

NFPA 69 Standard on Explosion Prevention Systems

1997 Edition



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An International Codes and Standards Organization

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NFPA 69
Standard on
Explosion Prevention Systems
1997 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 Fall Meeting held November 18–20, 1996, in Nashville, TN. It was issued by the Standards Council on January 17, 1997, with an effective date of February 7, 1997, and supersedes all previous editions.

This edition of NFPA 69 was approved as an American National Standard on February 21, 1997.

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. The results of that effort became the 1986 edition.

The 1992 edition of NFPA 69 incorporated a new chapter on deflagration isolation systems. Partial amendments were made to refine definitions, improve descriptions of oxidant concentration reduction techniques, improve material on deflagration suppression, and fine-tune deflagration pressure containment material.

The 1997 edition of this standard includes some reorganization and updating of the technical material to improve its usability. New material has been added on enrichment to operate above the upper flammable limit as a means of explosion protection with minimum oxidant concentrations for preventing explosions. Material has been added to the standard for provisions on reliability of explosion protection control systems and deflagration suppression systems for consistency with other NFPA standards.

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

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

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

Information on referenced publications can be found in Chapter 8 and Appendix E.

Chapter 1 General

1-1 Scope.

1-1.1 This standard shall apply to systems and equipment used for the prevention of explosions by the prevention or control of deflagrations.

1-1.2 This standard shall not apply to following:

- (a) Devices or systems designed to protect against detonations
- (b) *Design, construction, and installation of deflagration vents
- (c) Protection against overpressure due to phenomena other than internal deflagrations
- (d) Chemical reactions other than combustion processes
- (e) Unconfined deflagrations, such as open-air or vapor cloud explosions
- (f) Rock dusting of coal mines, as covered by Title 30, *Code of Federal Regulations*, Part 75
- (g) The general use of inert gas for fire extinguishment
- (h) *The preparation of tanks, piping, or other enclosures for hot work, such as cutting and welding
- (i) 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*
- (j) Marine vapor control systems regulated by Title 33, *Code of Federal Regulations*, Part 154
- (k) Marine vessel tanks regulated by Title 46, *Code of Federal Regulations*, Parts 30, 32, 35, and 39

1-1.3 Nothing in this standard shall be intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard, provided technical documentation is made available to the authority having jurisdiction to demonstrate equivalency and the system, method, or device is approved for the intended purpose.

1-1.4 Retroactivity. The provisions of this document are considered necessary to provide a reasonable level of protection from loss of life and property from fire and explosion. They reflect situations and the state-of-the-art prevalent at the time the standard was issued.

Unless otherwise noted, it is not intended that the provisions of this document be applied to facilities, equipment, structures, or installations that were existing or approved for construction or installation prior to the effective date of the document, except in those cases where it is determined by the

authority having jurisdiction that the existing situation involves a distinct hazard to life or adjacent property.

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

1-3* Techniques. Techniques are recognized in this standard and are grouped into two classes. One class is based on preventing combustion; the other is based on preventing or limiting damage after combustion occurs.

1-3.1 Methods Based on Preventing Combustion. The following shall be considered methods based on preventing combustion:

- (a) Oxidant concentration reduction
- (b) Combustible concentration reduction

1-3.2 Methods Based on Limiting or Preventing Damage. The following shall be considered methods based on limiting or preventing damage:

- (a) Deflagration suppression
- (b) Deflagration pressure containment
- (c) Spark extinguishing systems
- (d) Isolation methods

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 shall 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 using the following factors:

- (a) The system's design basis
- (b) The possibility of electrical and mechanical malfunction
- (c) Dependence on sophisticated activating systems
- (d) The need for special installation, training, operating, testing, and maintenance procedures

Further limitations presented in each chapter shall be considered.

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 are present, consideration shall be given to the safety of the personnel.

1-6 Plans. Plans, system specifications, and manufacturer's recommendations for testing and maintenance shall contain information 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 Acceptance Test.

1-7.1 All new system installations and modifications shall be tested or otherwise evaluated to confirm the operational integrity of the system.

1-7.2 Tests shall be according to the manufacturer's recommendations.

1-7.3 A written report of these tests shall be provided to the users.

1-8* Inspection and Maintenance.

1-8.1* All systems shall be inspected for operability with the manufacturer's recommendations. An inspection and preventive maintenance schedule shall be established in accordance with the manufacturer's recommendations.

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

Approved.* Acceptable to the authority having jurisdiction.

Authority Having Jurisdiction.* The organization, office, or individual responsible for approving equipment, an installation, or a procedure.

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.

Chemical Isolation. A means of preventing flame front and ignition from being conveyed past a predefined point by injection of a chemical suppressant.

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.

Combustible Particulate Solid.* Any combustible solid material comprised of distinct particles or pieces, regardless of size, shape, or chemical composition that is capable of being pneumatically conveyed. Combustible particulate solids include dusts, fibers, fines, chips, chunks, flakes, or mixtures of these.

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.

Deflagration Isolation. A method employing equipment and procedures that interrupts the propagation of a deflagration flame front past a point.

Deflagration Pressure Containment. The technique of specifying the design pressure of a vessel and its appurte-

nances so they are capable of withstanding the maximum pressures resulting from an internal deflagration.

Deflagration 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.

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

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

Fast-Acting Valves. A valve that closes a path of deflagration propagation in a pipe or duct in response to upstream detection of a deflagration.

Flame Arrester. A device that prevents the transmission of a flame through a flammable gas/air mixture by quenching the flame on the surfaces of an array of small passages through which the flame must pass. The emerging gases are sufficiently cooled to prevent ignition on the protected side.

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

Flame Front Diverter. A device that opens in response to the pressure wave preceding the flame front of the deflagration, venting the flame front and pressure wave.

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

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

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

Flow Isolation. A method employing equipment and procedures that interrupts the flow and prevents pressure rise beyond a point.

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

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

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

Ignition Source Isolation. A method employing equipment and procedures that interrupts the propagation of an igniting medium past a point.

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

Inerting. A technique by which a combustible mixture is rendered non-ignitable by addition of an inert gas or a non-combustible dust. (*See also Blanketing.*)

Isolation. A means of preventing certain stream properties (deflagration, mass flow, ignition capability) from being conveyed past a predefined point.

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

Limiting Oxidant Concentration (LOC).* The concentration of oxidant below which a deflagration cannot occur in a specified mixture.

Liquid Seals. A device for preventing the passage of flame by passing the gas mixture through a noncombustible liquid.

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

Lower Flammable Limit (LFL). The lower flammable limit is the lowest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

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

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

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.

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.*)

Pressure Piling. The condition during a deflagration when the pressure increases in the unreacted medium ahead of the propagating combustion zone.

Purge Gas. A gas that is continuously or intermittently added to a system to render the atmosphere non-ignitable. The purge gas can be inert or combustible.

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 a deflagration suppression system to extinguish the deflagration.

Upper Flammable Limit (UFL). The upper flammable limit is the highest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

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 for oxidant concentration reduction for deflagration prevention can be considered for application to any system where a mixture of oxidant and flammable material is confined to an enclosure within which the oxidant concentration can be controlled. The system shall be maintained at an oxidant concentration low enough to prevent a deflagration.

2-1.2 Oxidant concentration reduction can 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 Design and Operating Requirements.

2-2.1* The following factors shall be considered in the design of a system to reduce the oxidant concentration:

- Required reduction in oxidant concentration
- Variations in the process, process temperature and pressure, and materials being processed
- Purge gas supply source and equipment installation
- Compatibility of the purge gas with the process
- Operating controls
- Maintenance, inspection, and testing
- Leakage of purge gas to surrounding areas
- Need for breathing apparatus by personnel

2-2.2 Limiting Oxidant Concentrations (LOC).

2-2.2.1* Appendix Tables C-1, C-2, and C-3 shall be permitted to be used as a basis for determining limiting oxidant concentrations of flammable gases or suspensions of combustible dusts.

2-2.2.2 The extent of oxygen reduction shall be determined by testing where conditions vary significantly from the test conditions under which the data were obtained.

2-2.3 Use of Purge Gas Systems.

2-2.3.1 An additional backflash prevention or protection system shall be installed where a purge gas system is used for lines collecting flammable mixtures and where the collection system terminates at a flare or incinerator.

2-2.3.2 Hard-piped vapor control systems shall not generally require flame arresters at each source connection to the system, provided the system is designed to operate outside the flammable range.

2-2.3.3 Systems requiring hook-ups prior to vapor transfer, such as vapor collection from mobile vehicles, shall be purged to a safe level below the LOC prior to transfer, or backflash protection shall be provided near the point of connection.

2-2.3.4 Caution shall be exercised for those inerted systems that might form pyrophoric iron sulfide when allowing air to enter such systems.

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.

2-3.2 Possible sources of purge gas shall 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 can 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

2-4 Purge Gas Conditioning.

2-4.1 Purge gas shall be conditioned to minimize contaminants that might be harmful to the gas distribution system or that might interfere with the operation of the system.

2-4.2 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.

2-4.3 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. Where purge gas pressure exceeds 15 psig (103 kPa gauge), 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 Moisture Traps.

2-5.3.1 Where necessary, moisture traps shall be provided and lines shall drain toward the traps.

2-5.3.2 Blowdown connections shall be provided.

2-5.3.3 Moisture traps shall be protected from freezing.

2-5.4 When flue gas or combustion gas is used, 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.

2-5.6.1 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.

2-5.6.2 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* Instrumentation shall be provided to monitor the purge gas being supplied to the distribution system.

2-7.1.1 Instrumentation shall be properly calibrated at scheduled intervals.

2-7.1.2 When conditions being measured are critical to safety of personnel, alarms shall be provided to indicate abnormal operation of the system.

2-7.2 Systems Operated Below the Limiting Oxidant Concentration (LOC).

2-7.2.1* Instrumentation shall be installed in as many points as necessary to ensure the desired oxidant concentration reduction within the protected system.

2-7.2.2 The determination of the LOC for the system shall be based on the worst credible case gas mixture yielding the smallest LOC.

2-7.2.3 A safety margin shall be maintained between the LOC and the normal working concentration in the system.

2-7.2.4* The safety margin shall take into account the fluctuations occurring in the system, the sensitivity and reliability of monitoring and control equipment, and the probability and consequences of an explosion.

2-7.2.5 Where the oxidant concentration is continually monitored, a safety margin of at least 2 volume percent below the measured worst credible case LOC shall be maintained unless the LOC is less than 5 percent, in which case, the equipment shall be operated at no more than 60 percent of the LOC.

Exception: This requirement shall not apply to partial oxidation processes.

2-7.2.6 Where the oxygen concentration is not continuously monitored, the oxygen concentration shall be designed to operate at no more than 60 percent of the LOC, or 40 percent of the LOC if the LOC is below 5 percent. If the oxygen concentration is not continuously monitored, the oxygen concentration shall be checked on a regularly scheduled basis.

*Exception No. 1: * Low pressure field storage tanks that have padding shall not require checking of the oxygen concentration of the vapor space.*

Exception No. 2: The procedure of pulling partial vacuum and then breaking vacuum with inert gas shall be permitted without measuring the oxygen concentration if the following apply:

- (a) *The vacuum condition is held for a time to check for leakage.*
- (b) *The vacuum level is monitored.*
- (c) *The vacuum creating medium is compatible with the process chemistry.*
- (d) *The residual oxygen partial pressure is calculated or demonstrated by test to be at least 40 percent below the LOC.*

2-7.3 Systems Operated Above the Upper Flammable Limit (UFL).

2-7.3.1* Systems operating above the UFL shall be permitted to be used. Marine vent collecting header operation is regulated by Title 33, *Code of Federal Regulations*, Part 154.

2-7.3.2 Vent headers operated near atmospheric pressure and not containing any vapor with a UFL greater than that of hydrogen in air (75 percent), nor oxygen in concentrations greater than can be derived from ambient air, shall be permitted to be rendered nonflammable by the addition of at least 25 volume percent of natural gas or methane.

2-7.3.3 Instrumentation to control methane flow shall be acceptable to the authority having jurisdiction.

Chapter 3 Combustible Concentration Reduction

3-1* Application. The technique of combustible concentration reduction can 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.

3-2 Basic Design Considerations.

3-2.1 The following factors shall be considered in the design of a system to reduce the combustible concentration below the lower flammable limit (LFL):

- (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

3-2.2* The lower flammable limits of the combustible components shall be determined at all operating conditions, including startup and shutdown.

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 (LFL).

Exception No. 1: When automatic instrumentation with safety interlocks is provided, the combustible concentration shall be permitted to be maintained at or below 60 percent of the lower flammable limit.

Exception No. 2: Aluminum powder production systems designed and operated in accordance with NFPA 651, Standard for the Manufacture of Aluminum Powder, shall be permitted to be maintained at or below 50 percent of the lower flammable limit.

3-3.2* When catalytic oxidation is used for combustible concentration reduction, flame arresters shall be provided in all inlets to the catalytic oxidation unit. These flame arresters 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, dryers, or precipitators in the air intakes shall be located so that they are accessible for cleaning and maintenance.

3-4 Instrumentation.

3-4.1 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 Deflagration Suppression

4-1 Application.

4-1.1 The technique of deflagration suppression is applicable for most flammable gases, combustible mists, or combustible dusts that are subject to deflagration in a gas phase oxidant.

4-1.2 Enclosures that can be protected by a deflagration suppression system shall include but are not limited to the following:

- (a) Processing equipment, such as reactor vessels, mixers, blenders, pulverizers, mills, dryers, 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
- (e) Aerosol filling rooms

4-2 Limitations.

4-2.1 Deflagration suppression will be successful only where the suppressant can be effectively distributed during the early stages of flame development.

4-2.2 Deflagration suppression is limited by the physical and chemical properties of the reactants in the system as well as the design and construction of the enclosure.

4-2.3 Deflagration suppression is applicable when the maximum pressure from a suppressed deflagration is lower than the design strength of the protected enclosure.

4-3 Personnel Safety.

4-3.1* Disarming and Lockout/Tagout Procedures.

4-3.1.1 Disarming and lockout/tagout procedures shall be followed prior to entering equipment protected by deflagration suppression systems.

4-3.1.2 The deflagration suppression system shall be disarmed prior to performing maintenance operations on the protected equipment if discharging the suppressant could result in injury.

4-3.1.3 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 armed.

4-3.2 Personnel shall be trained relative to safety procedures to be carried out prior to, during, and after maintenance.

4-4 Basic Design Considerations.

4-4.1 The design of a deflagration suppression system shall include but shall not necessarily be limited to the following:

- (a) Deflagration characteristics of the combustible material
- (b) Equipment to be protected with its design specifications
- (c) Detection technique
- (d) Suppressant
- (e) Installation, operation, and test procedures

4-4.2 Process Analysis.

4-4.2.1 A thorough analysis of the process shall be conducted to determine the type and degree of deflagration hazards inherent in the process.

4-4.2.2 Such factors as type of combustible, internal geometry and total volume to be protected, operating conditions, etc., shall be reviewed in detail.

4-4.2.3 Possible malfunctions that can affect the extent of the deflagration hazard also shall be determined.

4-4.3 The deflagration suppression system also can actuate other devices or systems such as high speed isolation valves, rapid pneumatic conveying system shutdowns, or deflagration vents.

4-4.4 Drawings and Design Calculations.

4-4.4.1 Drawings and design calculations shall be developed for each system.

4-4.4.2 Calculations of final reduced deflagration pressures shall be provided.

4-5 Power/Control Units.

4-5.1 A power/control with 24-hour (minimum) standby battery backup shall be provided with each suppression system. It shall supply sufficient energy to accomplish the following:

- (a) Power all detection devices
- (b) Energize all electrically fired initiators
- (c) Energize visual and audible alarms
- (d) Transfer all auxiliary control and alarm contacts
- (e) Control system disabling interlock and process shutdown circuits

4-5.2 The power/control unit shall meet applicable requirements of NFPA 72, *National Fire Alarm Code*, 1-5.2 and Chapter 3.

4-5.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (a) Wiring circuits for opens and other faults
- (b) AC power supply (primary)
- (c) Battery voltage, presence, and polarity
- (d) System safety interlock circuitry
- (e) Releasing outputs
- (f) Electrical fired initiators
- (g) Detectors
- (h) Visual and audible alarms
- (i) System disabling interlock circuitry
- (j) Circuit ground fault

4-5.4 The supervisory signal circuits shall be provided with a visual and audible trouble signal. In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

4-6 Detectors.

4-6.1 The deflagration shall be detected by sensing either the pressure increase or the radiant energy from the combustion process.

4-6.2 Provisions shall be made to prevent obscuration of radiant energy detectors.

4-6.3 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

4-7 Electrically Fired Initiators.

4-7.1 Initiators shall be mounted so that their maximum temperature rating is not exceeded.

4-7.2 A source of electrical energy shall be used so that the firing characteristics of the initiators do not deviate from the manufacturer's specifications.

4-8* Suppressant and Suppressant Storage Containers.

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

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

4-8.3 Means shall be provided to verify the pressure of the pressurized reservoirs.

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 Suppressant discharge nozzles shall be mounted in such a way as to prevent damage or failure to any appurtenances or fixtures in the enclosure protected.

4-9.3 Means shall be used to protect detectors and suppressant discharge devices from accumulating foreign material that would prevent functioning.

4-9.4 Terminals and mechanical parts shall be protected from moisture and other contaminants.

4-9.5 Mounting locations shall be chosen to not exceed maximum operating temperatures of system components.

4-10 Electrical.

4-10.1 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

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

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

4-10.4 All wiring shall meet the applicable requirements of NFPA 70, *National Electrical Code*®.

4-11 Inspection and Maintenance of Deflagration Suppression Systems.

4-11.1* Equipment shall be designed to allow inspection of nozzles and detectors. Suppression systems shall be inspected and tested at three-month intervals by personnel trained by the system's manufacturer.

4-11.2* Containers of suppressant shall be checked for pressure and loss of agent. A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.

4-11.3 Detectors shall be tested and calibrated as necessary to meet system specifications.

4-11.4 System interlocks shall be verified for proper functioning.

4-11.5 The control unit shall be tested to ensure that the system will function as required and all external circuits are properly supervised.

4-11.6 A written report shall be kept on file for the last system inspection. The report shall include test and calibration data on all system components.

4-11.7 Extinguishing agent cylinders shall be hydrostatically tested consistent with DOT requirements.

4-12 Procedures After System Actuation. In the event of system actuation, inspection, and testing, as specified in 4-11.1, shall be performed before the system is placed back into service.

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 they are capable of withstanding the maximum pressures resulting from an internal deflagration.

5-1.2 This chapter shall provide the basis for determining the vessel design pressure required to withstand the pressures resulting from an internal deflagration.

5-1.3 This chapter shall be limited to systems where the oxidant is air.

5-1.4 The design pressure specified by this chapter shall be based on the most severe set of system conditions that can occur.

5-1.5* When deflagration pressure containment is applied to a vessel with attached equipment, the pressure loads imposed on the attached equipment can be equal to or greater than the pressure loads experienced by the protected vessel. Therefore, measures shall be taken to protect this attached equipment.

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 systems where two or more vessels are connected by large-diameter pipes or ducts.

Exception No. 1: Deflagration pressure containment shall be permitted to be used where interconnected piping is provided with deflagration isolation.

Exception No. 2: Deflagration pressure containment shall be permitted to be used where venting is provided for interconnected piping.

Exception No. 3: Deflagration pressure containment shall be permitted to be used where interconnected vessels are designed to contain the increased pressures due to the effects of pre-pressurization.

Exception No. 4: The use of deflagration isolation or venting of one vessel shall be permitted to be used.

5-2.3* Deflagration pressure containment shall be permitted for initial pressures exceeding 30 psig (2 bar gauge) only when the maximum deflagration pressure ratio (R) is determined by test or calculations.

Exception: 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. Due to the vacuum that can follow a deflagration, all vessels whose deflagration pressure containment design is based on preventing deformation also shall be designed to withstand an internal

pressure of 10 psia, or they shall be provided with vacuum relief.

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

$$P_f = \frac{1.5[R(P_i + 14.7) - 14.7]}{F_u} \quad (1)$$

$$P_d = \frac{1.5[R(P_i + 14.7) - 14.7]}{F_y} \quad (2)$$

where:

P_f = 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: 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. As a practical design basis (since optimum conditions seldom exist in industrial equipment) for most gas/air mixtures, R shall be taken as 9; for St-1 and St-2 dust/air mixtures, R shall be taken as 11. For St-3 dust/air mixtures, R shall be taken as 13.

Exception: A different value of R shall be permitted to be used if such value can be substantiated by test data or calculations.

5-3.3.2 The vessel design pressure shall be based on the wall thickness of the vessel, excluding any allowance for corrosion or erosion.

5-3.3.3 For operating temperatures below 25°C (77°F), the value of R' shall be calculated for use in equations 1 and 2:

$$R' = R \left(\frac{298}{273 + T_i} \right) \quad (3)$$

where:

R = the maximum deflagration ratio for the mixture measured at 25°C (77°F)

T_i = the operating temperature in °C

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

5-3.5* Maximum Pressure for Positive Pressure Systems.

5-3.5.1 For positive pressure 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.

5-3.5.2 For positive pressure 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.

5-3.5.3 For gravity discharge of dusts, the maximum initial pressure shall be taken as atmospheric pressure (0.0 psig or 0.0 bar gauge).

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 bar gauge).

5-3.7 The design shall take into consideration the minimum operating temperature at which a deflagration could occur. This minimum temperature shall 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.

5-3.8 Auxiliary equipment such as vent systems, manways, fittings, and other openings into the vessel shall be designed to ensure integrity of the total system and shall be inspected periodically.

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

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

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 Detection and Extinguishing Systems

6-1 Application. Spark extinguishing systems can be considered for reducing the frequency of deflagrations in transport and receiving systems that handle combustible particulate solids. Spark detection and extinguishing shall be used in conjunction with other explosion prevention or explosion protection measures, such as deflagration suppression or deflagration venting, for those systems posing a dust explosion hazard.

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 from 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 openings through which incident light can affect the detectors. Such systems shall be permitted to 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 designed to transport flammable gases.

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

6-2.3* Spark detection and extinguishing systems are limited to detection and extinguishment of sparks or embers traveling at the system transport velocity, and they shall not be intended for use in extinguishing deflagration flame fronts or flow isolation.

6-3 Spark Detection and Extinguishing System Design Considerations.

6-3.1* Spark detection and extinguishing systems shall be listed or approved.

6-3.2 Detectors.

6-3.2.1 Spacing between a detector and the extinguishing agent injection point shall be based on the linear velocity of the material in the duct, the response time of the detector, and the actuator circuitry.

6-3.2.2 The number of detectors shall be sufficient to detect a glowing particle at any location in the cross-sectional area of the duct.

6-3.2.3 Detectors shall be protected from obscuration of radiant energy by the accumulation of foreign materials or other items that would prevent them from proper functioning.

6-3.3 Power/Control Units.

6-3.3.1 A power/control unit with 24-hour (minimum) standby battery backup shall be provided with each suppression system. It shall supply sufficient energy to accomplish the following:

- (a) Power all detection devices
- (b) Energize all electrically actuated extinguishing systems
- (c) Energize visual and audible alarms
- (d) Transfer all auxiliary control and alarm contacts
- (e) Control system disabling interlock and process shutdown circuits

6-3.3.2 The power/control unit shall meet applicable requirements of NFPA 72, *National Fire Alarm Code*, 1-5.2 and Chapter 3.

6-3.3.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (a) Wiring circuits for opens and other faults
- (b) AC power supply (primary)
- (c) Battery voltage, presence, and polarity
- (d) System safety interlock circuitry
- (e) Releasing outputs
- (f) Electrical extinguishing actuators
- (g) Detectors
- (h) Visible and audible alarms
- (i) System disabling interlock circuitry
- (j) Circuit ground fault

6-3.3.4 The supervisory signal circuits shall be provided with a visual and audible trouble signal. In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

6-3.4 Extinguishing System.

6-3.4.1 Discharge nozzles shall be located and arranged so that solid particles will not obstruct the nozzles.

6-3.4.2 If water is used as the extinguishing agent, the water supply system shall be equipped with an in-line strainer.

6-3.4.3 The extinguishing agent supply system shall be capable of supplying all discharge nozzles at the rated volume and pressure.

6-3.4.4 The system shall contain enough extinguishing agent to provide for at least 100 operations of the system.

6-3.4.5 An alarm shall sound when the pressure of the extinguishing agent falls below the minimum supply pressure specified by the manufacturer.

6-3.4.6 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 an alarm shall sound at both the low and high temperature limits.

6-4 Testing. A functional test of the extinguishing portion of the system shall be conducted in accordance with the manufacturer's specifications.

6-5 Spark Detection and Extinguishing System Inspection and Maintenance.

6-5.1 Spark extinguishing systems shall be inspected and maintained in accordance with the manufacturer's recommendations.

6-5.2 A written report shall be available for the last system inspection. The report shall include test and calibration data on all system components.

Chapter 7 Isolation Methods

7-1 Introduction.

7-1.1* Isolation methods can be considered for interruption or mitigation of flame, deflagration pressures, pressure piling, and flame-jet ignition between equipment interconnected by pipes or ducts.

7-1.2 It shall be permitted to use one or more of the technologies described in this chapter with other explosion prevention systems described in this document, in addition to or in conjunction with deflagration venting.

7-2 Application.

7-2.1 Isolation methods are intended to prevent passage of, arrest, divert, or extinguish the deflagration flame front and, in some cases, the combustion generated pressure.

7-2.2 The technique of isolation shall be permitted for flammable gases or combustible dust systems.

7-2.3* Isolation system design shall be permitted to be based on various techniques that include, but are not limited to, the use of the following:

- (a) Rotary valves
- (b) Flame arresters
- (c) Automatic fast-acting valves
- (d) Flame front diverters
- (e) Flame front extinguishing systems
- (f) Liquid seals
- (g) Spark detection and extinguishing systems

7-2.4 General. When isolation methods are used, the strength of piping, ducts, and enclosures shall be designed to withstand anticipated pressures.

7-3* Rotary Valves.

7-3.1 Rotary valves shall be used only for systems handling combustible dust.

7-3.2 Rotary valves intended for deflagration isolation systems shall be designed with clearance between the rotor and the valve housing small enough to prevent the passage of a flame. At least two vanes on each side of the valve housing shall be in a position of minimum clearance at all times.

7-3.3 Rotary valves shall be capable of withstanding the maximum expected pressure.

7-3.4* Rotary valves intended for deflagration isolation systems shall have metal bodies and vanes unless it is shown by test data that nonmetallic or composite materials will prevent flame passage.

7-4* Flame Arresters.

7-4.1* Flame arresters shall be placed in the potential flame path between the source of ignition and the system to be protected.

7-4.2 This section shall not apply to the following:

- (a) Devices that utilize a liquid seal to prevent the passage of flame
- (b) Devices that rely on gas flow velocity to prevent upstream propagation of flame
- (c) Systems handling combustible dusts

7-4.3 Flame arresters shall be installed in accordance with the manufacturer's instructions.

7-4.4* Flame arresters for in-line use shall be tested for that application.

7-4.5* If an in-line arrester can experience continued burning for an interval of time exceeding that for which it was tested, some means of detecting such burning shall be provided on both sides of the arrester along with an alarm or automatic device to interrupt flow prior to failure. If thermocouples are used, they shall not be placed in thermowells.

7-4.6* Arresters shall be inspected periodically, based on facility experience, and after each incident where they have been called upon to function. The inspection shall determine

whether any damage has occurred that could affect the performance of the device. Damaged components shall be replaced.

7-5* Automatic Fast-Acting Valve Systems.

7-5.1 Automatic fast-acting valve systems shall be designed to detect a deflagration and to prevent propagation of flame and combustion-generated pressure beyond the fast-acting valves by providing a positive mechanical seal.

7-5.2 The following factors affect the performance of fast-acting automatic closing valves and shall be considered in design and applications. These factors include but are not limited to the following:

- (a) Deflagration characteristics of the combustible material
- (b) Volume, configuration, and operating characteristics of the vessel
- (c) Type of deflagration protection used on the vessel and piping
- (d) Volume, length, cross-sectional area, configuration, and strength of the piping
- (e) Velocity of combustible-air mixture in the pipe
- (f) Location of system components
- (g) Closure time of the valve, including control and detection components
- (h) Detection technique

7-5.3 Fast-acting valves and deflagration detectors shall be capable of withstanding the maximum expected deflagration pressures including pressure piling.

7-5.4* The fast-acting valve systems shall be of a design that has been tested under deflagration conditions to verify their performance.

7-5.5 Spacing between a detector and the fast-acting valve shall be based on the maximum flame speed expected in the duct and the response time of the detector, valve, and the actuator circuitry.

7-5.6 The diameter of the pipe leading to the automatic fast-acting valve shall not be decreased.

Exception: The automatic fast-acting valve has been specifically tested for the configuration.

7-5.7 Personnel shall be trained in safety procedures to be carried out prior to, during, and after maintenance.

7-5.8 Power/Control Units.

7-5.8.1 A power/control unit with 24-hour (minimum) standby battery back-up shall be provided with each suppression system. It shall supply sufficient energy to accomplish the following:

- (a) Power all detection devices
- (b) Energize all electrically actuated valve systems
- (c) Energize visual and audible alarms
- (d) Transfer all auxiliary control and alarm contacts
- (e) Control system disabling interlock and process shutdown circuits

7-5.8.2 The power/control unit shall meet applicable requirements of NFPA 72, *National Fire Alarm Code*, 1-5.2 and Chapter 3.

7-5.8.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (a) Wiring circuits for opens and other faults
- (b) AC power supply (primary)
- (c) Battery voltage, presence, and polarity
- (d) System safety interlock circuitry
- (e) Releasing outputs
- (f) Electrical valve actuators
- (g) Detectors
- (h) Visual and audible alarms
- (i) System disabling interlock circuitry
- (j) Circuit ground fault

7-5.8.4 The supervisory signal circuits shall be provided with a visual and audible trouble signal. In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

7-5.9 Detectors.

7-5.9.1 Detection of a deflagration shall be by sensing either the pressure increase or the radiant energy from the combustion process.

7-5.9.2* Provision shall be made to prevent obscuration of radiant energy detectors.

7-5.9.3 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

7-5.10 Electrically Fired Initiators. Electrically fired initiators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.

7-5.11 Pneumatic Valve Actuator Systems.

7-5.11.1 Pneumatic valve actuators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.

7-5.11.2 Means shall be provided to verify the pressure of the pressurized reservoir for the pneumatic valve actuator.

7-5.12 Electrical.

7-5.12.1 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

7-5.12.2 When environmental conditions warrant, conduits shall be sealed to prevent entrance of moisture and other contaminants.

7-5.12.3 When a conduit is used for wiring multiple installations, the wiring for each automatic fast-acting valve system shall be run in separate conduits. Alternatively, each system shall be permitted to be wired with shielded cables run in common conduits.

7-5.12.4 All wiring shall meet the applicable requirements of NFPA 70, *National Electrical Code*.

7-5.13 Installation of Automatic Fast-Acting Valve Systems.

7-5.13.1 All components of the system shall be mounted in the location and in the manner specified by the system designer.

7-5.13.2 Where necessary, measures shall be used to protect detectors and fast-acting valves from accumulating foreign material that would prevent effective operation.

7-5.13.3 Terminals and mechanical parts shall be protected from moisture and other contaminants.

7-5.13.4 Mounting locations shall be chosen so as not to exceed maximum operating temperatures of system components.

7-5.14 Inspection and Maintenance of Automatic Fast-Acting Valve Systems.

7-5.14.1 Automatic fast-acting valve systems shall be inspected and maintained in accordance with the manufacturer's recommendations.

7-5.14.2 A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.

7-5.14.3 A written report shall be available for the last system inspection. The report shall include test and calibration data on all system components.

7-5.15 Procedures After System Actuation. In the event of system actuation, inspection and testing, as specified by the manufacturer, shall be performed before the system is placed back into service.

7-6* Flame Front Diverters.

7-6.1 This is a device comprised of a body and a closure device. The pressure wave that precedes the flame front opens the closure and the body diverts the flame front to the atmosphere. Some flame front diverters are equipped with an internal closure that, upon activation, creates a physical barrier to downstream flame propagation. Flame front diverters shall be permitted to be used as a deflagration loss control measure.

7-6.2 Limitations of Flame Front Diverters. Flame front diverters have demonstrated the ability to divert deflagration flames by directing them to the atmosphere. However, in some cases, tests have indicated that some diverters have been ineffective in completely diverting a deflagration; but, where this has occurred, the deflagration severity in the system has been reduced.

7-6.3 Flame front diverter system design considerations shall include but not be limited to the following:

- (a) Deflagration characteristics of the combustible material
- (b) Volume, configuration, and operating characteristics of the equipment to be protected and conveying system
- (c) Type of deflagration protection used on the vessel
- (d) Length, cross-sectional area, configuration, and strength of the piping
- (e) Velocity of combustible-air mixture in pipe
- (f) Location of flame front diverter and its associated piping
- (g) Turbulence generating features in the piping such as fittings, valves, elbows, and wall roughness
- (h) Location of probable ignition sources

7-6.4 The body design shall divert the flame front to atmosphere and away from the downstream piping.

7-6.5 The body shall be capable of withstanding expected deflagration pressure.

7-6.6 The closure device shall be either a rupture disc or cover plate.

7-6.7 Where the closure device could be a missile hazard, it shall be either tethered or contained in a cage.

7-6.8 The hazard of flame discharge from the flame front diverter shall be considered when designing the placement of the device. The flame front diverter shall discharge to a safe, unrestricted, outdoor location.

7-6.9* **Design Requirements for Flame Front Diverters.** Flame front diverters shall be tested for the application.

7-7 Chemical Isolation Systems.

7-7.1 General Requirements.

7-7.1.1 Chemical isolation systems shall be permitted to be used to isolate interconnected process volumes from the effects of deflagration flame passage through interconnecting pipe.

7-7.1.2 Chemical isolation systems shall be designed to detect a deflagration flame event and to cause discharge of an extinguishing agent into a length of pipe sufficient to prevent flame propagation past the point of agent discharge.

7-7.1.3 Chemical isolation system components exposed to the process environment shall be capable of withstanding the maximum expected deflagration pressure.

7-7.1.4 A chemical isolation system shall be of a design that has been tested under deflagration conditions to verify performance.

7-7.1.5 The distance between the position of a deflagration flame event detector and the associated agent discharge point shall be based on the maximum deflagration flame speed expected in the pipe and the response time characteristics of the detector and the discharge rate from the agent containers.

7-7.1.6 Chemical isolation systems shall be disarmed before maintenance operations are performed on the system components.

7-7.1.7 Personnel shall be trained in safety procedures to be carried out prior to, during, and after maintenance.

7-7.2 Detectors.

7-7.2.1 Deflagration flame event detectors shall be of the pressure sensing or radiant energy sensing type.

7-7.2.2 Provision shall be made to prevent obscuration of radiant energy type detectors.

7-7.2.3 Provision shall be made to prevent blockage of access to the sensing surface of pressure type detectors.

7-7.3 Extinguishing Agent and Containers.

7-7.3.1 The extinguishing agent shall be chemically compatible with the material normally conveyed through the pipe system being protected.

7-7.3.2 The extinguishing agent shall be of a type that will be effective at all temperatures to be encountered in the application.

7-7.3.3 Extinguishing agent containers shall be designed to meet the requirements of the U.S. Department of Transportation, if used as shipping containers. If not used as shipping

containers, they shall be designed, fabricated, inspected, certified, and stamped in accordance with Section VIII of the ASME *Boiler and Pressure Vessel Code*. The design pressure shall be suitable for the maximum pressure developed at 130°F (55°C) or at the maximum controlled temperature limit.

7-7.4 Electrically Fired Initiators. Extinguishers shall be mounted so the temperature attained at the location of electrically fired initiators shall not exceed the maximum temperature for which they are rated.

7-7.5 Power/Control Units.

7-7.5.1 A power and control unit with 24-hour (minimum) standby battery power back-up shall be provided for each chemical isolation system. It shall supply sufficient energy to accomplish the following:

- (a) Power all detection devices
- (b) Energize all electrically actuated chemical isolation systems
- (c) Energize visual and audible alarms
- (d) Transfer all auxiliary control and alarm contacts
- (e) Control system disabling interlock and process shutdown circuits

7-7.5.2 The power/control unit shall meet the applicable requirements of NFPA 72, *National Fire Alarm Code*, 1-5.2 and Chapter 3.

7-7.5.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (a) Wiring circuits for opens and other faults
- (b) AC power supply (primary)
- (c) Battery voltage, presence, and polarity
- (d) System safety interlock circuitry
- (e) Releasing outputs
- (f) Electrical extinguishing actuators
- (g) Detectors
- (h) Visual and audible alarms
- (i) System disabling interlock circuitry
- (j) Circuit ground fault

7-7.5.4 The supervisory signal circuits shall be provided with a visual and audible trouble signal. In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

7-7.5.5 The power and control unit shall meet applicable requirements of NFPA 70, *National Electrical Code*.

7-7.6 Electrical.

7-7.6.1 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

7-7.6.2 When a conduit is used for wiring multiple installations, the wiring for each chemical isolation system shall be run in separate conduits, or each system shall be permitted to be wired with shielded cables run in common conduits.

7-7.6.3 All wiring shall meet the applicable requirements of NFPA 70, *National Electrical Code*.

7-7.7 Installation of Chemical Isolation Systems.

7-7.7.1 All components of the system shall be mounted in the location and in the manner specified by the system designer.

7-7.7.2 Where necessary, measures shall be used to protect detectors and extinguisher components from accumulating foreign material that would prevent effective operation.

7-7.7.3 Terminals and mechanical parts shall be protected from moisture and other contaminants.

7-7.7.4 Mounting locations shall be chosen so as not to exceed maximum operating temperatures of system components.

7-7.8 Inspection and Maintenance of Chemical Isolation Systems.

7-7.8.1 Chemical isolation systems shall be inspected and maintained in accordance with the manufacturer's recommendations.

7-7.8.2 A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.

7-7.8.3 A written report shall be available for the last system inspection. The report shall include test and calibration data on all system components.

7-7.9 Procedures After System Trouble or Actuation. In the event of system actuation, inspection and testing, as specified in 7-7.8, shall be performed before the system is placed back into service.

7-8 Liquid Seals.

7-8.1* A liquid seal is a device for preventing the passage of flame by passing the gas through a liquid. The liquid seal device shall be designed for the gases being handled at the flow velocities range in the system and to withstand the maximum anticipated deflagration pressure. The liquid seals shall be designed in accordance with other recognized practices.

7-8.2* Means for providing and maintaining the liquid level shall be provided as well as an alarm to detect malfunction.

Chapter 8 Referenced Publications

8-1 The following documents or portions thereof are referenced within this standard as mandatory requirements and shall be considered part of the requirements of this standard. The edition indicated for each referenced mandatory document is the current edition as of the date of the NFPA issuance of this standard. Some of these mandatory documents might also be referenced in this standard for specific informational purposes and, therefore, are also listed in Appendix E.

8-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code*, 1996 edition.

NFPA 72, *National Fire Alarm Code*, 1996 edition.

NFPA 86, *Standard for Ovens and Furnaces*, 1995 edition.

NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*, 1995 edition.

NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*, 1995 edition.

NFPA 327, *Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers Without Entry*, 1993 edition.

NFPA 651, *Standard for the Manufacture of Aluminum Powder*, 1993 edition.

8-1.2 ASME Publications. American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

ASME *Boiler and Pressure Vessel Code*, 1995.

ASME B31.3, *Process Piping Code*, 1996.

8-1.3 Government Publications. U.S. Government Printing Office, Washington, DC 20401.

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

Title 33, *Code of Federal Regulations*, Part 154.

Title 46, *Code of Federal Regulations*, Part 30.

Title 46, *Code of Federal Regulations*, Part 32.

Title 46, *Code of Federal Regulations*, Part 35.

Title 46, *Code of Federal Regulations*, Part 39.

Appendix A Explanatory Material

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

A-1-1.2(b) For information on deflagration venting, see NFPA 68, *Guide for Venting of Deflagrations*.

A-1-1.2(h) For information on cutting and welding practices, see NFPA 51B, *Standard for Fire Prevention Practices for Cutting and Welding Practices*. For information on preparation of tanks, piping, or other enclosures for hot work, see NFPA 327, *Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers Without Entry*.

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. (Deflagration venting is not addressed in this standard; see NFPA 68, *Guide for Venting of Deflagrations*.)

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-1-8.1 Analyzers and other system instrumentation can require more frequent periodic inspection than that required for other components of the system. These inspections should be made according to manufacturer's recommendations or as required by operating conditions and inspection history.

A-1-9 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A-1-9 Authority Having Jurisdiction. 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, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A-1-9 Combustible Particulate Solid. A definition of this breadth is necessary because it is crucial to address the fact that there is attrition of the material as it is conveyed. Pieces and particles rub against each other and collide with the walls of the duct as they travel through the system. This breaks the material down and produces a mixture of pieces and much finer particles, called “dusts.” Consequently, we should expect every conveying system to produce dusts, regardless of the starting size of the material, as an inherent byproduct of the conveying process.

A-1-9 Flammable Limits. See NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*.

A-1-9 Limiting Oxidant Concentration (LOC). Materials other than oxygen can act as oxidants.

A-1-9 Listed. 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.

A-2-1.1 Operation of a system with an oxidant concentration low enough to prevent a deflagration does not mean that incipient fires are prevented. Smoldering can occur in fibrous materials or dust layers at very low oxidant concentrations, later to result in a fire or explosion when exposed to higher oxidant concentrations. Caution should be exercised when opening such systems to the air. (*See Appendix B for a discussion of the control of combustible gas mixtures. Also see Appendix C for limiting oxidant concentrations.*)

A-2-2.1 Purge gases generated by any of the acceptable methods described in this standard might not necessarily be compatible 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 might be higher. The user is cautioned, however, that some halogenated hydrocarbons, carbon dioxide, and even nitrogen at elevated temperatures might react violently with certain dusts. Also, these gases might 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 might 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, personnel should use self-contained breathing apparatus, preferably the positive-pressure type. Canister-type gas masks should not be used; they do not supply oxygen and do not offer any protection. The toxicity of certain purge gases should be recognized. The potential for accidental release of purge gases into normally occupied areas should be recognized and necessary precautions taken.

A-2-2.2.1 The values were obtained under the conditions specified in the appendix tables. Higher energy ignition sources, higher temperatures, or higher pressures can reduce the LOC values shown. LOC values for dusts of a particular chemical composition can also vary with variations of physical properties such as particle size, shape, and surface characteristics. A particular dust can have combustion properties different from one listed in a table. Tabular data for combustion characteristics are examples only.

A-2-3.2(d) The rate of application for steam inerting should be sufficient to maintain a steam concentration of at least 2.5 lb/min/100 ft³.

A-2-5.5 This requirement is intended 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 where such flow would present a hazard.

A-2-6 Methods of Application. Any of several methods might be used to ensure the formation and maintenance of a non-combustible 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 siphon, vacuum, pressure, and venting to atmosphere.

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

Siphon Purging. Equipment might 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, might 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 might 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 should 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 might 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

might 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 might 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 might 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 in Figure A-2-6(a).

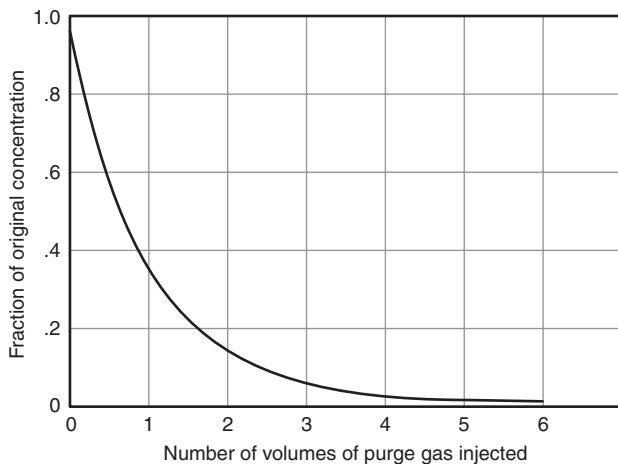


Figure A-2-6(a) Dilution ratio — purging at atmospheric pressure. (Complete mixing assumed.)

The following points should be noted:

- The total quantity required might be less than that for a series of steps of pressure purging.
- From four to five volumes of purge gas will suffice to almost completely displace the original mixture, assuming complete mixing.

Fixed-Rate Application. This method involves the continuous introduction of purge gas into the enclosure at a constant rate, which should be sufficient to supply the peak require-

ment in order that complete protection might be provided, and a corresponding release of purge gas and whatever gas, mist, or dust has been picked up in the equipment.

Factors to be noted about a fixed-rate application method include the following:

- Advantages are simplicity, lack of dependence on devices such as pressure regulators, and possible reduced maintenance.
- Disadvantages are as follows:
 - A continuous loss of product where the space contains a volatile liquid, due to constant “sweeping” of the vapor space by the purge gas
 - Increased total quantity of purge gas, because it is supplied whether needed or not
 - Possible disposal problems (toxic and other effects) for the mixture continuously released

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

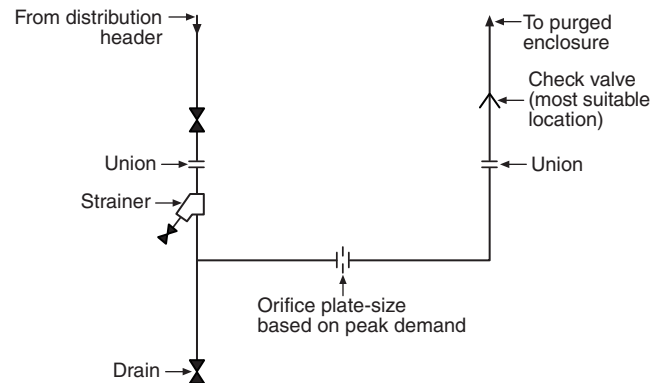


Figure A-2-6(b) Schematic sketch showing method of flow control that might be used with fixed-rate application.

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

Factors to be noted about the variable rate or demand application method include the following:

- Advantages are that purge gas is supplied only when actually needed and that it is possible, when desirable, to completely prevent influx of air.
- 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(c) shows a method of flow control that can be used with variable-rate application. Figure A-2-6(d) shows an alternate method that is applicable where the purge gas requirement during out-pumping is a large part of the peak demand.

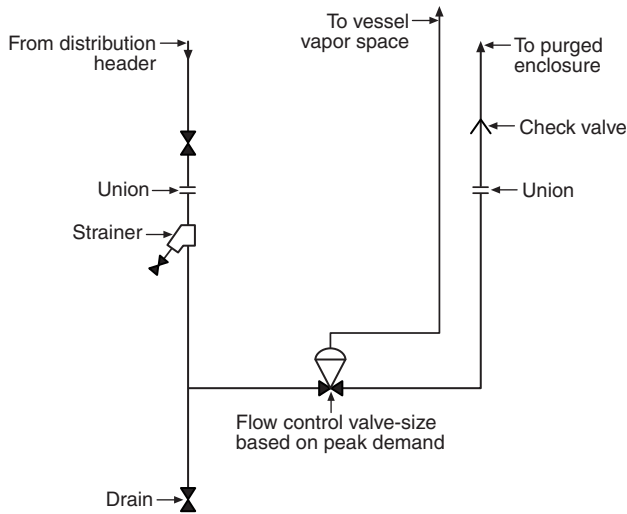


Figure A-2-6(c) Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(d).

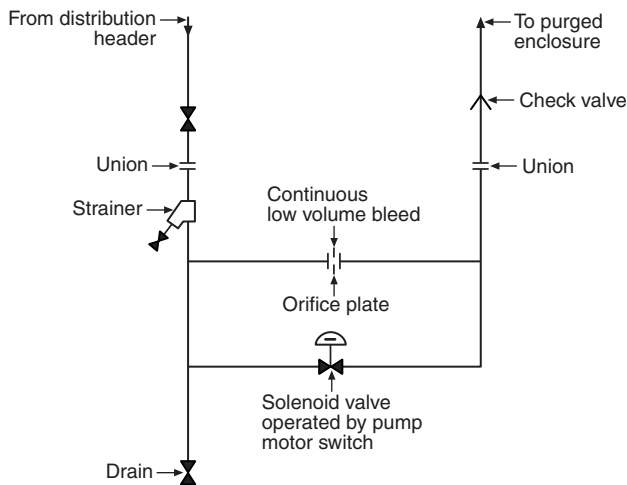


Figure A-2-6(d) Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(c).

Calculation of Peak Purge Gas Rates. Peak demand is described in Section 2-6 as the total expected system requirements.

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

- (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 could result in the following:

- (a) Impose excessive stresses on equipment or even collapse the vessel

- (b) Suck in air from joints that might not leak under internal pressure

- (c) Require high supply rates of inert gas

Each situation should be treated individually.

The peak supply rate should 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 might 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 ft³ (0.056 m³) of purge gas per hour for each square foot of total shell and roof area.

- (b) For smaller tanks, 1 ft³ (0.028 m³) 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 (38°C) per hour. (See *API Standard 2000, Venting Atmospheric and Low-Pressure Storage Tanks Nonrefrigerated and Refrigerated*, for further information.)

The rates for temperature change and liquid withdrawal should 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 might be dominated by leakage, and temperature change can be ignored.

A-2-7.1 The objective is to maintain operation outside of the flammable region. This can be achieved either by adding enrichment gas (natural gas or methane) or by adding an inert gas such as nitrogen. In either case, a safety factor should be maintained between the operating condition and the closest point of the flammable region. Instrumentation should have redundancy depending on the criticality of the operation.

A-2-7.2.1 As shown in Appendix B, any system of fuel plus oxidant plus inert gas requires a certain minimum concentration of oxidant for combustion. For oxidant concentrations less than the limiting oxidant concentration (LOC), no combination of fuel plus diluent will result in a flammable mixture.

A-2-7.2.4 Calculation of the LOC can result in an overestimate up to at least 2 volume percent oxygen relative to measured values, and this potential error should be taken into account when applying the safety margin.

A-2-7.2.6 Exception No. 1. Products having relatively high vapor pressures can by themselves maintain an atmosphere above the upper flammability limit of the vapor. Where flammable atmospheres are predicted, it is common practice to use a padding gas to maintain the oxygen content at less than the LOC. Since this typically involves almost complete replacement of air, oxygen analysis of the vapor space is not generally needed. It should be ensured that padding gas capacity will maintain padding under adverse conditions, such as simultaneous pump-out of several tanks connected to the same padding supply, possibly with a contraction of vapor volume caused by a sudden summer rainstorm. Such conditions might cause air to be drawn into a container to avoid underpressure damage. Also, some monomer tanks need several percent of oxygen to activate dissolved inhibitors. Such tanks might need oxygen monitoring.

A-2-7.3.1 The use of enrichment gas (methane or natural gas) serves three purposes: First, it elevates the total fuel concentration and can raise it to above the upper flammable limit (UFL); second, it decreases the oxidant concentration in proportion to the concentration of enrichment gas; and third, it elevates the LOC due to the better diluent qualities of enrichment gas relative to nitrogen in the air. Where header systems continuously convey vapors to a combustion device such as a flare, operation above the UFL can greatly reduce the quantity of enrichment gas relative to operation below the LOC.

Non-marine vent collection headers operated near atmospheric pressure and not containing any vapor with a UFL greater than 75 percent in air, nor oxygen in concentrations greater than can be derived from ambient air, can be rendered nonflammable by the addition of 25 volume percent or more of natural gas or methane. The use of oxygen analyzers to control enrichment gas flow is only practical in cases where the nitrogen-to-oxygen ratio is the same as in the air. Where a container has been partly inerted with a diluent such as nitrogen, enrichment gas should be added using flow control since control via oxygen analyzers would otherwise add insufficient enrichment gas to provide nonflammability. The flow control system can be augmented with gas analyzers to verify correct operation during installation and for periodic performance checks.

Where system temperatures and pressures significantly exceed atmospheric conditions or where gases with UFL above 75 percent in air are involved, or where oxygen enrichment might occur, no specific recommendations can be given, and testing is necessary to develop an enrichment method. The UFL generally increases with increased temperature and pressure; it can be sensitive to the precise gas composition and test conditions. Special procedures are needed for decomposable gases; these can involve inerting, enrichment, or deflagration isolation systems as described in Chapter 7.

A-3-1 See Appendix B for a discussion of the control of flammable gas mixtures. Also, see Appendix D for information on calculating the time required for ventilation.

A-3-2.2 See NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*.

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-4-3.1 Experience has shown that performing maintenance operations without disarming a suppression system could result in inadvertent discharge of the suppression system.

A-4-8 Halogenated hydrocarbons, such as bromochloromethane, or dry chemical agents might 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 might also be used as a suppressant if it can be demonstrated to be effective. If ambient temperatures below 0°C (32°F) are expected, freeze protection should be provided.

A-4-11.1 Ease of inspection should be taken into account when designing systems.

A-4-11.2 The quantity of agents in containers can be checked by weighing or by using a reliable level measuring device.

A-5-1.5 Pressure piling and flame jet ignition can significantly increase deflagration pressures in attached equipment. Techniques such as isolation or venting should be considered.

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 might 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 might do so in pipework. Internals in equipment can promote the transition from deflagration to detonation.

A-5-2.2 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 might be substantially greater than would normally happen in a single vessel. (See *W. Bartknecht, Explosions: Course, Prevention, Protection, pp. 18-23.*)

A-5-2.3 Only limited information is available for deflagration containment of systems with initial pressures exceeding 30 psig (206.7 kPa gauge). Increased initial pressure might increase the potential for detonation. For this reason it is recommended that, for systems that might operate at an initial pressure of 30 psig (206.7 kPa gauge) or higher, deflagration pressure containment be used only where applicable test data are available. The testing should be carefully designed because the detonation potential of a system is affected by vessel dimensions.

A-5-3.3 For vessels fabricated of low carbon steel and low alloy stainless steel, $F_u = 4.0$ and $F_v = 2.0$, approximately. The formulas are based on a paper by Noronha et al.

A-5-3.3.1 The maximum deflagration pressures for several dusts can be found in Appendix D of NFPA 68, *Guide for Venting of Deflagrations*.

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) might raise the concentration of fuel in the vapor phase above its upper flammable limit and would not constitute a deflagration hazard.

A-6-2.3 The effectiveness of spark detection and extinguishing systems are limited by detection of radiant energy emitted from sparks or embers in the material being conveyed, and the ability to deliver extinguishment medium (usually water) in a timely manner. For pneumatic conveying systems, detection of sparks or embers is a function of pipe diameter, material-to-air ratio, conveying velocity, material density and particle size distribution, and the radiant energy absorption characteristic of the material. Manufacturers should be consulted for the applicability of spark detection and extinguishing systems for specific applications. In some cases, testing could be required.

A-6-3.1 For information on detectors, see Section 5-4 of NFPA 72, *National Fire Alarm Code*.

A-7-1.1 It is frequently impossible to design and operate equipment without interconnecting pipes or ducts. Uses of pipes or ducts include conveying, transferring, and ventilating. Where the pipes or ducts contain flammable or combustible materials plus an oxidant, ignition can result in communication of combustion between the interconnected equipment. This can sometimes increase the violence of the deflagration resulting in pressure piling and accelerated rates of pressure rise in the interconnected equipment from flame-jet ignition. Pressure piling can increase P_{max} , thus increasing the demands of deflagration pressure containment; and flame-jet ignition can increase deflagration venting requirements. (See NFPA 68, *Guide for Venting of Deflagrations*.) In extreme cases, the accelerating effect of turbulent combustion through pipes or ducts plus any increased effects from pressure piling can result in detonations.

A-7-2.3 See Table A-7-2.3.

Table A-7-2.3 Isolation Features of Pipe and Duct Protection Systems

System	Deflagration Isolation	Ignition Source Isolation	Flow Isolation
Rotary valves	Yes	Note	Yes
Flame arresters	Yes	Yes	No
Automatic fast-acting valves	Yes	Yes	Yes
Flame front diverters	No	No	Yes
Flame front extinguishing systems	Yes	Yes	No
Liquid seals	Yes	Yes	No

Note: Rotary valves are capable of preventing flame front passage under certain conditions, but will not always prevent the passage of burning embers.

A-7-3 The acceptance of a rotary valve for use as a deflagration isolation device should consider the minimum ignition energy and the ignition temperature of the dust. Additionally, the width and the length of the gap should be related to these factors. Information about the testing techniques and the relationship of the factors is found in a paper by G. Schuber, "Rotary Valves for Explosion Isolation."

The passage of a flame front through the rotary valve is not the only mechanism by which ignition can occur downstream of a rotary valve. The passage of smoldering embers through the valve might be a source of ignition on the downstream side of the valve.

A-7-3.4 The use of plastics, elastomers, or other synthetic material either for the full vane or as wear strips might allow the flame front to pass through the valve. This might be because of a lack of mass and low specific heat that is not sufficient to cool the flame during its passage.

A-7-4 Flame arresters are manufactured in several mechanical configurations, which include, but are not limited to, the following:

- Banks of closely spaced parallel plates
- Banks of small diameter tubes
- Wire screens
- Elements consisting of alternating flat and crimped plates that are spirally wound together to produce the equivalent of small diameter tubes
- Porous or sintered metal elements

A-7-4.1 The ignition source might be outside the protected system as in the case of a flame arrester on a tank vent. Alternatively, the ignition source might be within the system as in the case of a flame arrester installed in a pipe that connects two or more tank vents.

A-7-4.4 Flame arresters are reliable only where installed within the parameters for which they have been tested. These conditions include the following:

- The fuel mixture used in the test should be the same as, or have flame propagation characteristics similar to, those encountered in the application.
- The length of pipe between the arrester and the likely ignition source should be less than or equal to the maximum length for which it was successfully tested.
- The smallest and largest size of a particular type of arrester should be tested.
- The arrester should be tested in the same configuration in which it will be installed, including the arresting element, the case where it is contained, the hardware for mounting the element in its case, any gaskets or seals required, the flange or other connector used to attach the arrester to the system, and materials of construction.
- The maximum temperature and pressure likely to exist at the arrester at the moment of ignition should be used.
- Where appropriate for the specific application, testing with ignition both upstream and downstream (relative to the gas flow direction) should be done.
- The device should be tested over the range of flow velocities that could be encountered.
- If continuous burning can occur at the arrester, the test procedure should include a continuous burn test.

A-7-4.5 The functionality of a flame arrester can be destroyed if it is heated to an excessively high temperature by the combustion gases reaching it or by exposure to an external source of heat such as a flame.

The functionality-limiting temperature is dependent upon the design, mass, and material of construction of the flame arrester and is unique to the design. It should be determined by test and should be below the autoignition temperature.

A-7-4.6 If the arrester is used in a service where freezing or plugging might occur, some means of detecting the onset of plugging, such as a differential pressure switch, should be provided.

A-7-5 See Figure A-7-5.

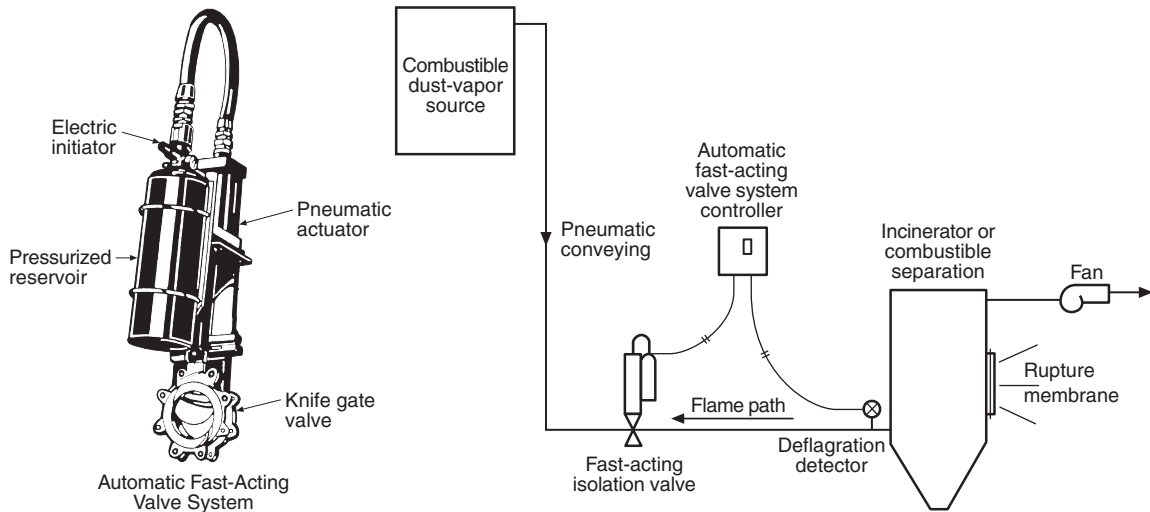


Figure A-7-5 Typical application and design of fast-acting, automatic closing valve assembly.

A-7-5.4 Fast-acting valve systems are reliable only when designed and installed within the parameters for which they have been tested. These parameters include, but are not limited to, the following:

- (a) The flame propagation characteristics used in the placement design should be representative of the fuel mixture giving the highest flame speed and the maximum conveying velocities to be encountered in the application.
- (b) The response time of the fast-acting valve system shall be established by testing. This response time will be used in

the placement design to calculate the required length of pipe between the fast-acting valve and the detector.

A-7-5.9.2 Detectors that respond to radiant energy might be used provided that the application environment will not inhibit their proper operation. Airborne dust particles, dust coating of the detector viewing window, certain gases, and the distance to the ignition source might inhibit sufficiently rapid response to the hazard.

A-7-6 See Figure A-7-6.

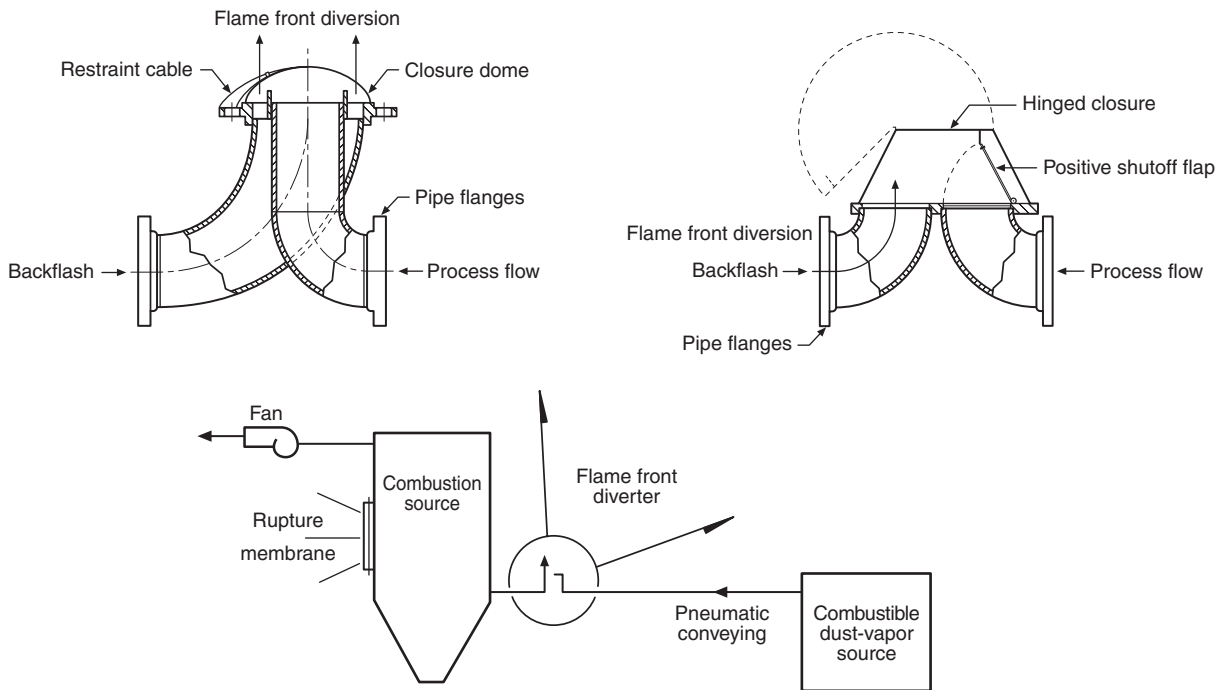


Figure A-7-6 Typical application and design of flame front diverters.

A-7-6.9 The testing of flame front diverters should include, but not be limited to, the following items:

(a) The test fuel mixture should be the same as, or have flame propagation characteristics similar to, those encountered.

(b) The length of pipe between the installed flame front diverter and the ignition source should be less than or equal to the maximum length for which the diverter was tested.

(c) Ignition source location (upstream, downstream, or both locations) should be tested in the same configuration as the protection application.

(d) For upstream ignition, the diverter should be tested over the range of flow velocities that could be encountered at the time of ignition or that might develop as a result of ignition.

(e) Installation and maintenance:

1. Flame front diverters should be installed and maintained according to manufacturer's instructions.

2. Flame front diverters should be inspected periodically, based on facility experience, and after each operation. Inspection should determine whether any damage that could affect the performance of the device has occurred. Damaged components should be repaired or replaced.

A-7-8.1 For most systems, API Recommended Practice 521, *Guide for Pressure-Relieving and Depressuring Systems*, should be used when designing liquid seals. For systems where the oxidant/flammable gas might approach a stoichiometric mixture, tests should be performed to determine the design of liquid seals.

A-7-8.2 Where the inlet gas is a combustible mixture, additional precautions should be taken to prevent overheating of inlet piping within the liquid seal device by a continuous fire in the seal enclosure.

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

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

B-1 General. As covered in Chapters 2 and 3, a flammable gas/oxidant mixture might 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.

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 ignitable 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.

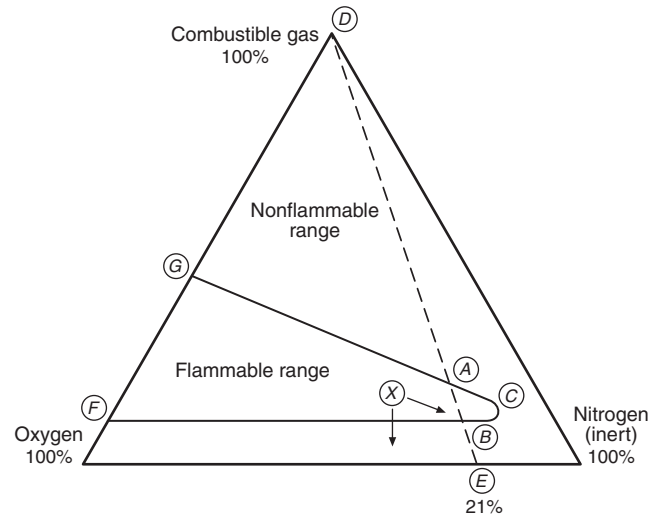


Figure B-1 Typical flammability diagram.

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 limiting oxidant 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 limiting oxidant 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.

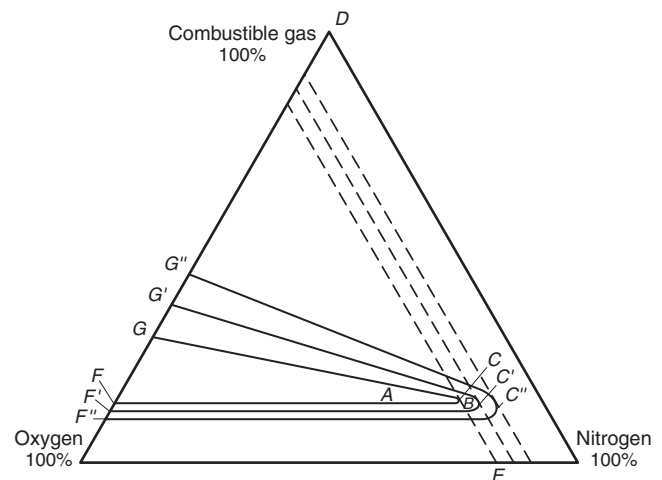


Figure B-2 Effect of pressure on flammability diagram.

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, should 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 limiting oxidant concentration. Figure B-3 illustrates the effect of some typical diluents on the flammability limits of methane. This figure shows that nitrogen is more effective than helium and carbon dioxide is more effective than nitrogen.

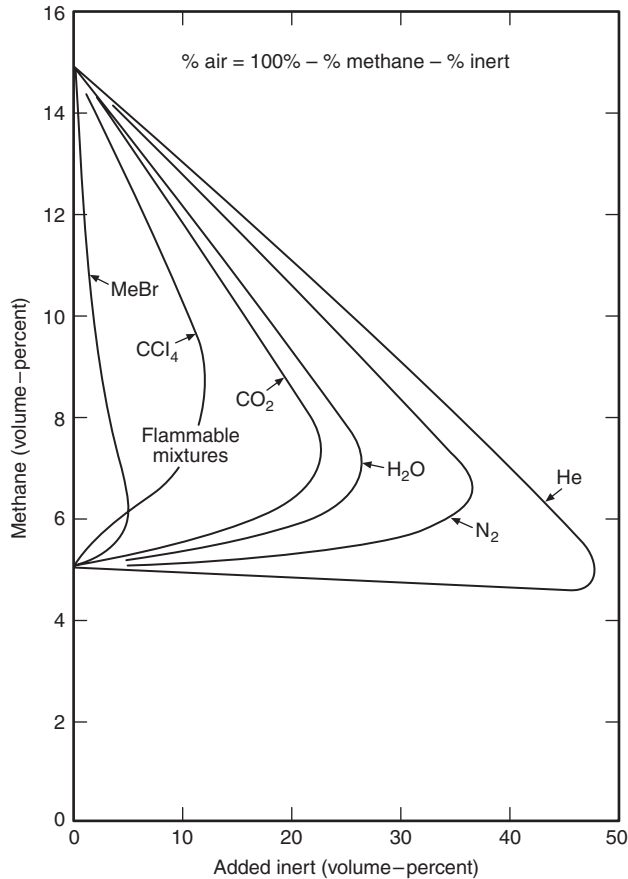


Figure B-3 Limits of flammability of methane-inert gas-air mixtures at 25°C (77°F) and atmospheric pressure. See H. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors."

B-4 Oxidant Concentration Reduction. Referring back to the flammability diagram in Figure B-1, the point X represents some arbitrary mixture of flammable 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 toward 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 might be altered by reducing the concentration of flammable gas. In simpler terms, point X moves away from

the flammable gas apex and eventually drops below the lower flammability line *FBC*.

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

$$LFL = \frac{P_1 + P_2 + \dots + P_n}{\frac{P_1}{LFL_1} + \frac{P_2}{LFL_2} + \dots + \frac{P_n}{LFL_n}} \quad (4)$$

$$UFL = \frac{P_1 + P_2 + \dots + P_n}{\frac{P_1}{UFL_1} + \frac{P_2}{UFL_2} + \dots + \frac{P_n}{UFL_n}} \quad (5)$$

where:

$P_1 \dots P_n$ = the volume fractions of components 1,2,3,..., n of the mixture

$LFL_1 \dots LFL_n$ = the lower flammable limits of components 1,2,3,..., n of the mixture

$UFL_1 \dots UFL_n$ = the upper flammable limits of components 1,2,3,..., n of the mixture

Appendix C Limiting Oxidant Concentrations

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

Table C-1 Limiting Oxidant Concentrations for Flammable Gases When Using Nitrogen or Carbon Dioxide as Diluents

Gas or Vapor	Limiting Oxidant Concentration	Limiting Oxidant Concentration	Reference
	N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	CO ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	
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

Table C-1 Limiting Oxidant Concentrations for Flammable Gases When Using Nitrogen or Carbon Dioxide as Diluents (continued)

Gas or Vapor	Limiting Oxidant Concentration	Limiting Oxidant Concentration	Reference
	N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	CO ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	
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
1,1, 1-trichloroethane	14	—	3
Trichloroethylene	9 (100°C)	—	3
Acetone	11.5	14	4
n-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
Propylene oxide	7.8	—	8
Methyl ether	10.5	13	4
Methyl formate	10	12.5	4
Methyl ethyl ketone	11	13.5	4
UDMH (dimethylhydrazine)	7	—	6
Vinyl chloride	13.4	—	7
Vinylidene chloride	15	—	7

NOTE 1: See 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 for Table C-1.

1. H. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors," Bulletin 503, U.S. Bureau of Mines, 1952, 155 pp.
2. G. W. Jones, 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, Wright-Patterson AFB, OH, Technical Report 52-35, Supplement I, 1954, 57 pp.
3. J. M. Kuchta, 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," *Journal of Chemical and Engineering Data*, Vol. 13, No. 3, July 1968, p. 421.
4. M. G. Zabetakis, "Flammability Characteristics of Combustible Gases and Vapors," Bulletin 627, U.S. Bureau of Mines, 1965, 121 pp.
5. M. G. Zabetakis and B. H. Rosen, "Considerations Involved in Handling Kerosine," *Proceedings API*, Vol. 37, Sec. III, 1957, p. 296.
6. Unpublished data, U.S. Bureau of Mines.
7. Unpublished data, Dow Chemical Co.
8. U.S. Bureau of Mines.

Table C-2 Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen or Carbon Dioxide as Diluents

Dust	Limiting Oxidant Concentration	Limiting Oxidant Concentration
	N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	CO ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)
	Agricultural	
Coffee		17
Cornstarch		11
Dextrin	11	14
Soy Flour		15
Starch		12
Sucrose	10	14
	Chemical	
Ethylene Diamine Tetra-Acetic Acid		13
Isatoic Anhydride		13
Methionine		15
Ortazol		19
Phenothiazine		17
Phosphorous Pentasulfide		12
Salicylic Acid	15	17
Sodium Lignosulfate		17
Stearic Acid & Metal Stearates	10.6	13
	Carbonaceous	
Charcoal		17
Coal, Bituminous		17
Coal, Sub-bituminous		15
Lignite		15
	Metal	
Aluminum	5*	2
Antimony		16
Chromium		14
Iron		10
Magnesium	0	0
Manganese		14

Table C-2 Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen or Carbon Dioxide as Diluents (continued)

Dust	Limiting Oxidant Concentration	Limiting Oxidant Concentration
	N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	CO ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)
Silicon	11	12
Thorium	2	0
Titanium	4	0
Uranium	1	0
Vanadium		14
Zinc	9	10
Zirconium	0	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	13	14
Isophthalic Acid		14
Paraformaldehyde	8	12
Pentaerythritol	13	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	13	14
Plastics — Thermoplastic Resins		
Acetal		11
Acrylonitrile		13
Butadiene-Styrene		13
Carboxymethyl Cellulose		16
Cellulose Acetate	9	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

Table C-2 Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen or Carbon Dioxide as Diluents (continued)

Dust	Limiting Oxidant Concentration	Limiting Oxidant Concentration
	N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)	CO ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)
Dimethyl Isophthalate		13
Dimethyl Terephthalate		12
Epoxy		12
Melamine Formaldehyde		15
Polyethylene Terephthalate		13
Urea Formaldehyde		16

*Determined by test; see R. K. Eckhoff, *Dust Explosions in the Process Industries*, p. 586. Also see NFPA 651, *Standard for the Manufacture of Aluminum Powder*, which addresses the passivation of freshly produced aluminum surfaces in the presence of low concentrations of oxygen. 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 and no data are listed in the table, the following equation should be used to calculate the oxygen value for carbonaceous dusts:

$$O_n = 1.3(O_c - 6.3)$$

where

O_n = the limiting oxygen concentration for dilution by nitrogen (N)

O_c = the limiting oxygen concentration for dilution by carbon dioxide (CO₂)

NOTE 3: See 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 6549, 6561, and 6811.

NOTE 5: The values in this table can differ from those in Table C-3 because of differences in test methods and dust characteristics, such as particle size, and other factors.

Table C-3 Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen as a Diluent

Dust	Median Particle Diameter by Mass (μm)	Limiting Oxidant Concentration
		N ₂ /Air (Volume % O ₂ Above Which Deflagration Can Take Place)
Cellulosic Materials		
Cellulose	22	9
Cellulose	51	11
Wood flour	27	10
Food and Feed		
Pea flour	25	15
Corn starch	17	9
Waste from malted barley	25	11
Rye flour	29	13
Starch derivative	24	14
Wheat flour	60	11

Table C-3 Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen as a Diluent (continued)

Dust	Median Particle Diameter by Mass (μm)	Limiting Oxidant Concentration N_2/Air (Volume % O_2 Above Which Deflagration Can Take Place)
Coals		
Brown coal	42	12
Brown coal	63	12
Brown coal	66	12
Brown coal briquette dust	51	15
Bituminous coal	17	14
Plastics, Resins, Rubber		
Resin	<63	10
Rubber powder	95	11
Polyacrylonitrile	26	10
Polyethylene, h.p.	26	10
Pharmaceuticals, Pesticides		
Aminophenazone	<10	9
Methionine	<10	12
Intermediate Products, Additives		
Barium stearate	<63	13
Benzoyl peroxide	59	10
Bisphenol A	34	9
Cadmium laurate	<63	14
Cadmium stearate	<63	12
Calcium stearate	<63	12
Methyl cellulose	70	10
Dimethyl terephthalate	27	9
Ferrocene	95	7
Bis(trimethylsilyl)urea	65	9
Naphthalic acid anhydride	16	12
2-Naphthol	<30	9
Paraformaldehyde	23	6
Pentaerythritol	<10	11
Metals, Alloys		
Aluminum	22	5
Calcium/aluminum alloy	22	6
Ferrosilicon magnesium alloy	17	7
Ferrosilicon alloy	21	12
Magnesium alloy	21	3
Other Inorganic Products		
Soot	<10	12
Soot	13	12
Soot	16	12
Others		
Bentonite derivative	43	12

See R. K. Eckhoff, *Dust Explosions in the Process Industries*, 1991.

NOTE: The data came from 1-m³ and 20-L chambers using strong chemical igniters.

Table C-4 Inerting of Dust Clouds by Mixing the Combustible Dust with Inert Dust

Dust	Combustible Dust Median Particle Size by Mass (μm)	Inert Dust		
		Type of Dust	Median Particle Size by Mass (μm)	Minimum Mass % Inert of Total Mass Required for Inerting
Methyl cellulose	70	CaSO_4	<15	70
Organic pigment	<10	$\text{NH}_4\text{H}_2\text{PO}_4$	29	65
Bituminous coal	20		14	65
Bituminous coal	20	NaHCO_3	35	65
Sugar	30	NaHCO_3	35	50

See R. K. Eckhoff, *Dust Explosions in the Process Industries*, 1991.

NOTE: Data were obtained from tests conducted in 1 m³ Standard ISO (1985) vessel with a 10-kJ chemical igniter.

Appendix D Ventilation Calculations

D-1 Time Required for Ventilation. An estimate of the time required to reduce the concentration of a flammable 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

$$(V) dC = Q (C) dt \quad (7)$$

By rearranging

$$\int_{C_0}^C \frac{dC}{C} = \frac{Q}{V} \int dt \quad (8)$$

where:

C_0 = initial concentration of gas

t = time required to reach the desired concentration

Integrating (8) yields

$$\ln \left(\frac{C}{C_0} \right) = \left(\frac{-Q}{V} \right) t \quad (9)$$

Equation (9) assumes perfect mixing. Since this is not the case in actual practice, a correction factor, K , should be introduced:

$$\ln \left(\frac{C}{C_0} \right) = \left(\frac{-Q}{V} \right) K(t) \quad (10)$$

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

Method of Supplying	Efficiency (K) Values	
	Single Exhaust Opening	Multiple Exhaust Openings
<i>—No Positive Supply</i>		
Infiltration through cracks,	0.2	0.3
open doors, or windows	0.2	0.4
<i>—Forced Air Supply</i>		
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 ft³ (28 m³), by means of a 2000 ft³/min (56 m³/min) ventilation rate, from 20 volume percent to the following:

- The upper flammable limit, or 7.6 percent
- The lower flammable limit, or 1.4 percent
- 25 percent of lower flammable limit, or 0.35 percent

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

Using Equation (9),

(a)

$$\ln\left(\frac{7.6}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (11)$$

$$\ln 0.38 = -2K(t) \quad (12)$$

$$t = \frac{\ln 0.38}{-2K} = \frac{-0.97}{-2K} \quad (13)$$

$$t = \frac{0.485}{K} \quad (14)$$

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

(b)

$$\ln\left(\frac{1.4}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (15)$$

$$\ln 0.07 = -2K(t) \quad (16)$$

$$t = \frac{\ln 0.07}{-2K} = \frac{-2.66}{-2K} \quad (17)$$

$$t = \frac{1.33}{K} \quad (18)$$

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

(c)

$$\ln\left(\frac{0.35}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (19)$$

$$\ln 0.018 = -2K(t) \quad (20)$$

$$t = \frac{\ln 0.018}{-2K} = \frac{-4.02}{-2K} \quad (21)$$

$$t = \frac{2.01}{K} \quad (22)$$

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 in Section D-1 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:

$$\frac{C}{C_0} = e^{-KN} \quad (23)$$

where:

N = the required number of air changes

Equation (23) can be rewritten:

$$\ln\left(\frac{C}{C_0}\right) = -KN \quad (24)$$

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

$$\ln\left(\frac{7.6}{20.0}\right) = -0.2N \quad (25)$$

$$N = \frac{\ln 0.38}{-0.2} = \frac{-0.97}{-0.2} = 4.8 \quad (26)$$

Since the airflow rate is 2000 ft³/min (56 m³/min) and the volume of the enclosure is 1000 ft³ (28 m³), it turns out that a complete air change takes 1/2 min. Equation (26) indicates that 4.8 air changes are needed. This translates to a required time of 2.4 min, or exactly what was calculated in D-1.

D-3 Buildup of Combustible Concentration in Enclosed Area. If a constant source of a flammable gas, such as a leak, is introduced into an enclosed volume, Equation (24) should be modified as follows:

$$C = \frac{G}{Q}(1 - e^{-KN}) \tag{27}$$

where:

- C = concentration
- G = combustible (ft³/min)
- Q = air (ft³/min)
- K = mixing efficiency factor
- N = number of theoretical air changes

As an example, consider a leak of 100 ft³/min (2.8 m³/min) of a 15 percent flammable gas/air mixture in a room of 1000 ft³ (28 m³). 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,

$$C = 0.05$$

$$G = 15 \text{ ft}^3/\text{min} \quad (100 \times 0.15)$$

$$Q = 85 \text{ ft}^3/\text{min} \quad (100 - 15)$$

$$K = 0.2$$

Equation (27) can be rewritten into a more convenient logarithmic form:

$$\ln \left[1 - \frac{CQ}{G} \right] = -KN \tag{28}$$

$$\ln \left[1 - \frac{0.05(85)}{15} \right] = -0.2N \tag{29}$$

$$\ln (0.71667) = -0.2N \tag{30}$$

$$-0.33314 = -0.2N \tag{31}$$

$$1.67 = N \tag{32}$$

Since the volume is 1000 ft³ and the leak is at 100 ft³/min,

$$\left(\frac{1000 \text{ ft}^3}{100 \text{ ft}^3/\text{min}} \right) (1.67) = 16.7 \text{ min} \tag{33}$$

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

Equations (24) and (27) can be plotted as shown in Figures D-2(a) and (b).

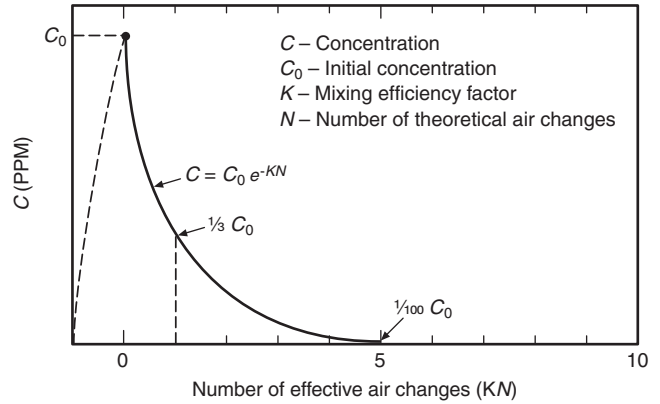


Figure D-2(a) Combustible decay curve. General ventilation: instantaneous release.

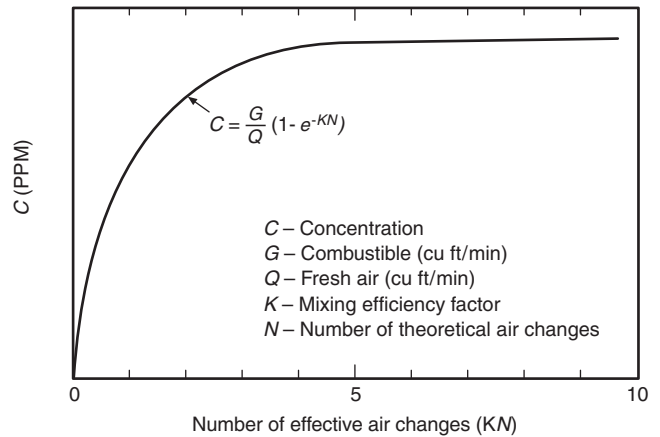


Figure D-2(b) Combustible buildup curve. General ventilation: continuous release.

With respect to Figure D-2(b), which illustrates a continuous release in an enclosed volume, once a continuous release begins, the combustible concentration increases rapidly until three air changes occur. After three air changes, the bracketed term in Equation (27) 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 in the following situations:

- (a) The operator or ignition sources might be very close to the point of flammable release.
- (b) The flammable escape rate is uncertain.
- (c) Local ventilation is used to control combustible dusts.

Local exhaust ventilation captures the combustible at its source, and a properly designed system will achieve 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 are thus not considered part of the requirements of this standard unless also listed in Chapter 8. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this standard.

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

NFPA 51B, *Standard for Fire Prevention in Use of Cutting and Welding Processes*, 1994 edition.

NFPA 68, *Guide for Venting of Deflagrations*, 1994 edition.

NFPA 72, *National Fire Alarm Code*, 1996 edition.

NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1994 edition.

NFPA 327, *Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers Without Entry*, 1993 edition.

NFPA 651, *Standard for the Manufacture of Aluminum Powder*, 1993 edition.

E-1.2 Other Publications.

E-1.2.1 Bureau of Mines Publications. The following publications are available from the U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center, 4800 Forbes Avenue, Pittsburgh, PA 15213.

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

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

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

E-1.2.2 API Publications. The following publications are available from the American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

API RP 521, *Guide for Pressure-Relieving and Depressuring Systems*, Third Edition, 1990.

API STD 2000, *Venting Atmospheric and Low-Pressure Storage Tanks Nonrefrigerated and Refrigerated*, Fourth Edition, 1992.

E-2 Bibliography. This part of the appendix lists other publications that are pertinent to the subject of this NFPA document and that might or might not be referenced.

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

Brenn- und Explosions-Kenngrößen von Stauben, Berufsgenossenschaftliches Institut für Arbeitssicherheit (BIA) Bergbau-Versuchsstrecke, Institut für Explosionsschutz und Sprengtechnik, Sonderdruck der sicherheitstechnischen.

Coward, J. F. and G. W. Jones, "Limits of Flammability of Gases and Vapors," Bulletin 503, U.S. Bureau of Mines, Pittsburgh, PA, 1952.

Eckhoff, R. K., *Dust Explosions in the Process Industries*, Butterworth-Heinemann, Oxford, England, 1991.

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, Wright-Patterson AFB, OH, Technical Report 52-35, Supplement I, 1954, 57 pp.

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," *Journal Chemical and Engineering Data*, Vol. 13, No. 3, July 1968, (American Chemical Society, Washington, D.C.) p. 421.

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

Schuber, G., "Rotary Valves for Explosion Isolation: Approval Without Testing," European Information Centre for Explosion Protection—International Symposium, Antwerp, Belgium, September, 1989.

VDI Richtlinie 3673, Verein Deutscher Ingenieure-Kommission Reinhaltung der Luft, Düsseldorf, VDI Verlag GmbH, Düsseldorf, 1979 and 1983.

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, Pittsburgh, PA, 1961.

Zabetakis, M. G., and B. H. Rosen, "Considerations Involved in Handling Kerosine," *Proceedings*, API, Vol. 37, Sec. III, 1957, p. 296.

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