiveness of the system. Details shall include pertinent chemical and physical characteristics of the materials involved, location of hazards, the enclosures or limits and isolation of the hazards, and exposures to the hazards.

**1-7 Approval of Installations.** The complete system shall be tested in accordance with the requirements of the authority having jurisdiction.

### 1-8* Inspection and Maintenance.

1-8.1 All systems shall be thoroughly inspected for proper operation. A suitable inspection and preventive maintenance schedule shall be established.

1-8.2 Analyzers and other system instrumentation may require more frequent periodic inspection than that required for other components of the system. Such tests shall be made according to manufacturer's recommendations or as required by operating conditions.

**1-9 Definitions.** For the purpose of this standard, the following terms shall have the meanings given below.

**Approved.** Acceptable to the "authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

**Authority Having Jurisdiction.** The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

NOTE: The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

**Blanketing (or Padding).** The technique of maintaining an atmosphere that is either inert or fuel-enriched in the vapor space of a container or vessel.

**Combustible.** Capable of undergoing combustion.

**Combustible Concentration Reduction.** The technique of maintaining the concentration of combustible material in a closed space below the lower flammable limit.

**Combustible Dust.** Any finely divided solid material, 420 microns or less in diameter (i.e., material passing through a U.S. No. 40 Standard Sieve), that presents a fire or explosion hazard when dispersed and ignited in air or other gaseous oxidizer.

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

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

**Deflagration Pressure Containment.** The technique of designing a vessel and its auxiliary equipment so that it can withstand the pressures resulting from a deflagration originating within the vessel.

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

**Explosion.** Bursting or rupture of a building or a container due to the development of internal pressure.

**Explosion Suppression.** The technique of detecting and arresting combustion in a confined space while the combustion is still in its incipient stage, thus preventing the development of pressures that could result in an explosion.

**Flammable Limits.** The minimum and maximum concentrations of a combustible material in a homogeneous mixture with a gaseous oxidizer that will propagate a flame. (*See NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*)

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

**Gas.** A fluid, such as air, that has neither independent shape nor volume, but tends to expand indefinitely. Used synonymously with vapor.

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

**Inert Gas.** A noncombustible, nonreactive gas that renders the combustible material in a system incapable of supporting combustion.

**Inerting.** A technique by which a combustible mixture is rendered nonignitable by addition of an inert gas. (*See also Blanketing.*)

**Labeled.** Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

**Listed.** Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

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

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

**Oxidant Concentration Reduction.** The technique of maintaining the concentration of the oxidant in a closed space below the concentration required for ignition to occur.

**Padding.** (*See Blanketing.*)

**Purge Gas.** A gas that is continuously added to a system to render the atmosphere nonignitable. The purge gas may be inert or combustible. (*See Chapter 2.*)

**Shall.** Indicates a mandatory requirement.

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

**Spark Extinguishing System.** A technique by which the radiant energy of a spark or an ember is detected and the spark or ember is quenched.

**Suppressant.** The chemical agent used in an explosion suppression system to extinguish the incipient explosion.

**Vapor.** (*See Gas.*)

**Ventilation.** The process of supplying or removing an atmosphere to or from any space by natural or mechanical means.

## Chapter 2 Oxidant Concentration Reduction

### 2-1 Application.

2-1.1 The technique of oxidant concentration reduction may be considered for application to any system where a mixture of an oxidant and a combustible material is confined to an enclosure, within which the oxidant concentration can be controlled. (*See Appendix B for a discussion of the control of combustible gas mixtures. Also, see Appendix C for maximum oxygen concentrations.*)

2-1.2 This technique may be applied to rooms or buildings. However, since oxygen-deficient atmospheres cannot sustain life, operations in such areas shall be remotely controlled or operating personnel shall be provided with breathing apparatus, as well as other safeguards.

**2-2* Basic Design Considerations.** The following factors shall be considered in the design of a system to reduce the oxidant concentration:

(a) required reduction in oxidant concentration;

(b) variations in the process, process temperature and pressure, and materials being processed;

(c) gas supply source and equipment installation;

(d) compatibility of the purge gas with the process;

(e) operating controls;

(f) maintenance, inspection, and testing;

(g) leakage of purge gas to surrounding areas;

(h) need for breathing apparatus by personnel.

### 2-3 Purge Gas Sources.

2-3.1 The purge gas shall be obtained from a reliable source that is capable of continuously supplying the required amount of purge gas to maintain the necessary degree of oxidant deficiency. Possible sources include, but are not limited to, the following:

(a) Commercially available inert gas, such as nitrogen, carbon dioxide, argon, or helium, supplied from high pressure tanks or cylinders or from air separation plants.

(b) Inert gas supplied from a gas generator that burns or catalytically oxidizes a hydrocarbon to produce an oxygen-deficient purge gas.

(c) The products of combustion from process furnaces or boiler furnaces. Purification or cooling may be necessary to avoid contamination.

(d) Steam, if it can be supplied at a rate sufficient to raise and maintain the protected vessel or system at a high enough temperature to prevent condensation of the steam.

(e) High purity nitrogen supplied by air oxidation of ammonia.

(f) Inert gas supplied by removal of oxygen from air by absorption, adsorption, chemical reaction, or membrane permeation.

(g) Fuel gases such as methane or natural gas.

2-3.2 The purge gas supply shall have the capacity to meet total projected system requirements.

2-3.3 Electrical power and fuel supplies for purge gas generating systems shall be designed to minimize outages.

### 2-4 Gas Conditioning.

2-4.1 Purge gas shall be conditioned to minimize contaminants that might be harmful to the gas distribution system or to the product or material being protected.

2-4.1.1 Where flue gas is used as a purge gas, entrained dust, soot, or other foreign particles shall be removed if they can interfere with the operation of the system.

2-4.1.2 Before introduction, the purge gas shall be at a temperature compatible with the process being protected. This will minimize the chance of thermal ignition or condensation.

2-4.1.3 Purge gas that is distributed in a system subject to freezing temperatures shall have a dew point such that water will not condense out at the minimum ambient temperature to which the system will be exposed.

### 2-5 Piping Systems.

2-5.1 Purge gas distribution systems shall be designed and installed in accordance with recognized engineering practices.

2-5.1.1 Where purge gas pressure exceeds 15 psig (103 kPa gage), the piping system shall be designed according to ANSI/ASME B31.3, *Chemical Plant and Petroleum Refinery Piping Code.*

2-5.2 Where necessary, piping systems shall be provided with filters, screens, or other means of preventing foreign material from entering critical parts of the system, such as pressure regulators, valves, and instrumentation.

2-5.3 Where necessary, moisture traps shall be provided and lines shall drain towards the traps. Adequate blowdown connections shall be provided. Moisture traps shall be protected from freezing.

2-5.4 When flue gas or combustion gas is used, suitable means shall be provided to prevent propagation of flame into the system being protected.

2-5.5* Manual shutoff valves shall be provided at each major division point in the distribution system.

2-5.6 The inert gas distribution system shall be designed to prevent contamination by hazardous process materials. Where necessary, check valves or other design features shall be incorporated to prevent the potential for contamination either because of loss of purge gas supply or because of excessive pressure in the process unit being protected.

2-5.6.1 A single check valve shall not be considered a positive backflow connection.

2-5.7* Cross connections between the purge gas distribution system and any other system shall be prohibited unless positive measures are taken to prevent backflow from the other system into the purge gas system.

*Exception: Cross connections to backup purge gas systems shall be permitted without backflow prevention unless backflow could create a hazard.*

2-5.8 The entire distribution system shall be cleaned and functionally tested prior to being placed in service.

2-5.9 The gases from an enclosure or vessel being purged shall be vented to a safe location.

### 2-6* Application of Purge Gas at Points of Use.

2-6.1 Purge gas shall be introduced and exhausted so that effective distribution is ensured and the desired oxidant concentration reduction is maintained throughout the system being protected. Multiple inlets and outlets shall be permitted.

2-6.2 Connections between the purge gas distribution piping and the protected enclosure or system shall be designed for maximum purge gas pressure.

### 2-7 Instrumentation.

2-7.1 Suitable instrumentation shall be provided to monitor the purge gas being supplied to the distribution system.

2-7.2* Instrumentation shall be installed at as many points as necessary to ensure the desired oxidant concentration reduction within the protected system.

2-7.3 At scheduled intervals, instrumentation shall be properly calibrated.

2-7.4 When conditions being measured are critical to safety of personnel, suitable alarms shall be provided to indicate abnormal operation of the system.

## Chapter 3 Combustible Concentration Reduction

**3-1 Application.** The technique of combustible concentration reduction may be considered for application to any system where a mixture of a combustible material and an oxidant is confined to an enclosure and where the concentration of the combustible can be maintained below the lower flammable limit. (*See Appendix B for a discussion of the control of combustible gas mixtures. Also, see Appendix D for information on calculating the time required for ventilation.*)

**3-2 Basic Design Considerations.** The following factors shall be considered in the design of a system to reduce the combustible concentration below the lower flammable limit:

(a) required reduction in combustible concentration;

(b) variations in the process, process temperature and pressure, and materials being processed;

(c) operating controls;

(d) maintenance, inspection, and testing.

3-2.1 The lower flammable limits of the combustible components shall be determined at all operating conditions, including startup and shutdown. (*See NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*)

### 3-3 Design and Operating Requirements.

3-3.1 The combustible concentration shall be maintained at or below 25 percent of the lower flammable limit.

*Exception: When automatic instrumentation, with safety interlocks, is provided, the combustible concentration may be maintained at or below 60 percent of the lower flammable limit.*

3-3.2* When catalytic oxidation is used for combustible concentration reduction, flame arrestors shall be provided in all inlets to the catalytic oxidation unit. These flame arrestors shall be periodically inspected and properly maintained.

### 3-3.3 Ventilation or Air Dilution.

3-3.3.1 If ventilation is used, the outlets from the protected equipment shall be located so that hazardous concentrations of the exhausted air cannot enter or be drawn into fresh air intakes of environmental air handling systems.

3-3.3.2 Air intakes shall be located so that combustible material cannot enter the system even in the event of spills or leaks.

3-3.3.3 Filters, driers, or precipitators in the air intakes shall be located so that they are accessible for cleaning and maintenance.

### 3-4 Instrumentation.

3-4.1 Suitable instrumentation shall be provided to monitor the control of the concentration of combustible components.

3-4.2 At scheduled intervals instrumentation shall be properly calibrated.

3-4.3 Where the system being protected presents a personnel hazard, alarms shall be provided to indicate abnormal operation of the system.

## Chapter 4 Explosion Suppression

### 4-1 Application.

4-1.1 The technique of explosion suppression may be considered for any enclosure in which combustible gases, mists, or dusts are subject to deflagration in a gas phase oxidant.

4-1.2 Equipment that may be protected by an explosion suppression system includes but is not limited to:

(a) processing equipment, such as reactor vessels, mixers, blenders, pulverizers, mills, driers, ovens, filters, screens, and dust collectors;

(b) storage equipment, such as atmospheric or low pressure tanks, pressure tanks, and mobile facilities;

(c) material handling equipment, such as pneumatic and screw conveyors, and bucket elevators;

(d) laboratory and pilot plant equipment, including hoods, glove boxes, test cells, and other equipment.

### 4-2 Limitations.

4-2.1 Explosion suppression will be successful only where the suppressant can be effectively distributed.

4-2.2 Explosion suppression is limited by the physical and chemical properties of the reactants in the system.

4-2.3 Explosion suppression is applicable only to systems involving deflagrations that take place in a gas phase oxidant.

### 4-3 Personnel Safety.

4-3.1 The explosion suppression system shall be disarmed prior to performing any maintenance operations on the protected equipment. Operation of the protected equipment shall be interlocked through the suppression system control panel so that operation cannot be resumed until the suppression system is rearmed.

4-3.2 Personnel shall be trained with regard to safety procedures to be carried out prior to and during maintenance.

**4-4 Basic Design Considerations.** The design of an explosion suppression system shall include but shall not necessarily be limited to:

(a) deflagration characteristics of the combustible material;

(b) equipment to be protected;

(c) detection technique;

(d) suppressant;

(e) installation, operation, and test procedures.

4-4.1 A thorough analysis of the hazard shall be conducted to determine the type and degree of explosion hazard inherent in the process. Such factors as type of combustible, combustible-to-oxidant ratio, total volume to be protected, operating conditions, etc., shall be reviewed in detail. Possible malfunctions that may affect the extent of the explosion hazard shall also be determined.

4-4.2 Discharge of the explosion suppression system may also actuate other devices or systems, such as high speed isolation valves, rapid pneumatic conveying system shutdowns, or deflagration vents.

### 4-5 Detectors.

4-5.1 The incipient deflagration shall be detected by sensing either the pressure increase or the radiant energy from the combustion process.

4-5.2 Detectors that respond to a rate of pressure rise are used primarily when the normal process pressure is relatively low, i.e. below 12.7 psia (87.5 kPa absolute).

4-5.3 Detectors that respond to a fixed pressure rise are used when the normal process pressure is approximately atmospheric and relatively constant.

4-5.4 Detectors that respond to radiant energy shall be used for systems open to the atmosphere so that incipient stage pressure development is hindered.

4-5.5 Provisions shall be made to prevent obscuration of radiant energy detectors.

4-5.6 The detection circuits shall be continuously supervised. The supervisory system shall sound an alarm in event of failure of the detection circuits.

### 4-6 Electrically Fired Initiators.

4-6.1 Electrically fired initiators shall be used to release the suppressant.

4-6.2 Care shall be taken to mount the initiators so that their maximum temperature rating is not exceeded.

4-6.3* The wiring circuits for the initiators shall be continuously supervised.

4-6.3.1 The supervisory system shall sound an alarm in the event of loss of circuit continuity.

4-6.4 A reliable source of electrical energy shall be used so that the firing characteristics of the initiators do not deviate from the manufacturer's specifications.

### 4-7 Power Units.

4-7.1 A power unit with standby battery power backup shall be provided in each suppression system. It shall be capable of supplying sufficient energy to:

(a) actuate all initiators;

(b) energize visual and audible alarms.

4-7.2 The power unit shall meet applicable requirements of NFPA 70, *National Electrical Code*®.

4-7.3 Supervisory circuits shall be provided to detect open circuits or other faults. The supervisory circuits shall be interlocked with a visual trouble signal.

### 4-8* Suppressant.

4-8.1 The suppressant shall be compatible with the combustible material in the protected enclosure.

4-8.2 The suppressant shall operate at the expected extremes of temperature encountered in the protected enclosure.

### 4-9 Installation.

4-9.1 All components of the system shall be mounted in the location and in the manner specified by the system designer.

4-9.2 Detectors and suppressant discharge nozzles shall be mounted so that environmental- or vibration-induced malfunctions are minimized.

4-9.3 Suppressant discharge nozzles shall be mounted so as to prevent damage or failure to any appurtenances or fixtures in the enclosure protected.

4-9.4 Suitable means shall be used to protect detectors and suppressant discharge devices from accumulating foreign material that would prevent functioning.

4-9.5 Terminals and mechanical parts shall be protected from moisture and other contaminants.

4-9.6 Mounting locations shall be chosen so as not to exceed maximum operating temperatures of system components.

### 4-10 Electrical.

4-10.1 All wiring to the suppression system and between components of the system shall be grounded and shall be isolated and shielded from all other wiring to prevent possible induced currents.

4-10.2 When environmental conditions warrant, conduits shall be sealed to prevent entrance of moisture and other contaminants.

4-10.3 When conduit is used for wiring multiple installations, the wiring for each suppression system shall be run in separate conduits. Alternatively, each system may be wired with shielded cables run in common conduits.

### 4-11 Inspection and Maintenance.

4-11.1 Suppression systems shall be thoroughly inspected and tested at three-month intervals by personnel trained by the system's manufacturer. Containers of suppressant shall be checked for leakage and the quantity of agent, and the container pressure of refillable containers shall be confirmed.

4-11.2 Any container shown to have suffered a net weight loss exceeding 5 percent or net pressure loss (adjusted for temperature) exceeding 10 percent shall be refilled or replaced.

4-11.3 In the event of system operation, all components shall be inspected, replacement parts installed if necessary, and the system tested prior to restoration to full operating condition.

## Chapter 5 Deflagration Pressure Containment

### 5-1 General.

5-1.1 Deflagration pressure containment is a technique for specifying the design pressure of a vessel and its appurtenances so that they are capable of withstanding the pressures resulting from an internal deflagration.

5-1.2 This chapter is limited to determining the vessel design pressure required to withstand the pressures resulting from an internal deflagration. This chapter is also limited to systems in which the oxidant is air.

5-1.3 The design pressure specified by this chapter shall be based on the most severe set of system conditions that may occur.

5-1.4 When deflagration pressure containment is applied to a vessel with attached equipment, the pressure loads imposed on the attached equipment may be equal to or greater than the pressure loads experienced by the protected vessel. Therefore, measures shall be taken to protect this attached equipment. Techniques such as isolation and/or venting shall be considered.

### 5-2 Design Limitations.

5-2.1* Deflagration pressure containment techniques shall not be applied to systems for the purpose of containing a detonation.

5-2.2* Deflagration pressure containment shall not be applied to vessels having a length-to-diameter (L/D) ratio greater than 5 unless appropriate test data are available.

**5-2.3*** Deflagration pressure containment shall not be applied to systems where two or more vessels are connected by large-diameter pipes or ducts, unless appropriate test data is available.

**5-2.4*** Deflagration pressure containment shall not be applied to any system where the initial pressure exceeds 30 psig (206.7 kPa gage) unless appropriate test data are available.

## 5-3 Design Bases.

**5-3.1** Vessels designed for deflagration pressure containment shall be designed and constructed according to the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, which takes into consideration sources of overpressure other than deflagration.

**5-3.2** The design pressure of the vessel, as calculated in 5-3.3, shall be based either on preventing rupture of the vessel (i.e., on the ultimate strength of the vessel) or on preventing permanent deformation of the vessel (i.e., on the yield strength of the vessel) from internal positive overpressure.

**5-3.2.1** Due to the vacuum that can follow a deflagration, all vessels whose deflagration pressure containment design is based on preventing deformation shall also be designed to withstand full vacuum.

**5-3.3** The design pressure shall be calculated according to the following equations:

$$P_r = \frac{1.5\,[R(P_i + 14.7) - 14.7]}{F_u}$$

$$P_d = \frac{1.5\,[R(P_i + 14.7) - 14.7]}{F_y}$$

Where: $P_r$ = the design pressure to prevent rupture due to internal deflagration, psig;

$P_d$ = the design pressure to prevent deformation due to internal deflagration, psig.

$P_i$ = the maximum initial pressure at which the combustible atmosphere exists, psig;

$R$ = the ratio of the maximum deflagration pressure to the maximum initial pressure, as described in 5-3.3.1;

$F_u$ = the ratio of the ultimate stress of the vessel to the allowable stress of the vessel;

$F_y$ = the ratio of the yield stress of the vessel to the allowable stress of the vessel.

NOTE: 1 psi = 6.89 kPa.

**5-3.3.1** The dimensionless ratio R is the ratio of the maximum deflagration pressure, in absolute pressure units, to the maximum initial pressure, in consistent absolute pressure units. For gas/air mixtures, R shall be taken as 9.0; for dust/air mixtures, R shall be taken as 10.0.

*Exception: A different value of R may be used if appropriate test data or calculations are available to confirm its suitability.*

**5-3.3.2** For operating temperatures below 25°C, the value of R shall be adjusted according to the following formula:

$$R' = R \times \left(\frac{298}{273 + Ti}\right)$$

where R is either 9.0 or 10.0 and Ti is the operating temperature in °C.

**5-3.3.3** For vessels fabricated of low carbon steel and low alloy stainless steel $F_u = 4.0$ and $F_y = 2.0$.

**5-3.4** The presence of any pressure relief device on the system shall not cause the design pressure calculated by 5-3.3 to be reduced.

**5-3.5*** For systems handling gases and liquids, the maximum initial pressure, $P_i$, shall be the maximum pressure at which a combustible mixture can exist, but not higher than the setting of the pressure relief device plus its accumulation. For systems handling dusts, this maximum initial pressure shall be the maximum possible discharge pressure of the compressor or blower that is suspending or transporting the material or the setting of the pressure relief device on the vessel being protected plus its accumulation, whichever is greater. For gravity discharge of dusts, the maximum initial pressure shall be taken as 0.0 psig (0.0 kPa gage).

**5-3.6** For systems operating under vacuum, the maximum initial pressure shall be taken as no less than atmospheric pressure (0.0 psig or 0.0 kPa gage).

**5-3.7** The vessel design pressure shall be based on the wall thickness of the vessel, neglecting any allowance for corrosion or erosion.

**5-3.8** The design must take into consideration the minimum operating temperature at which a deflagration may occur. This minimum temperature must be compared with the temperature characteristics of the material of construction of the vessel to ensure that brittle fracture will not result from a deflagration.

**5-4 Maintenance.** Relief devices shall be inspected periodically to ensure that they are not plugged, frozen, or corroded.

## 5-5 Vessel Appurtenances.

**5-5.1** Threaded fasteners on vessel appurtenances shall be inspected to ensure that design pressure ratings are maintained.

**5-5.2** Vent systems, manways, fittings, and other openings into the vessel shall be designed and inspected to ensure integrity of the total system.

**5-6 Inspection After a Deflagration.** Any vessel designed to contain a deflagration that experiences a deflagration shall be thoroughly inspected to verify that the vessel is still serviceable for its intended use.

## Chapter 6 Spark Extinguishing Systems

### 6-1 Application

6-1.1 Spark extinguishing systems are for the detection and extinguishment of sparks or embers as they pass through ducts that transport combustible dusts or solids.

6-1.2 The system operates by means of detectors that sense the radiation of a hot or glowing particle and actuate a special extinguishing system that quenches the particle. Because the detection is by means of radiation, the spark detection systems shall not be used in duct systems that have places through which incident light can affect the detectors.

*Exception: Such systems may be used in duct systems that have openings, if the detectors are designed to be insensitive to visible light.*

### 6-2 Limitations.

6-2.1 Spark extinguishing systems shall not be used for ducts that transport combustible gases.

6-2.2 Spark extinguishing systems shall not be used where the extinguishing agent may create a hazard.

### 6-3 System Design.

#### 6-3.1 Detectors.

6-3.1.1 Spacing between a detector and the extinguishing agent injection point shall be based on the linear velocity of the material in the duct and the response time of the detector and the actuator circuitry.

6-3.1.2 The number of detectors shall be sufficient to detect a glowing particle at any location in the cross-sectional area of the duct.

6-3.1.3 All detector circuits shall be supervised and shall sound a manual reset alarm upon circuit failure.

#### 6-3.2 Power Supply.

6-3.2.1 The primary power supply shall be supervised and upon failure shall cause automatic engagement of the emergency power supply.

6-3.2.2 Each spark extinguishing system shall have a connected emergency power supply capable of operating the system for 24 hours.

6-3.2.3 A manual reset alarm shall sound upon loss of the primary power supply or the protected system shall be interlocked to shut down upon loss of power to the spark extinguishing system.

#### 6-3.3 Extinguishing System.

6-3.3.1 Discharge nozzles shall be located and arranged so that solid particles will not obstruct the nozzle.

6-3.3.2 The electric circuit for the automatic injection valve shall be supervised and shall sound a manual reset alarm upon loss of power.

6-3.3.3 If water is used as the extinguishing agent, the water supply system shall be equipped with an in-line strainer.

6-3.3.4 The extinguishing agent supply system shall be capable of supplying all discharge nozzles at the rated volume and pressure.

6-3.3.5 The system shall contain enough extinguishing agent to provide for at least 100 operations of the system.

6-3.3.6 A manual reset alarm shall sound when the pressure of the extinguishing agent falls below 50 percent of the system's operating design pressure.

6-3.3.7 Auxiliary heating systems for extinguishing agent storage shall be provided when necessary. When such heating systems are provided, the temperature of the extinguishing agent shall be supervised and a manual reset alarm shall sound at both the low and high temperature limits.

**6-4 Testing.** The spark extinguishing system shall be tested weekly.

*Exception: For systems that have a permanently installed test light that automatically tests the detection system, regular testing may be done monthly instead of weekly.*

## Chapter 7 Referenced Publications

7-1 The following documents or portions thereof are referenced within this standard and shall be considered part of the requirements of this document. The edition indicated for each reference is current as of the date of the NFPA issuance of this document. These references are listed separately to facilitate updating to the latest edition by the user.

**7-1.1 NFPA Publications.** National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 68-1978, *Guide for Explosion Venting.*

NFPA 70-1987, *National Electrical Code.*

NFPA 86-1985, *Standard for Ovens and Furnaces.*

NFPA 86C-1984, *Standard for Industrial Furnaces Using a Special Processing Atmosphere.*

NFPA 86D-1985, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere.*

NFPA 325M-1984, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*

NFPA 327-1982, *Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers.*

**7-1.2 ASME Publications.** American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, or American National Standards Institute, 1430 Broadway, New York, NY 10018.

*ASME Pressure Vessel Code*, Section VIII, Division 1.

*ASME Chemical Plant and Petroleum Refinery Piping Code*, B31.3.

**7-1.3 Federal Publication.** U.S. Government Printing Office, Washington, DC.

*Code of Federal Regulations*, Part 75, Title 30.

# Appendix A

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

A-1-3 It should be recognized that there are other methods for preventing combustion. These include changing the process to eliminate combustible material either used or generated in the process.

A-1-8 Inspection, maintenance, and operator training are necessary requirements of any explosion prevention system. Reliability of the system and its instrumentation will only be as good as the inspection and periodic preventive maintenance they receive. Operator response and action to correct adverse conditions, as indicated by instrumentation or other means, will only be as good as the frequency and thoroughness of training provided.

A-2-2 Purge gases generated by any of the acceptable methods described in this standard may not necessarily be suitable for all applications. In general, the physical and chemical properties of the combustible materials involved will govern the type and required purity of the purge gas needed. Chlorinated and fluorinated hydrocarbons are sometimes used. Although these gases are more costly than carbon dioxide or nitrogen, the allowable oxygen concentration may be higher. The user is cautioned, however, that some halogenated hydrocarbons, carbon dioxide, and even nitrogen at elevated temperatures may react violently with certain dusts. Also, these gases may not be effective in providing explosion protection for certain combustible metal dusts, such as aluminum, magnesium, titanium, zirconium, thorium, and uranium. Argon, helium, and other rare gases may have to be used for inerting certain systems.

In general, personnel should not enter enclosures where the atmosphere is oxygen deficient. If it is necessary to enter such an enclosure, they must use self-contained breathing apparatus, preferably the positive pressure type. Canister-type gas masks must not be used; they do not supply oxygen and do not offer any protection. The toxicity of certain purge gases must be recognized. The potential for accidental release of purge gases into normally occupied areas must be recognized and necessary precautions taken.

A-2-5.5 The intent of this requirement is to provide for a sufficient number of isolation points to facilitate maintenance, while holding the number of isolation valves to a manageable number so that accidental shutoff is minimized.

A-2-5.7 Consideration should be given to providing positive means of preventing backflow of purge gas into other systems when such flow would present a hazard.

**A-2-6 Methods of Application.**

Any of several methods may be used to ensure the formation and maintenance of a noncombustible atmosphere in an enclosure to be protected. These include "batch" methods applicable to "one-time" or occasional use, as in purging equipment during shutdown, and "continuous" methods intended to ensure safe conditions during normal operations.

**Batch Purging Methods.** Include syphon, vacuum, pressure, and venting to atmosphere.

**Continuous Purging Methods.** Include fixed rate application and variable rate or demand application.

**Syphon Purging.** Equipment may be purged by filling with liquid and introducing purge gas into the vapor space to replace the liquid as it is drained from the enclosure.

The volume of purge gas required will be equal to the volume of the vessel, and the rate of application can be made to correspond to the rate of draining.

**Vacuum Purging.** Equipment that normally operates at reduced pressure, or in which it is practical to develop reduced pressure, may be purged during shutdown by breaking the vacuum with purge gas. If the initial pressure is not low enough to ensure the desired low oxidant concentration it may be necessary to re-evacuate and repeat the process. The amount of purge gas required will be determined by the number of applications required to develop the desired oxidant concentration. Where two or more containers or tanks are joined by a manifold and must be purged as a group, the vapor content of each container or tank should be checked to determine that complete purging has been accomplished.

**Pressure Purging.** Enclosures may be purged by increasing the pressure within the enclosure by introducing purge gas under pressure and, after the gas has diffused, venting the enclosure to the atmosphere. More than one pressure cycle may be necessary to reduce the oxidant content to the desired percentage. Where two or more containers or tanks are joined by a manifold and should be purged as a group, the vapor content of each container or tank should be checked to determine that desired purging has been accomplished. Where a container filled with combustible material is to be emptied and then purged, purge gas may be applied to the vapor space at a pressure consistent with equipment design limitations, thus accomplishing both the emptying of the vessel and the purging of the vapor space in the same process.

**Sweep-Through Purging.** This process involves introducing a purge gas into the equipment at one opening, and letting the enclosure content escape to the atmosphere through another opening, thus sweeping out residual vapor. The quantity of purge gas required will depend on the physical arrangement. A pipeline can be effectively purged with only a little more than one volume of purge gas if the gas can be introduced at one end and the mixture released at the other. However, vessels will require quantities of purge gas much in excess of their volume.

If the system is complex, involving side branches through which circulation cannot be established, the sweep-through purging method may be impractical, and pressure or vacuum purging might be more appropriate.

The relationship between the number of volumes of purge gas circulated and the reduction in concentration of the critical component in original tank contents, assuming complete mixing, is shown on the graph, Figure A-2-6(a).

It will be noted that:

(a) The total quantity required may be less than that for a series of steps of pressure purging.

(b) From four to five volumes of purge gas will suffice to almost completely displace the original mixture, assuming complete mixing.

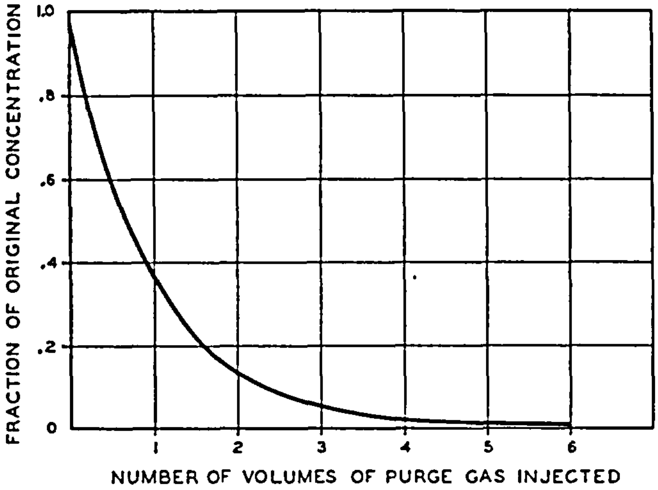

Figure A-2-6(a) Dilution ratio — Purging at Atmospheric Pressure. (Complete mixing assumed.)

**Fixed Rate Application.** This method involves the continuous introduction of purge gas into the enclosure at a constant rate, which must be sufficient to supply the peak requirement in order that complete protection may be provided, and a corresponding release of purge gas and whatever gas, mist, or dust has been picked up in the equipment.

(a) Advantages are simplicity, lack of dependence on devices such as pressure regulators, and possible reduced maintenance.

(b) Disadvantages are:

1. Where the space contains a volatile liquid, a continuous loss of product due to constant "sweeping" of the vapor space by the purge gas.

2. Increased total quantity of purge gas, because it is supplied whether needed or not.

3. Possible disposal problems (toxic and other effects) for the mixture continuously released.

(c) *Flow Control.* Figure A-2-6(b) shows a method of flow control that can be used with fixed rate application.

**Variable Rate or Demand Application.** This method involves the introduction of purge gas into an enclosure at a variable rate dependent on demand, based usually on maintaining within the protected enclosure an arbitrarily selected pressure slightly above that of the surrounding atmosphere. Peak supply rate must be computed as described in subsection (c) below.

(a) Advantages are that purge gas is supplied only when actually needed, and that it is possible, when desirable, to completely prevent influx of air.

(b) A disadvantage is that operation depends on the functioning of pressure control valves operating at sometimes very low pressure differentials, which are sometimes difficult to maintain.

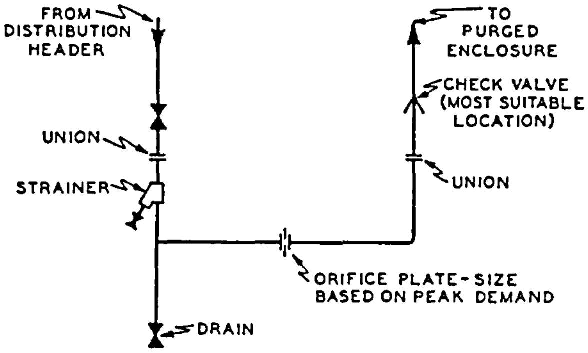

Figure A-2-6(b). Schematic Sketch Showing Method of Flow Control That May Be Used with Fixed Rate Application.

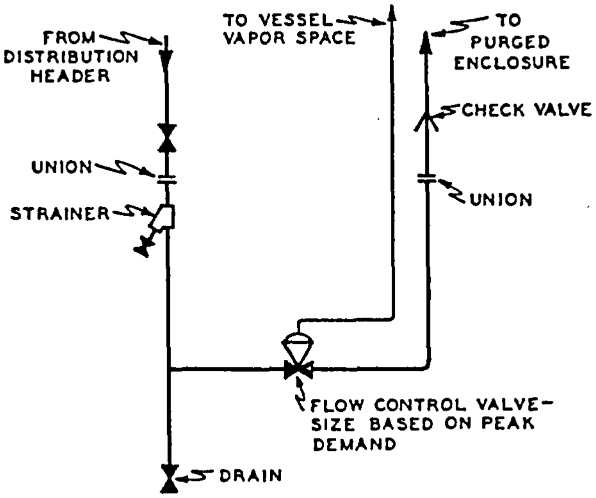

Figure A-2-6(c). Schematic Sketch Showing a Method of Flow Control That Can Be Used with Variable Rate Application. See also Figure A-2-6(d).

(c) Figure A-2-6(c) shows a method of flow control that can be used with variable rate application. Figure A-2-6(d) shows an alternate method applicable where the purge gas requirement during out pumping is a large part of the peak demand.

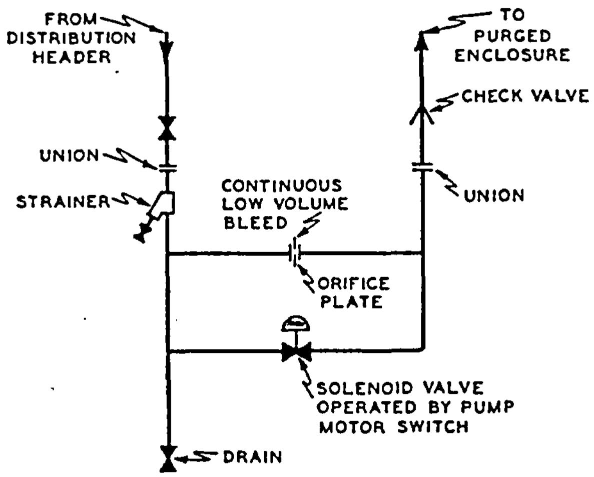

Figure A-2-6(d). Schematic Sketch Showing a Method of Flow Control That Can Be Used with Variable Rate Application. See also Figure A-2-6(c).

**Calculation of Peak Purge Gas Rates.** Peak demand is defined in Chapter 2 as the total projected system requirements.

For any one element of the system, the peak demand is controlled by such factors as:

(a) maximum withdrawal rate;

(b) temperature change;

(c) leaks;

(d) rapid atmospheric pressure changes.

Cooling of the contents of a vessel containing a vapor or hot liquid presents a special and frequent case of vacuum purging. Condensation of vapor to a liquid or reduction in pressure of the gas phase can rapidly produce partial vacuum, which may impose excessive stresses on equipment or even collapse of the vessel, may suck in air from joints that may not leak under internal pressure, and may require high supply rates of inert gas. Each situation must be treated individually.

The peak supply rate must be computed for each case with consideration being given to cooling rate, vessel size, and configuration, which determine the rate of condensation.

If neither the reducing valve nor the source gas can be sufficiently reliable to supply the amount of inert gas required to prevent reduction of pressure below atmospheric, the vessel may have to be designed for full vacuum.

For a vessel containing a liquid, the purge gas demand from liquid withdrawal, change of liquid composition from mixing, or increasing solubility of purge gas in the liquid will be the volume equivalent of the capacity of the largest pump that can withdraw liquid, or the maximum possible gravity outflow rate, whichever is greater. Where two tanks are manifolded together, so that one can flow by gravity into the other, a vapor space interconnection is sometimes used to reduce the required purge gas supply from outside sources.

For outdoor tanks operating at or near atmospheric pressure, the maximum demand from temperature change will occur in outdoor tanks operating at near atmospheric pressure, as a result of sudden cooling by a summer thunderstorm. The rate of purge gas supply necessary to prevent vessel pressure falling significantly below atmospheric pressure can be calculated as follows:

(a) For tanks over 800,000 gal (3.028 million L) capacity, 2 cu ft (0.056 cu m) of purge gas per hour for each square foot of total shell and roof area.

(b) For smaller tanks, 1 cu ft (0.028 cu m) purge gas per hour for each 40 gal (151 L) of tank capacity, or the rate corresponding to a mean rate of the change of the vapor space temperature of 100°F (37.8°C) per hour. (*See API Standard 2000, Venting Atmospheric and Low Pressure Storage Tanks, for further information.*)

The rates for temperature change and liquid withdrawal must be added unless there is some special circumstance that will prevent them from occurring simultaneously.

In some equipment, such as pulverizers, the rate of purge gas supply necessary to exclude air may be dominated by leakage, and temperature change can be ignored.

A-2-7.2 Where the oxygen concentration is continuously monitored in each vessel, the oxygen concentration should be maintained at no more than 60 percent of the maximum oxygen concentration to prevent combustion, as given in Appendix C. In equipment where the oxygen concentration is not continuously monitored the oxygen concentration should be maintained at no more than 40 percent of the maximum oxygen concentration to prevent combustion.

A-3-3.2 The combustible concentration can be reduced by recirculating the atmosphere containing it through a catalytic oxidation unit where the combustible material and oxidant undergo catalytic oxidation at concentrations below the lower flammable limit.

A-4-6.3 The explosive device and the firing circuit should be continuously supervised.

A-4-8 Halogenated hydrocarbons, such as bromochloromethane and bromotrifluoromethane, or dry chemical agents may be used with most combustibles. Suitability of the suppressant should be determined if elevated temperatures or pressures are anticipated or if the oxidant is a material other than air.

Water may also be used as a suppressant if it can be demonstrated to be effective. If ambient temperatures below 0°C are expected, a suitable antifreeze must be used.

A-5-2.1 Deflagration pressure containment is not adequate for detonable systems because the maximum pressure rise will be much greater than the factors established in 5-3.3.1 and 5-3.3.2. It should be recognized that some systems may be capable of deflagration or detonation. For example, systems containing a substantial proportion of hydrogen are prone to detonation, as are systems containing acetylene or acetylenic compounds. Saturated organic compounds such as propane, ethane, and alcohols generally will not detonate in vessels, but may do so in pipework.

A-5-2.2 The intent of this requirement is to prevent the application of deflagration pressure containment to any vessel that may be susceptible to pressure piling. Vessels with a higher L/D ratio may be designed for deflagration pressure containment using other techniques for estimating the required design pressure.

A-5-2.3 When two vessels connected by a large-diameter pipe both contain a combustible mixture, a deflagration in one vessel can precompress the unburned mixture in the other vessel. The maximum deflagration pressure that can be developed in the second vessel may be substantially greater than would normally happen in a single vessel (See Bartknecht, W.; *Explosions: Course, Prevention, Protection*; Springer-Verlag; Heidelberg; 1981; pp 18-23).

A-5-2.4 Only limited information is available for deflagration containment of systems with initial pressures exceeding 30 psig (206.7 kPa gage). Increased initial pressure may increase the potential for detonation. For this reason, it is recommended that, for systems that may operate at an initial pressure of 30 psig (206.7 kPa gage) or higher, deflagration pressure containment be used only where appropriate test data are available. The testing must be carefully designed because the detonation potential of a system is affected by vessel dimensions.

A-5-3.5 The maximum initial pressure will depend on the origin of the pressure. In some cases, this pressure will be determined by the setting of a relief device on the system. In these cases, the maximum initial pressure is the sum of the relief device set pressure and the relief device accumulation pressure. Overpressure due to boiling of the vessel contents (as, for example, from external fire exposure) may raise the concentration of fuel in the vapor phase above its upper flammable limit and would not constitute a deflagration hazard.

## Appendix B Control of Combustible Gas Mixtures by Oxidant Concentration Reduction and Combustible Concentration Reduction

**B-1 General.** As covered in Chapters 2 and 3, a combustible gas/oxidant mixture may be controlled by reducing the concentration of oxidant or by adding an inert constituent to the mixture. Both processes can be explained most easily by referring to a "flammability diagram." Figure B-1 shows a typical flammability diagram that represents a mixture of a combustible gas, an inert gas, nitrogen, and an oxidant, oxygen, at a given temperature and pressure.

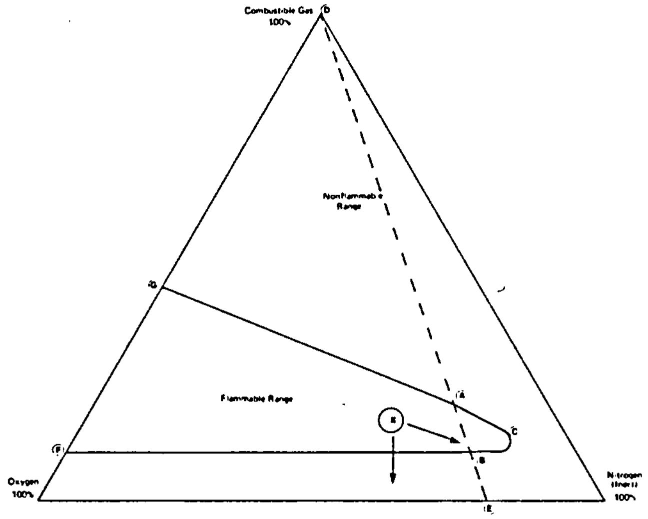

Figure B-1 Typical Flammability Diagram.

A mixture of air (79 percent $N_2$ and 21 percent $O_2$, by volume) and combustible gas is represented by the line DABE. A given mixture of the combustible gas and air, whether ignitible or not, is specified by some point on this line. Point A indicates the "upper flammable limit" of this mixture, while Point B represents its "lower flammable limit."

Any point within the area bounded by FBCAG is in the flammable range and can be ignited. Any point outside this area represents a mixture that cannot be ignited. Point C represents the maximum permissible oxygen concentration to prevent ignition; any mixture containing less oxygen cannot be ignited. (*See Appendix C.*)

Any mixture of oxygen and combustible gas alone, i.e., without any nitrogen, is represented by the left-hand side of the triangle. Any mixture of nitrogen and combustible gas alone, i.e., no oxygen present, is represented by the right-hand side of the triangle.

**B-2 Effect of Pressure and Temperature.** As shown in Figure B-2, pressure and temperature can have an effect on the flammability diagram. An increase in pressure results in an increase in the upper flammable limit and a decrease in the maximum permissible oxygen concentration to prevent ignition, Points C, C′, and C″. There is a slight effect on the lower flammable limit — a decrease — but the effect is not as pronounced as that of the upper limit.

An increase in temperature has a similar effect on the flammability diagram.

The exact effects on a system, produced by changes in pressure or temperature, must be determined for each system.

**B-3 Effect of Inert Diluents.** The addition of an inert diluent to a mixture of combustible material and oxidant will affect the lower and upper flammable limits and the minimum oxygen concentration. Figure B-3 illustrates the effect of some typical diluents on the flammability limits of methane. This figure shows that nitrogen is more

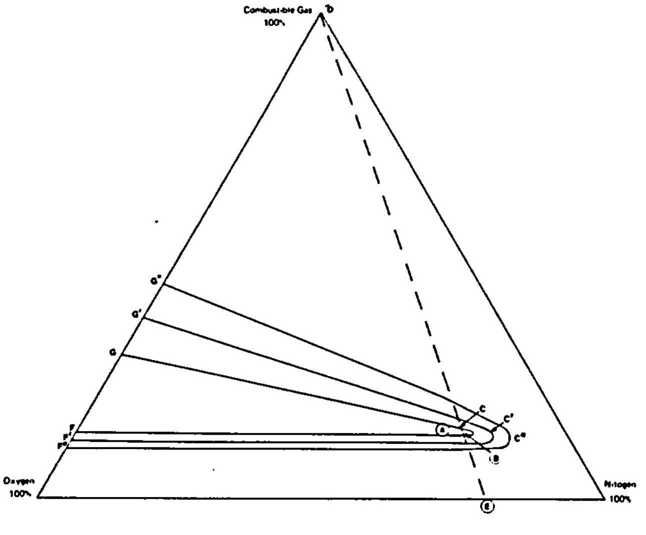

Figure B-2 Effect of Pressure on Flammability Diagram.

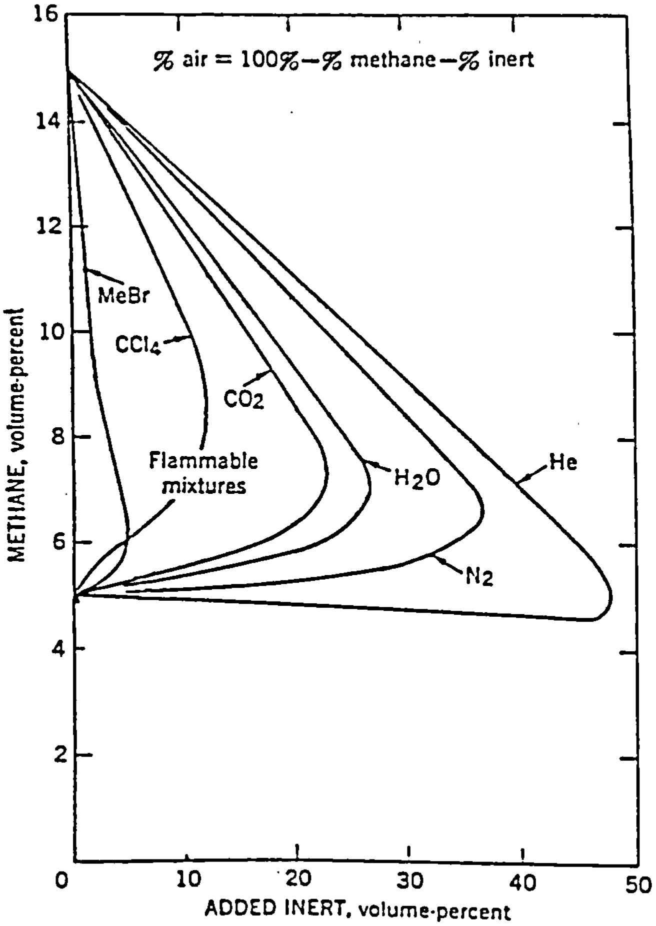

Figure B-3 Limits of Flammability of Methane-Inert Gas-Air Mixtures at 25°C and Atmospheric Pressure.

effective than helium and carbon dioxide is more effective than nitrogen.

**B-4 Oxidant Concentration Reduction.** Referring back to the flammability diagram in Figure B-1, the point "x" represents some arbitrary mixture of combustible gas, oxygen, and nitrogen that lies well within the flammable range. If it is desired to change the composition of the mixture so that it lies outside the flammable range, one way to do this is by reducing the concentration of oxidant. As the concentration of oxygen decreases, the concentration of nitrogen increases. Point "x," in effect, moves towards the inert gas apex.

**B-5 Combustible Concentration Reduction.** Again referring to Figure B-1, with "x" in the flammable range, the composition of the mixture may be altered by reducing the concentration of combustible gas. In simpler terms, point "x" moves away from the combustible gas apex and eventually drops below the lower flammability line FBC.

**B-6 Mixtures of Gases.** Where mixtures of two or more combustible gases are encountered, the limits of flammability of the mixture can often be reliably predicted by the following formulas suggested by Le Chatelier:

$$\text{Lower Flammable Limit} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{\frac{P_1}{LFL_1} + \frac{P_2}{LFL_2} + \ldots\ldots + \frac{P_n}{LFL_n}}$$

$$\text{Upper Flammable Limit} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{\frac{P_1}{UFL_1} + \frac{P_2}{UFL_2} + \ldots\ldots + \frac{P_n}{UFL_n}}$$

Where $P_1$, $P_2$, etc. are the volume fractions of components 1, 2, 3, etc. of the mixture, $LFL_1$, $LFL_2$, $LFL_3$, etc. are the lower flammable limits of components 1, 2, 3, etc. respectively, and $UFL_1$, $UFL_2$, $UFL_3$, etc. are the upper flammable limits at components 1, 2, 3, etc. respectively.

## Appendix C Maximum Oxygen Concentrations

Table C-1
Maximum Oxygen Concentration to Prevent Combustion of Combustible Gases Using Nitrogen and Carbon Dioxide or Diluents

| Gas or Vapor | $N_2$/Air % $O_2$ Above Which Combustion Can Take Place | $CO_2$/Air % $O_2$ Above Which Combustion Can Take Place | Reference |
|---|---|---|---|
| Methane | 12 | 14.5 | 1 |
| Ethane | 11 | 13.5 | 1 |
| Propane | 11.5 | 14.5 | 1 |
| n-Butane | 12 | 14.5 | 1 |
| Isobutane | 12 | 15 | 1 |
| n-Pentane | 12 | 14.5 | 1 |
| Isopentane | 12 | 14.5 | 2 |
| n-Hexane | 12 | 14.5 | 1 |
| n-Heptane | 11.5 | 14.5 | 2 |
| Ethylene | 10 | 11.5 | 1 |
| Propylene | 11.5 | 14 | 1 |
| 1-Butene | 11.5 | 14 | 1 |
| Isobutylene | 12 | 15 | 4 |
| Butadiene | 10.5 | 13 | 1 |
| 3-Methyl-1-butene | 11.5 | 14 | 4 |
| Benzene | 11.4 | 14 | 1, 7 |
| Toluene | 9.5 | — | 7 |
| Styrene | 9.0 | — | 7 |
| Ethylbenzene | 9.0 | — | 7 |
| Vinyltoluene | 9.0 | — | 7 |
| Divinylbenzene | 8.5 | — | 7 |
| Diethylbenzene | 8.5 | — | 7 |
| Cyclopropane | 11.5 | 14 | 1 |
| Gasoline | | | |
| (73/100) | 12 | 15 | 2 |
| (100/130) | 12 | 15 | 2 |
| (115/145) | 12 | 14.5 | 2 |
| Kerosene | 10(150°C) | 13(150°C) | 5 |
| JP-1 fuel | 10.5(150°C) | 14(150°C) | 2 |
| JP-3 fuel | 12 | 14.5 | 2 |
| JP-4 fuel | 11.5 | 14.5 | 2 |
| Natural gas (Pittsburgh) | 12 | 14.5 | 1 |
| n-Butyl chloride | 14 | — | 3 |
| | 12(100°C) | | 3 |
| Methylene chloride | 19(30°C) | — | 3 |
| | 17(100°C) | | 3 |
| Ethylene dichloride | 13 | — | 3 |
| | 11.5(100°C) | | 3 |
| Methyl chloroform | 14 | — | 3 |
| Trichloroethylene | 9(100°C) | | 3 |
| Acetone | 11.5 | 14 | 4 |
| t-Butanol | NA | 16.5(150°C) | 4 |
| Carbon disulfide | 5 | 7.5 | 4 |
| Carbon monoxide | 5.5 | 5.5 | 4 |
| Ethanol | 10.5 | 13 | 4 |
| 2-Ethyl butanol | 9.5(150°C) | — | 4 |
| Ethyl ether | 10.5 | 13 | 4 |
| Hydrogen | 5 | 5.2 | 4 |
| Hydrogen sulfide | 7.5 | 11.5 | 4 |
| Isobutyl formate | 12.5 | 15 | 4 |
| Methanol | 10 | 12 | 4 |
| Methyl acetate | 11 | 13.5 | 4 |
| Methyl ether | 10.5 | 13 | 4 |
| Methyl formate | 10 | 12.5 | 4 |
| Methyl ethyl ketone | 11 | 13.5 | 4 |
| UDMH (dimethylhydrazine) | 7 | — | 6 |

NOTE 1: See A-2-7.2 for the required oxygen level in equipment.

NOTE 2: Data were determined by laboratory experiment conducted at atmospheric temperature and pressure. Vapor-air-inert gas samples were placed in explosion tubes and ignited by electric spark or pilot flame.

**References.**

1. Coward, H. F., and G. W. Jones. *Limits of Flammability of Gases and Vapors.* BuMines Bulletin 503, 1952, 155 pp.

2. Jones, G. W., M. G. Zabetakis, J. K. Richmond, G. S. Scott, and A. L. Furno. Research on the Flammability Characteristics of Aircraft Fuels. Wright Air Development Center, Tech. Report 52-35, Supplement I, 1954, 57 pp.

3. Kuchta, J. M., A. L. Furno, A. Bartkowiak, and G. H. Martindill. Effect of Pressure and Temperature on Flammability Limits of Chlorinated Combustibles in Oxygen-Nitrogen and Nitrogen Tetroxide-Nitrogen Atmospheres. *Jour. Chem. Eng. Data*, v. 13, July 1968, p. 421.

4. Zabetakis, M. G. Flammability Characteristics of Combustible Gases and Vapors. BuMines Bulletin 627, 1965, 121 pp.

5. Zabetakis, M. G., B. H. Rosen. Considerations Involved in Handling Kerosine. *Proc. API*, v. 37, Sec. III, 1957, p. 296.

6. Unpublished data, U.S. Bureau of Mines.

7. Unpublished data, Dow Chemcial Co.

Table C-2
Maximum Oxygen Concentration to Prevent Combustion of Suspensions of Combustible Dust in Air-Carbon Dioxide Mixtures

| Dust | Maximum $O_2$ Concentration % |
|---|---|
| **Agricultural** | |
| Coffee | 17 |
| Cornstarch | 11 |
| Dextrin | 14 |
| Soy Flour | 15 |
| Starch | 12 |
| Sucrose | 14 |

Table C-2 (Cont.)
Maximum Oxygen Concentration to Prevent Combustion of Suspensions of Combustible Dust in Air-Carbon Dioxide Mixtures

Table C-2 (Cont.)
Maximum Oxygen Concentration to Prevent Combustion of Suspensions of Combustible Dust in Air-Carbon Dioxide Mixtures

| Dust | Maximum $O_2$ Concentration % |
|---|---|
| **Chemical** | |
| Ethylene Diamine Tetra-Acetic Acid | 13 |
| Isatoic Anhydride | 13 |
| Methionine | 15 |
| Ortazol | 19 |
| Phenothiazine | 17 |
| Phosphorous Pentasulfide | 12 |
| Salicylic Acid | 17 |
| Sodium Lignosulfate | 17 |
| Stearic Acid & Metal Stearates | 13 |
| **Carbonaceous** | |
| Charcoal | 17 |
| Coal, Bituminous | 17 |
| Coal, Sub-bituminous | 15 |
| Lignite | 15 |
| **Metal** | |
| Aluminum | 2 |
| Antimony | 16 |
| Chromium | 14 |
| Iron | 10 |
| Magnesium | 0 |
| Manganese | 14 |
| Silicon | 12 |
| Thorium | 0 |
| Titanium | 0 |
| Uranium | 0 |
| Vanadium | 14 |
| Zinc | 10 |
| Zirconium | 0 |
| **Miscellaneous** | |
| Cellulose | 13 |
| Paper | 13 |
| Pitch | 11 |
| Sewage Sludge | 14 |
| Sulfur | 12 |
| Wood Flour | 16 |
| **Plastics Ingredients** | |
| Azelaic Acid | 14 |
| Bisphenol A | 12 |
| Casein, rennet | 17 |
| Hexamethylene tetramine | 14 |
| Isophthalic Acid | 14 |
| Paraformaldehyde | 12 |
| Pentaerythritol | 14 |
| Phthalic Anhydride | 14 |
| Terephthalic Acid | 15 |
| **Plastics — Special Resins** | |
| Coumarone-Indene Resin | 14 |
| Lignin | 17 |
| Phenol, Chlorinated | 16 |
| Pinewood Residue | 13 |
| Rosin, DK | 14 |
| Rubber, Hard | 15 |
| Shellac | 14 |
| Sodium Resinate | 14 |
| **Plastics — Thermoplastic Resins** | |
| Acetal | 11 |
| Acrylonitrile | 13 |
| Butadiene-Styrene | 13 |
| Carboxymethyl Cellulose | 16 |
| Cellulose Acetate | 11 |
| Cellulose Triacetate | 12 |
| Cellulose Acetate Butyrate | 14 |
| Ethyl Cellulose | 11 |
| Methyl Cellulose | 13 |
| Methyl Methacrylate | 11 |
| Nylon | 13 |
| Polycarbonate | 15 |
| Polyethylene | 12 |
| Polystyrene | 14 |
| Polyvinyl Acetate | 17 |
| Polyvinyl Butyrate | 14 |
| **Plastics — Thermosetting Resins** | |
| Allyl Alcohol | 13 |
| Dimethyl Isophthalate | 13 |
| Dimethyl Terephthalate | 12 |
| Epoxy | 12 |
| Melamine Formaldehyde | 17 |
| Polyethylene Terephthalate | 13 |
| Urea Formaldehyde | 16 |

NOTE 1: Data in this table were obtained by laboratory tests conducted at room temperature and pressure, using a 24-watt continuous-spark ignition source and were reported in U.S. Bureau of Mines Report of Investigation 6543.

NOTE 2: Where nitrogen is used as the diluent, the values shown in the table should be adjusted according to the following equation:

$$O_n = 1.3\, O_c - 6.3$$

Where $O_n$ = the maximum oxygen concentration for nitrogen dilution; and

$O_c$ = the maximum oxygen concentration from Table C-2.

NOTE 3: See A-2-7.2 for the required oxygen level in equipment.

NOTE 4: Data on the use of dry powders or water as inerting materials and on the effects of inerting on pressure development in a closed vessel are given in U.S. Bureau of Mines Reports of Investigations 6543, 6561, and 6811.

## Appendix D Ventilation Calculations

**D-1 Time Required for Ventilation.** An estimate of the time required to reduce the concentration of a combustible gas to a safe limit by purging with fresh air can be calculated using the following method:

For an enclosed volume, V, the change in concentration, dC, over a given time period, dt, using a fixed flowrate of fresh air, Q, is given by:

$$VdC = QCdt \qquad (1)$$

By rearranging:

$$\int_{Co}^{C} \frac{dC}{C} = \frac{Q}{V} \int_{o}^{t} dt \qquad (2)$$

where Co = initial concentration of gas
t = time required to reach the desired concentration.

Integrating (2) yields:

$$\ln\left(\frac{C}{Co}\right) = \left(\frac{-Q}{V}\right) t. \qquad (3)$$

Equation (3) assumes perfect mixing. Since this is not the case in actual practice, a correction factor, K, must be introduced:

$$\ln\left(\frac{C}{Co}\right) = \left(\frac{-Q}{V}\right) (K) t. \qquad (4)$$

In perfect mixing K = 1.0. Table D-1 lists values of K for certain conditions.

**Table D-1 Mixing Efficiency for Various Ventilation Arrangements**

| | Efficiency (K) Values | |
|---|---|---|
| Method of Supplying | Single Exhaust Opening | Multiple Exhaust Openings |
| *—No Positive Supply* | | |
| Infiltration through Cracks | 0.2 | 0.3 |
| Open Doors or Windows | 0.2 | 0.4 |
| *—Forced Air Supply* | | |
| Grills and Registers | 0.3 | 0.5 |
| Diffusers | 0.5 | 0.7 |
| Perforated Ceiling | 0.8 | 0.9 |

Few data exist on defining the degree of mixing. Most authorities recommend a K value no greater than 0.25.

Consider the problem of reducing the gasoline vapor concentration of an enclosure of 1000 cu ft (28 cu m), by means of a 2000 cu ft/min (56 cu m/min) ventilation rate, from 20 volume percent to:

(a) the upper flammable limit, 7.6%
(b) the lower flammable limit, 1.4%
(c) 25% of lower flammable limit, 0.35%.

The difference between K = 1 (perfect mixing) and K = 0.2 in calculating the time needed to reduce the concentration to the levels specified may be shown.

Using Equation (3):

$$(a)\ \ln\left(\frac{7.6}{20.0}\right) = \left(\frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.38 = -2(K)(t)$$

$$t = \frac{\ln 0.38}{-2(K)} = \frac{-0.97}{-2(K)}$$

$$t = \frac{0.485}{(K)}$$

For K = 1, t = 0.49 min
For K = 0.2, t = 2.5 min.

$$(b)\ \ln\left(\frac{1.4}{20}\right) = \left(\frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.07 = -2(K)(t)$$

$$t = \frac{\ln 0.07}{-2(K)} = \frac{-2.66}{-2(K)}$$

$$t = \frac{1.33}{(K)}$$

For K = 1, t = 1.33 min
For K = 0.2, t = 6.65 min.

$$(c)\ \ln\left(\frac{0.35}{20}\right) = \left(\frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.018 = -2(K)(t)$$

$$t = \frac{\ln 0.018}{-2(K)} = \frac{-4.02}{-2(K)}$$

$$t = \frac{2.01}{K}$$

For K = 1, t = 2 min
For K = 0.2, t = 10 min.

**D-2 Number of Air Changes Required for Inerting.** The calculation method described above provides a solution expressed directly in terms of time. To develop a solution in terms of required number of air changes, the equation is written as follows:

$$\left(\frac{C}{Co}\right) = e^{-KN} \qquad (5)$$

Where N = required number of air changes.
Equation (5) can be rewritten:

$$\ln\left(\frac{C}{Co}\right) = -KN. \qquad (6)$$

Using the example in D-1, the number of air changes required to reach the upper flammable limit, 7.6%, at K = 0.2, is:

$$\ln\left(\frac{7.6}{20}\right) = -0.2\ N$$

$$N = \frac{\ln 0.38}{-0.2} = \frac{-0.97}{-0.2} = 4.8.$$

Since the airflow rate is 2000 cu ft/min (56 cu m/min) and the volume of the enclosure is 1000 cu ft (28 cu m), it turns out that a complete air change takes ½ min. Equation (6) indicates that 4.8 air changes are needed. This translates to a required time of 2.4 minutes, exactly what was calculated in D-1.

**D-3 Buildup of Combustible Concentration in Enclosed Area.** If a constant source of a combustible gas, such as from a leak, is introduced into an enclosed volume, Equation (6) must be modified as follows:

$$C = \left(\frac{G}{Q}\right)\ (1-e)^{-KN} \qquad (7)$$

C = Concentration
G = Combustible, cu ft/min
Q = air, cu ft/min
K = Mixing efficiency factor
N = Number of theoretical air changes.

As an example, consider a leak of 100 cu ft/min (2.8 cu m/min) of a 15 percent combustible gas/air mixture in a room of 1000 cu ft (28 cu m). How long would it take to reach a concentration of 5 percent throughout the enclosure, assuming a mixing coefficient, K, equal to 0.2? Thus:

$C = 0.05$
$G = 15\ \text{ft}^3/\text{min}\ (100 \times 0.15)$
$Q = 85\ \text{ft}^3/\text{min}\ (100 - 15)$
$K = 0.2.$

Equation (7) can be rewritten into a more convenient logarithmic form:

$$\ln\left(1 - \frac{CQ}{G}\right) = -KN \qquad (8)$$

$$\ln\left[1 - \frac{0.05\ (85)}{15}\right] = -0.2N$$

$$\begin{aligned} \ln(0.71667) &= -0.2N \\ \ln(-0.33314) &= N \\ 1.67 &= N. \end{aligned}$$

Since the volume is 1000 cu ft and the leak is at 100 cu ft/min,

$$\left(\frac{1000\ \text{ft}^3}{100\ \text{ft}^3/\text{min}}\right) \times (1.67) = 16.7\ \text{min}.$$

A concentration of 5 percent will be reached in 16.7 minutes.

Equations (5) and (7) can be plotted as shown in Figures D-1 and D-2.

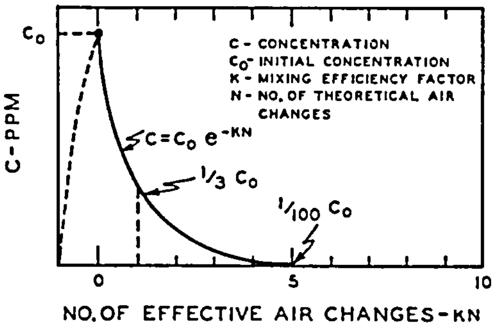

Figure D-1. Combustible decay curve. General ventilation: instantaneous release.

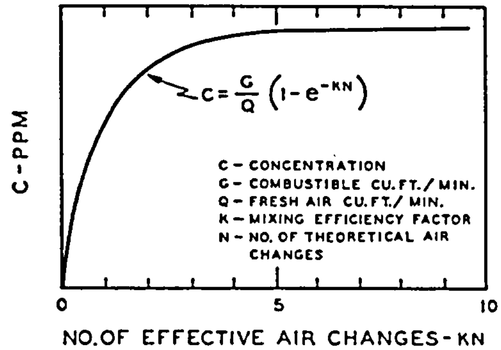

Figure D-2. Combustible buildup curve. General ventilation: continuous release.

With respect to Figure D-2, which illustrates a continuous release in an enclosed volume, once a continuous release begins, the combustible concentration increases rapidly until three (3) air changes occur. After three air changes, the bracketed term in Equation (7) approaches unity and concentration does not change much. Thus, steady-state concentration is independent of air-change rate and really depends on the volumetric flow of fresh air. For design purposes it is best to specify in terms of cubic feet per minute and avoid using the approach of specifying in terms of air changes per hour.

Although general ventilation is helpful in removing airborne combustibles, better control can be achieved in many cases by supplementing general ventilation with local ventilation.

Local ventilation can be used when the source of emission can be predicted. For example, local ventilation rather than general ventilation is recommended when:

(a) The operator or ignition sources must be very close to the point of combustible release.

(b) The combustible escape rate is uncertain.

(c) Controlling combustible dusts.

Local exhaust ventilation captures the combustible at its source, and a properly designed system achieves almost 100 percent effectiveness provided that the local exhaust pickup can be placed close to the point of release.

## Appendix E Referenced Publications

**E-1** The following documents or portions thereof are referenced within this standard for informational purposes only and thus should not be considered part of the requirements of this document. The edition indicated for each reference is current as of the date of the NFPA issuance of this document. These references are listed separately to facilitate updating to the latest edition by the user.

**E-1.1 NFPA Publications.** National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 30-1984, *Flammable and Combustible Liquids Code.*

NFPA 54-1984, *National Fuel Gas Code*

NFPA 58-1986, *Standard for the Storage and Handling of Liquefied Petroleum Gases.*

NFPA 59-1984, *Standard for the Storage and Handling of Liquefied Petroleum Gases at Utility Plants.*

NFPA 85F-1982, *Standard for the Installation and Operation of Pulverized Fuel Systems.*

NFPA 495-1985, *Code for the Manufacture, Transportation, Storage, and Use of Explosive Materials.*

NFPA 496-1986, *Standard for Purged and Pressurized Enclosures for Electrical Equipment in Hazardous (Classified) Locations.*

**E-2 Bureau of Mines Publications.** The following publications are available form the U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center, 4800 Forbes Avenue, Pittsburgh, PA 15213.

Nagy, J.; Dorsett, H.G., Jr.; Jacobson, M: *Preventing Ignition of Dust Dispersions by Inerting*; Report of Investigations 6543; 1964.

Nagy, J.; Cooper, A.R.; Stupar, J.M.: *Pressure Development in Laboratory Dust Explosions*; Report of Investigations 6561; 1964.

Nagy, J; and Surincik, D.J.: *Thermal Phenomena During Ignition of a Heated Dust Dispersion*; Report of Investigation 6811; 1966.

**E-3 Bibliography.** This part of the Appendix lists other publications pertinent to the subject of this NFPA document and which may or may not be referenced.

Bartknecht, W.; *Explosions: Course, Prevention, Protection*; Springer-Verlag; Heidelberg; 1981.

Coward, J.F. and Jones, G. W.; *Limits of Flammability of Gases and Vapors*; Bulletin 503; U.S. Bureau of Mines; Pittsburgh, PA; 1951.

Jones, G. W., M. G. Zabetakis, J. K. Richmond, G. S. Scott, and A. L. Furno. Research on the Flammability Characteristics of Aircraft Fuels. Wright Air Development Center, Tech. Report 52-35, Supplement I, 1954, 57 pp.

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Noronha, J. A.; Merry, J. T.; and Reid, W.C.; *Deflagration Pressure Containment for Vessel Safety Design, Plant/Operations Progress*, Vol. 1, No. 1; American Institute of Chemical Engineers; New York, NY; Jan., 1982.

Zabetakis, M.G.; *Flammability Characteristics of Combustible Gases and Vapors*; Bulletin 627; U.S. Bureau of Mines, Pittsburgh, PA; 1965.

.Zabetakis, M.G.; *Gasfreeing of Cargo Tanks*; Information Circular 7994; U.S. Bureau of Mines; Pittsburg, PA; 1961.

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