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Standards for

INERTING for FIRE and EXPLOSION PREVENTION

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NATIONAL FIRE PROTECTION ASSOCIATION
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National Fire Protection Association

INTERNATIONAL

Executive Office: 60 Batterymarch St., Boston 10, Mass.

The National Fire Protection Association was organized in 1896 to promote the science and improve the methods of fire protection and prevention, to obtain and circulate information on these subjects and to secure the cooperation of its members in establishing proper safeguards against loss of life and property by fire. Its membership includes nearly two hundred national and regional societies and associations (list on outside back cover) and more than sixteen thousand individuals, corporations and organizations. Anyone interested may become a member; membership information is available on request.

This pamphlet is one of a large number of publications on fire safety issued by the Association including periodicals, books, posters and other publications; a complete list is available without charge on request. All NFPA standards adopted by the Association are published in six volumes of the **National Fire Codes** which are re-issued annually and which are available on an annual subscription basis. The standards, prepared by the technical committees of the National Fire Protection Association and adopted in the annual meetings of the Association, are intended to prescribe reasonable measures for minimizing losses of life and property by fire. All interests concerned have opportunity through the Association to participate in the development of the standards and to secure impartial consideration of matters affecting them.

NFPA standards are purely advisory as far as the Association is concerned, but are widely used by law enforcing authorities in addition to their general use as guides to fire safety.

Definitions

The official NFPA definitions of shall, should and approved are:

SHALL is intended to indicate requirements.

SHOULD is intended to indicate recommendations, or that which is advised but not required.

APPROVED refers to approval by the authority having jurisdiction.

Units of measurements used here are U. S. standard. 1 U. S. gallon = 0.83 Imperial gallons = 3.785 liters.

Approved Equipment

The National Fire Protection Association does not "approve" individual items of fire protection equipment, materials or services. The standards are prepared, as far as practicable, in terms of required performance, avoiding specifications of materials, devices or methods so phrased as to preclude obtaining the desired results by other means. The suitability of devices and materials for installation under these standards is indicated by the listings of nationally recognized testing laboratories, whose findings are customarily used as a guide to approval by agencies applying these standards. Underwriters' Laboratories, Inc., Underwriters' Laboratories of Canada and the Factory Mutual Laboratories test devices and materials for use in accordance with the appropriate standards, and publish lists which are available on request.

Inerting for Fire and Explosion Prevention.

(NFPA No. 69—1956)

During 1953 a new NFPA Committee was appointed to develop Standards for Fire and Explosion Prevention by Inerting. The original draft was tentatively adopted in 1955 and finally adopted at the NFPA Annual Meeting in Boston, Mass., June 6, 1956.

The present standard incorporates and considerably extends the coverage of the 1941 "Standards for Inert Gas for Fire and Explosion Prevention", former NFPA 12A, which was initiated jointly by the NFPA Committees on Dust Explosion Hazards and on Manufacturing Hazards in 1930 and 1931 and adopted in 1931, with minor amendments in 1938 and 1941.

Committee on Inerting for Fire and Explosion Prevention.

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FOREWORD

Certain processing, material handling and storage facilities that contain hazardous materials may be protected against fire and explosion by inerting. This fire prevention procedure rerequires the exclusion of oxygen from enclosures or reduction of oxygen content to the point where combustion cannot occur. The hazard of ignition sources can be minimized if enclosures are inerted.

There are many types of equipment and machinery that can be protected by inerting systems. Such factors as the physical properties of the flammable materials, size and shape of equipment, the required amount and purity of inerting media, the reliability of supply of inerting media, operational controls, and maintenance requirements must be given careful consideration for each specific installation. General specifications are included herein. Details of each installation will necessarily vary according to the local conditions and the hazard involved. Authorities having jurisdiction should be consulted as to the application of these standards. It should be emphasized that inerting protection may not afford the desired degree of overall protection without supplementation. Reference should be made to other NFPA fire protection standards.

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INTRODUCTION

1. **Purpose.** These standards outline the minimum requirements for the installation of inerting systems and application of inerting media for the prevention of fires and explosions in enclosures where flammable gases, vapors, dusts, or certain combustible solids may be confined. Basic information is included for the guidance of design engineers, authorities having jurisdiction and others concerned with this type of protection.

2. **Scope.** These standards are limited to the design, construction, operation, maintenance and testing of inerting systems for fire and explosion prevention.

These Standards Do Not Cover the Preparation of Tanks, Piping or Other Enclosures for Hot Work or Entry.

The use of an inert gas for fire extinguishment is not included in this standard. For use of carbon dioxide to extinguish fires see Standards for Carbon Dioxide Extinguishing Systems (NFPA No. 12).*

NOTE: The following procedures are not covered under the provisions of this standard:

a. The use of flammable gases to render an atmosphere safe by reduction of the oxygen content. The atmosphere is not to be considered as inerted within the meaning of this standard.

b. The use of solids for inerting (rock dusting coal mines). This procedure is governed by the Federal Mine Safety Code. (See Appendix A-2.)

3. **Definitions.** The dictionary and technical definitions of the terms "inerting" and "inert gas" are not descriptive of the usage required for this standard. The following specific definitions shall apply to the terms as hereafter used:

a. INERTING as it pertains to fire and explosion prevention is the use of an inert gas to reduce the oxygen content in an enclosure to a point at which combustion cannot occur.

b. INERT GAS as it pertains to fire and explosion prevention is any gas which is nonflammable, chemically inactive and noncontaminating for the use intended, and oxygen-deficient to the extent required.

c. INERT ATMOSPHERE as it pertains to fire and explosion prevention is an atmosphere in which combustion cannot occur.

d. PURGING (as used in this standard) is the process of displacing substantially all flammable materials from an enclosure with inert gas. Residues require special consideration.

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*See Appendix B, page 69-45, for availability.

e. VENTILATION (as used in this standard) is the process of replacing a purging medium with air and maintaining an atmosphere in the enclosure that will permit human occupancy.

f. SHALL is intended to indicate requirement.

g. SHOULD is intended to indicate recommendations, or that which is advised but not required.

h. APPROVED refers to approval by the authority having jurisdiction.

i. The terms "psia" and "psig" as used in this standard refer to pounds per square inch absolute and pounds per square inch gauge respectively.

j. STANDARD CUBIC FEET designates the volume in cubic feet at standard temperature and pressure, i.e., at 68° F. and 14.7 psia.

4. **Characteristics of Flammables.** The principal characteristics of flammable materials from the standpoint of fire and explosion prevention are listed in the Appendix A-4.

5. **Ignition Sources.** Inert gas can be used effectively to reduce the hazard of certain types of ignition sources, which for practical reasons cannot be eliminated from hazardous areas. Examples include maintaining an inert atmosphere on enclosed collector rings of synchronous motors, instrument housings, or other enclosed equipment which otherwise would provide a source of ignition. (See Appendix A-5.)

6. **Authority Having Jurisdiction** is usually the purchaser or the competent engineer or organization appointed by him to interpret and make decisions as set forth in these standards. Where insurance is involved, the inspection department representing the insurance carrier generally becomes the authority having jurisdiction. In some cases, civil or military authorities may have final jurisdiction.

CHAPTER 1. GENERAL REQUIREMENTS.

11. Uses.

111. General Purposes. Inert gas(es) are applicable for protection against hazards where flammable vapor-air, gas-air or dust-air mixtures are confined within an enclosure. In such enclosures, an inert atmosphere can be established and maintained to prevent combustion. Inert gas systems may be installed independently of, or supplementary to, other facilities for fire protection and prevention.

112. Enclosures which contain flammable gases or liquids. Processing equipment can be maintained oxygen-free or oxygen concentration can be reduced to the point where combustion cannot occur. Vacuum should be broken on equipment with inert gas instead of air to prevent formation of flammable gas-air or vapor-air mixtures in the vapor space of the equipment.

NOTE: The vapors from inerted enclosures should be vented at a safe point outside of enclosures and away from ignition sources.

1121. Storage equipment, atmospheric or low pressure tanks, pressure vessels, mobile facilities, including tank cars, tank trucks, barges and cargo ships can be safeguarded against explosion as described for processing equipment.

NOTE: Reference should be made to NFPA No. 306 Standards for the Control of Gas Hazards on Vessels to be Repaired and NFPA No. 312 — Fire Protection of Vessels During Construction, Layup and Repair.*

1122. Transfer of flammable liquids. During transfer operations, inert gas can be used as a means for clearing the transfer line of flammable liquid and to inert the vapor space which results from emptying the container or enclosure.

1123. Purging. Inert gas can be used for purging equipment and piping systems as a safeguard against ignition of flammable gases or vapors by frictional sparks, static electricity, hot work (welding, cutting or metalizing), acetylides, peroxides or other sources. Refer to Paragraph 223.

NOTE: Air is not an inert gas, but can be used for ventilation following removal of flammable materials by purging. Example: Hydrogen-cooled generators which are first purged with inert gas can be safely ventilated and opened to facilitate maintenance work.

1124. Testing. Inert gas can be used to test equipment and piping for leaks.

NOTE: This use is included to encourage substitution of inert gas for air where combustible residues may exist in equipment which must be tested.

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*See Appendix B, page 69-45, for availability.

113. Enclosures which contain flammable solids or dusts. The oxygen concentration within equipment such as hammer mills, pulverizers, and mixing equipment can be reduced to a point where combustion cannot take place.

1131. Storage bins can be maintained under an inert atmosphere to prevent explosions.

1132. In the transfer of combustible dusts in pneumatic conveyors, or by "airveying," an inert gas may be used. The use of air to transfer hazardous dusts should be avoided. Refer to Tables in Appendix. In systems operating at a slight vacuum by suction fans or blowers, great care must be taken to prevent leakage of air into the system. Bucket and scraper conveyors may also be maintained oxygen-free to avoid the possibility of dust explosions.

Note: Refer to NFPA No. 91 Standards on Blower and Exhaust Systems.*

12. Limitations of Inerting Methods.

121. Limitations. The limitations of inerting methods must be recognized. Such limitations involve:

a. The reliability of the source and adequacy of supply of inert gas.

b. Freedom of inert gases from moisture or other constituents which might contaminate the material protected. Contamination by absorption in long time storage may occur. Certain inert gases may be excessively soluble at application pressure or may be reactive with certain materials.

c. Dependability of instrumentation and venting devices.

d. Dependability of adequate supplies and pressure for peak demands at points of use.

e. Design of supply systems for adequate application rates at points of use based on peak demand.

f. Adequacy of operation and maintenance controls.

122. Suitability of Gases from Various Sources. It must be recognized that inert gases generated by any of the several acceptable methods outlined in these standards may not necessarily be suitable for all applications. In general, the physical and chemical properties of the flammable materials involved will govern the type and purity of inert gas selected for use.

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*See Appendix B, page 69-45, for availability.

123. Availability of Inert Gases. In general, large quantity usage of inert gas is limited to carbon dioxide, nitrogen, and mixtures of nitrogen and carbon dioxide produced by combustion as in fuel gas, internal combustion engine exhaust and other inert gas producers. Chlorinated or fluorinated hydrocarbons are sometimes used and, even though costly, the maximum permissible oxygen in a safe mixture may be considerably higher than is permissible when using carbon dioxide or nitrogen. Attention is called to the fact that carbon dioxide, and in some cases at elevated temperatures nitrogen, atmospheres are ineffective in providing protection against explosions of certain combustible dusts; for example: magnesium, titanium, zirconium, thorium and uranium. Also, magnesium, aluminum, and possibly some other metal powders under some conditions react violently with certain halogenated hydrocarbons. Argon, helium and other rare gases are used for inerting in some special applications involving liquid metals, where contamination with the more common gases must be avoided.

124. Personnel Safety. Persons must be protected by oxygen or air-supplied respiratory equipment before entering an enclosure in which an inert atmosphere or oxygen deficient atmosphere exists. Canister type gas masks must not be worn for respiratory protection against inert gases because they do not supply oxygen. Toxic hazards of certain inerting gases must be recognized. Inadvertent release of inert gas into occupied areas also requires consideration.

13. Basic Design Considerations.

131. General. In the design of an inerting system, basic design steps listed below should be considered:

a. Determination of hazards to be protected.

b. Determination of type of inert gas.

c. Determination of amount of inert gas required.

d. Determination of inert gas supply source and installation method.

e. Determination of operational control requirements.

132. Determination of Hazards to be Protected. Of first importance is determination of the total inert gas requirement for the plant, the particular operation within a plant, and the specific items of equipment to be protected by inert gas. This overall evaluation is necessary to plan properly the most practical installation and distribution system. Adequate allowances for future expansion should be made. The availability or nonavailability of inert gas may influence basic plant layout and equipment design, such as limiting size of equipment, indicating the most "fire-safe" and economical type of storage tank, and locating large points of use nearest to inert gas generating or storage facilities.

NOTE: Proper Inerting Methods Recognition. Proper inerting of any tank or container which is adequately vented for fire exposure may obviate the need for certain types of fixed fire protection equipment, such as foam chambers and flame arresters, upon approval of the authority having jurisdiction. Under the aforementioned conditions, top filling of flammable liquids may be permissible.

133. Determination of Type of Inert Gas. There are a number of inert gases, each of which has its particular advantages for protection of certain types of equipment and processes. Physical and chemical properties, availability, and cost are primary factors to be considered. Other factors are:

a. Volumes required.

b. Supply pressure required.

c. Stand-by or reserve supplies.

d. Oxygen-free versus oxygen-deficient.

e. Manifolded systems and their limitations.

f. Type of venting devices or systems.

g. Conservation of product.

h. Temperature control for conservation of inert gas by water cooling, insulation, or earth or other suitable cover.

1331. Constituents which may be contaminating, corrosive, or reactive to the materials with which they come in contact (this includes the piping involved, as well as contents) should be determined.

1332. Moisture-free inert gas may be required to avoid product contamination, to avoid the hazard of water as a reactive agent (chemical processes), to avoid freezing, and to avoid accelerated internal corrosion of distribution systems.

1333. The required composition of a suitable inert gas depends on process requirements and the combustibles handled. Where easily oxidized materials are to be protected, inert gas should be free of oxygen.

1334. The maximum permissible oxygen percentage to prevent ignition varies with the flammable material involved, as shown in Tables 1, 2 and 3. The data in these tables were obtained from publications of the U. S.Bureau of Mines unless otherwise noted. (See Appendix A-1334.)

1335. The normal variations of atmospheric pressure do not appreciably affect the limits of flammability (and therefore do not appreciably affect the oxygen concentration required to form a barely explosive mixture). This has been shown both by direct observation and by deduction from the course of curves showing the variation of limits over much wider variations of pressure than those of the atmosphere.

a. The effect of larger variations in pressure is neither simple nor uniform but is specific for each flammable mixture. So far as is known, reduction in pressure below 760 mm. generally narrows the range of flammability by raising the lower limit and decreasing the higher limit. This change is often imperceptible for the first few hundred millimeters' fall in pressure below atmospheric, but thereafter the effect increases until at a suitably low pressure the limits coincide; below this point no mixture can propagate flame. This pressure limit depends on the size of the test apparatus; in large diameter vessels the limiting pressure is lower than in narrow vessels.

b. Increase of pressure above that of the atmosphere does not always widen the limits. On the contrary, the range of flammability of some mixtures is narrowed by increase of pressure, so that a mixture that can propagate flame at atmospheric pressure may not be able to do so at higher pressures. For such mixtures the lower limit may pass through a minimum and the higher limit through a maximum at pressures (not necessarily the same) equal to or greater than that of the atmosphere.

NOTE: Section 1335 is quoted from the Bureau of Mines Bulletin 503, "Limits of Flammability of Gases and Vapors." A discussion of the effect of pressure on individual mixtures, more especially those of air with hydrogen, carbon monoxide, the simpler paraffin hydrocarbons, natural gas, and ethylene will be found in Bulletin 503.

134. Determination of Amount of Inert Gas Required. The rate of application and amount of inert gas required depend on:

a. Permissible oxygen concentration.

b. Oxygen content of the inert gas.

c. Factor of safety desired.
d. Operating conditions.
e. Size and shape of facilities to be protected.
f. Atmospheric conditions.
g. Method of application.
h. Rate of leakage or seepage.

135. Methods of Application. Any of three methods may be used to insure the formation of a noncombustible atmosphere in the enclosure to be protected. Examples of each method, including advantages and disadvantages, may be found in Chapter 2, "Methods of Inert Gas Application". These methods are:

a. Fixed volume requirements.

b. Fixed rate control — where dependence is placed on maintaining a constant rate of application in excess of any requirements.

c. Variable rate control — where a varying rate may be applied which is regulated in accordance with computed requirements.

136. Determination of Inert Gas Supply Source and Installation Method. Inert gas for fire and explosion prevention shall be obtained from a dependable source which is capable of either (1) supplying peak demands or (2) supplying average demands with storage capacity sufficient for peak demands as indicated by a survey. Inert gases shall be properly conditioned or purified for the intended use and shall be distributed in conformance with accepted piping standards, capacity, protection against mechanical damage, protection against system contamination, identification and painting. Piping, instrumentation, valving and other mechanical parts of the system shall be in accordance with requirements of the equipment protected.

137. Determination of Operational Control Requirements. During design and installation, proper consideration shall be given to factors affecting operation, periodic maintenance and inspection.

1371. Delegation of responsibility for controlled inert gas usage shall be defined.

1372. Operational control is considered very important in that the degree of protection afforded is dependent on inert gas generating equipment, distribution facilities, instrumentation and proper conformance to prescribed operating procedures. Cross-connections with other piping systems (for example, compressed gas or air) must be prohibited to prevent contamination of the inert gas system or vice versa.

14. Plans and Specifications.

141. General. The design and installation of inert gas systems should be entrusted to none but fully experienced and responsible persons. Details for each installation will necessarily vary according to the local conditions and the hazard involved. Authorities having jurisdiction should be consulted as to the application of these standards and regarding all details of installation, including the question of what additional special hazard protection, if any, should be provided, and what other standards are applicable.

Plans and specifications pertinent to any installation shall be reviewed by the authorities having jurisdiction prior to installation.

142. Large Scale Units. Large scale inert gas systems should be designed, installed, operated, and maintained consistent with normal practice for other utilities. Plans should be drawn to scale showing all essential details. Information which may be required includes designed purpose of system, description and estimated reliability of inert gas supply source, detailed layout of piping and supplementary details of each specific hazard to be protected.

143. Small Scale Units. For individual unit or local systems designed for protection of a single group or single item of equipment, plans should be drawn to scale showing all essential piping and instrumentation detail. Calculations to determine the amount of inert gas required should be filed for future reference.

CHAPTER 2. METHODS OF INERT GAS APPLICATION.

21. General.

211. Preparation for Continuous Application. The oxygen content in the enclosures to be protected must be reduced to a safe point by purging before continuous inerting becomes effective.

212. Peak Volume Requirements. System requirements for the amount of inert gas shall be based on maximum demand conditions (peak requirement is the maximum inbreathing rate under conditions of sudden cooling such as in a rain or hail storm, plus the maximum emptying rate).

2121. Where conditions are such that no oxygen can be tolerated in the enclosure, the supply of oxygen-free inert gas shall be adequate to satisfy peak volume requirements as specified in paragraph 212.

2122. Where conditions require oxygen reduction to prevent existence of a flammable mixture, rather than complete oxygen elimination, an inert gas containing some oxygen may be used. The oxygen content of the inert gas must be considered in calculating inert gas requirements.

213. Methods of Application. There are three general methods of applying inert gas, as follows:

a. Fixed volume application, in which an enclosure is purged to render the atmosphere inert.

b. Fixed rate application, in which an inert gas is admitted into an enclosure at a fixed rate in order to maintain an existing inert atmosphere.

c. Variable rate application, in which an inert gas is admitted into an enclosure on a demand basis in order to maintain an existing inert atmosphere.

22. Fixed Volume Application.

221. Vacuum Inerting. Enclosures may be purged by reducing the pressure in the enclosure to less than atmospheric, and then relieving the vacuum with inert gas.

2211. Equipment normally operating under a vacuum may be inerted during shutdown by relieving the vacuum with an inert gas rather than air.

2212. Equipment may be evacuated (depending on design limitations) and the resulting vacuum relieved with an inert gas.

2213. Equipment may be inerted by the syphon inerting system, in which the enclosure is filled with liquid, and the inert gas introduced into the vapor space as the liquid is drained from the enclosure. Refer to "Suggested Procedures for Safeguarding Aircraft Fuel Tank Atmospheres", *NFPA Pamphlet No. 405T–2; tentatively adopted 1956.

2214. The quantity of inert gas required under paragraph 2213 is equal to the volume of liquid drained from the system. The oxygen content of the enclosure will be equal to the oxygen content of the inert gas used, provided the enclosure was initially 100 per cent full of liquid.

2215. Where two or more containers or tanks are joined by a manifold and must be inerted as a group, the vapor content of each container or tank should be checked to determine that complete inerting has been accomplished. Refer to Paragraph 2213 for an exception.

222. Pressure Inerting. Enclosures may be purged by increasing the pressure within the enclosure (dependent upon equipment design consideration) by the introduction of inert gas under pressure and, after the gas has diffused, venting the enclosure to the atmosphere.

2221. More than one pressuring cycle may be necessary to reduce the oxygen content of the enclosure to the desired percentage.

2222. A variation of the pressure purging method is useful in cases where a container filled with a flammable material is to be emptied and then purged. Inert gas may be applied to the vapor space at a pressure consistent with equipment design limitations, thus accomplishing both the emptying of the vessel and the inerting of the vapor space in the same process.

2223. The quantity of inert gas required under Section 222 may be calculated by the method outlined under paragraph 2214.

2224. Where two or more containers or tanks are joined by a manifold and must be inerted as a group, the vapor content of each container or tank should be checked to determine that complete inerting has been accomplished.

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*See Appendix B, page 69-45, for availability.

223. Inerting by Purging an Enclosure Having an Open Vent. Enclosures may be purged by either displacing or diluting the flammable vapors, at substantially atmospheric pressure.

2231. If mixing of the inert gas and the flammable vapor is anticipated, inerting by purging may be accomplished by introducing the inert gas at the bottom of the enclosure and venting at the top. The volume of inert gas required must be determined by tests, based on the time required to reduce the oxygen content to the required percentage.

2232. If the inert gas and the flammable vapor can be kept from mixing, purging can be accomplished by introducing a heavier gas at the bottom of the enclosure, forcing the flammable vapor out of a top opening, or by introducing a lighter gas at the top of the enclosure, forcing the flammable vapor out of a bottom opening. It is difficult to avoid mixing of the inert gas and the flammable vapor, and some mixing should be assumed in applying this method.

2233. Where two or more containers or tanks are joined by a manifold and must be inerted as a group, the vapor content of each container or tank should be checked to determine that complete inerting has been accomplished.

NOTE: Reference is made to "Purging Principles and Practice," American Gas Association, 1954, for guidance and instruction.*

Recommended practices for cleaning tanks and removing sludge and residue may be obtained from API Accident Prevention Manual No. 1, Cleaning Petroleum Storage Tanks; Section A, Crude Oil and Unfinished Products; Section B, Gasoline Tanks.*

For chemicals the Manufacturing Chemists Association or other authority should be consulted.*

23. Fixed Rate Application.

231. Rate Required. When an inert atmosphere is maintained by the introduction of inert gas into the enclosure at a constant rate, the rate shall be sufficient to supply the peak requirement in order that complete protection may be provided.

NOTE: In the case of an inerted enclosure around instruments and motor or generator brushes or slip rings, the required rate is equal to the rate of leakage.

232. Advantages. The primary advantage of this method is the fact that no dependence need be placed on mechanical devices such as regulators and motor valves. Further, a minimum capital investment is required.

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*See Appendix B, page 69-45, for availability.

233. Disadvantages. The principal disadvantages of the fixed rate method are listed below.

(a) Inert gas is wasted since the peak rate is applied continuously.

(b) Restriction orifices are subject to plugging from rust and scale and to freezing.

(c) Vapor losses from volatile liquid storage containers are increased due to constant "sweeping" of the vapor space by the inert gas.

(d) A personnel safety hazard may exist because of an oxygen deficiency in the immediate area of the vent of the inerted enclosure.

234. Flow Control. Figure 1 shows a method of flow control which can be used with fixed rate application.

24. Variable Rate Application.

241. Rate Required. When an inert atmosphere is maintained by the introduction of inert gas into an enclosure at a variable rate dependent on demand, the maximum rate of flow through the regulating device shall be at least equal to the peak demand.

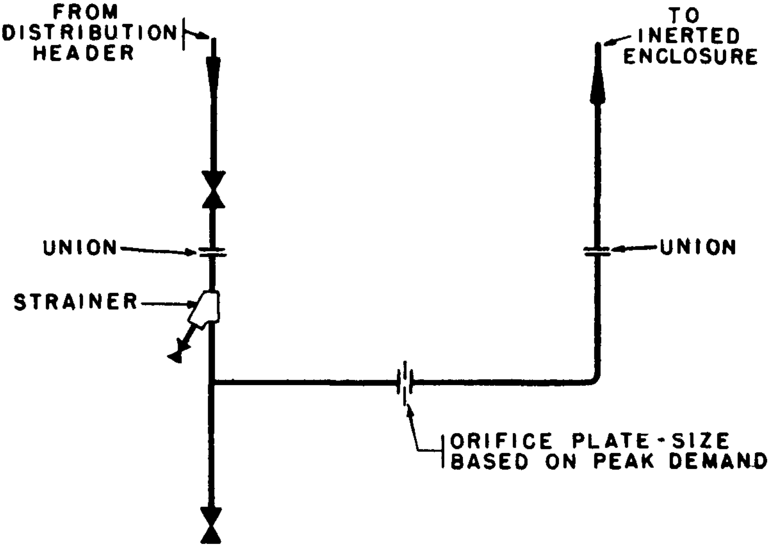

Figure 1. Schematic sketch showing method of flow control that may be used with fixed rate application.

242. Method of Calculation. For method of calculating peak requirements, refer to Appendix A.

For installations in which high or low pressure holders are used, the inert gas generating capacity should be based on the average annual demand. The holders will have to be sufficiently large to satisfy the peak volume requirements of the system for a reasonable period of time.

243. Smaller Vessels. A variation of the fixed rate application is sometimes used for smaller vessels with high throughput and for vessels inside buildings which are not subject to normal outdoor fluctuations of ambient temperature. A solenoid valve actuated by the pump switch is provided to increase the inert gas flow when the tank is being emptied.

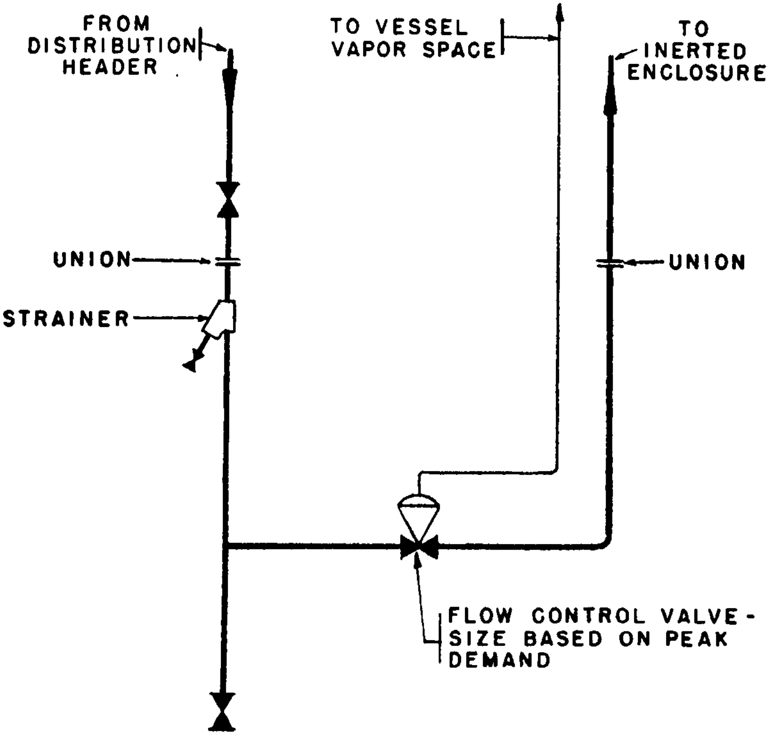

Figure 2. Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure 3.

244. Suggested Uses. The variable rate method is recommended for maintaining an inert atmosphere in enclosures subject to wide variation in inert gas demand.

245. Advantages. The principal advantages of the variable rate method of application are:

a. Allows the most efficient use of inert gas, since the gas is introduced only during inbreathing, when a container would normally be taking in air.

b. Conserves vapors of volatile materials by maintaining a positive pressure on the vessel, and by avoiding the constant "sweeping" of the vapor space.

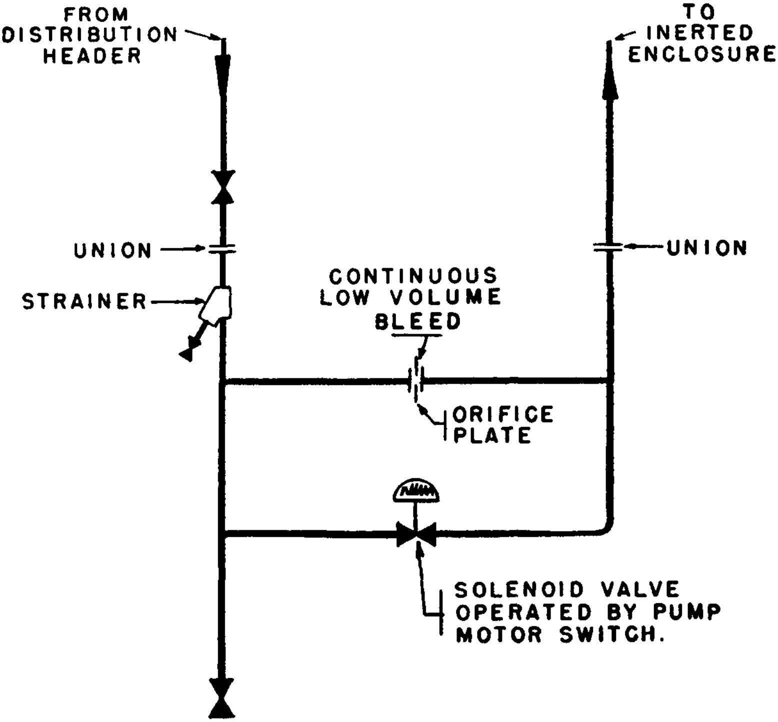

Figure 3. Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure 2.

CHAPTER 3. INERT GAS SUPPLY

31. Classification of Supply Sources.

311. General. Inerting media for fire and explosion prevention shall be obtained from a dependable source capable of supplying continuously the amount required to maintain the desired degree of oxygen deficiency within the enclosure protected.

312. Types of Systems. The seven types of inerting systems are listed below:

a. Multiple sources of supply independent of process operations (power houses or process units), with total capacity such that loss of any one unit will not reduce available capacity below peak requirements. Generating equipment provided for the purpose.

b. One source of supply plus holder (same as above).

c. Same as a. except 50 per cent of the sources may be dependent on by-product inert gas from a processing unit.

d. Same as b. above except single source dependent on by-product inert gas from a processing unit; holder provided.

e. One source only independent of by-product inert gas from a processing unit.

f. One source dependent on by-product inert gas from a processing unit.

g. Holder capacity only.

32. Types of Inert Gas Supply.

321. General. There are a number of sources of inert gas which are suitable within prescribed limitations set forth in Article 12 for the reduction of fire and explosion hazards.

322. Hydrocarbon combustion (natural gas or bottled gas, propane, as fuel). In many cases the inert gas generated by the combustion of hydrocarbons is of sufficient purity to use without further treatment. The composition of this gas is approximately 87 per cent nitrogen, 12 per cent carbon dioxide, and about ½ per cent oxygen, and this mixture is saturated with water vapor. If a purified gas is necessary, the oxygen and traces of carbon monoxide must be removed in one operation and the carbon dioxide, if it is undesirable, must be removed in a second operation. (See appendix A-322.)

323. Ammonia Combustion. The second method consists of the catalyzed oxidation of ammonia with air to produce directly a high purity nitrogen which contains less than 0.02 per cent carbon dioxide, 0.25 per cent hydrogen, 0.001 per cent residual ammonia, and merely a trace of oxygen (See appendix A-323.)

324. Air Fractionation. The third method consists of the liquefaction of air and subsequent fractionation to produce nitrogen. Several companies are now producing "package" units for various capacities using the air fractionation techniques. (See appendix A-324.)

325. Purification of Furnace or Boiler Flue Gas, or "blow-off gas" from certain chemical oxidation processes. In some cases the gas available from boilers, furnaces or processing units is of sufficient quality for immediate use. These gases can be purified if desirable but in the case of the furnace and boiler gas, the economics of the purification is usually not favorable. (See appendix A-325.)

326. Commerically Available Inert Gas. Purchase of liquefied carbon dioxide or nitrogen. Liquefied carbon dioxide or nitrogen is available in bulk or may be procured in cylinders.

33. Location of Generator or Supply Facility.

331. The facilities for the generation, purification, and/or centralized storage of inert gas shall be located in a safe area.

3311. Care must be exercised to insure against fire exposure or other plant operating condition causing loss of inert gas production or storage capacity.

3312. Where the combustion method of producing inert gas is used, the existence of the facility constitutes an ignition source in itself; therefore, its location with respect to hazardous operations is important.

34. Capacity and Reliability.

341. The expected rate of application of inert gas under most unfavorable conditions shall serve as a basis for calculating generation or storage capacity. Proper allowance should be made for expansion of operations or plant facilities which require inert gas protection.

3411. A reliable and continuous supply of inert gas in connection with gasometers or storage tanks of such capacity as to assure a continuous supply under peak demands is considered the most reliable method.

3412. If gas is obtained only from storage tanks or gasometers, provision shall be made to maintain the supply while recharging the tank or tanks. A duplicate set of tanks may be necessary unless the system is arranged so that a sufficient reserve supply can be maintained to provide protection during the recharging period.

3413. If gas producers are used without storage tanks or gasometers, their combined capacity shall be such that loss of a single unit will not reduce the supply below the peak demand requirements.

3414. When inert gas is obtained from boiler settings or special furnaces, provision shall be made to maintain the supply at all times. If the gas supply should fail and the process protected is continuous, a reserve supply in storage tanks should be available. If gas is obtained from the breeching of a battery of boilers, provision shall be made through the use of dampers or valves to prevent dilution of the flue gas with fresh air drawn through the grates or openings of any boilers which are idle or shut down.

3415. The utilities provided for the inert gas generating equipment should be reliable under adverse conditions. For example, potential loss of natural gas supply for combustion process should justify storage of propane or other fuel.

35. Gas Conditioning Equipment.

351. General Requirements. Inert gas used for protection of any process or equipment must be conditioned to insure freedom of contamination that would be injurious to the gas distribution system or to the product or material being protected.

3511. When exhaust gases from an internal combustion engine are used, precautions shall be taken to keep the air-fuel ratio 12 to 1 or higher; otherwise, the exhaust gases themselves may contain sufficient combustibles to form explosive mixtures with air.

3512. Suitable filters or spray washers should be used to remove dust, soot, and cinders from flue gases used for inerting.

NOTE: Special fans or filters can be used to remove a large percentage of the dust, soot, and cinders generally present in flue gas. Spray washers can be used to remove very fine dust, soot, and certain other impurities.

3513. Inert gases obtained from a combustion process shall be cooled to approximately atmospheric temperature before being introduced into a vessel.

3514. Periodic sampling of large scale inert gas installations at frequent points throughout the system affords protection against inadvertent cross-connections or loss in efficiency of gas conditioning facilities.

3515. The metering of inert gas supplies to specific groups of equipment under inert gas protection may be advantageous from the standpoint of operating control and as an indicator of system efficiency.

352. Instrumentation. Suitable analyzing (indicating or recording) equipment shall be provided to indicate the quantity and quality of the inert gas available. Some of the factors which may require measurement are: pressure, temperature, rate of flow, dew point, oxygen content, and purity. Purity is determined by measuring such undesired contaminants as may be present.

CHAPTER 4. DISTRIBUTION OF INERT GAS

41. General.

411. Distribution Facilities. Facilities for the distribution of inert gas to the various machines, enclosures, or other specific points to be protected shall be designed and installed in accordance with good engineering practice and specific requirements as set forth below.

42. Piping.

421. Size. Distribution piping shall be of ample size to deliver the required volume of inert gas at adequate pressure to points of use. Expected peak rates of inert gas usage shall be the basis for determining friction loss in the distribution system.

422. Materials. Fittings, pipe, valves and appurtenances shall be of material and strength suitable for the prescribed operating pressures and temperatures, and for anticipated corrosion, vibration, or other limiting condition. Cast iron shall not be used.

423. Testing. The distribution system shall be tested and cleaned before being placed in service.

424. Moisture Traps. Moisture traps shall be provided where necessary and lines shall drain toward the traps. Adequate blow-down connections shall be provided.

425. Strainers. Strainers should be provided as necessary to remove rust and scale from the system.

426. Back Pressure Valve. Each branch from a main distribution line shall be provided with a back pressure valve, which is a pressure controller installed so as to prevent excessive demand in the branch line from reducing the pressure in the main distribution line below a predetermined set pressure.

43. System Protection.

431. Headers. In large areas, a properly valved loop system of headers is recommended to insure continuation of supply should a main distribution header rupture or be removed from service for any reason.

432. Fire Exposure. Main distribution lines shall be located so that damage by exposure to fire is minimized.

433. Piping Supports. All piping shall be adequately supported.

44. Contamination of Inert Gas System.

441. Check Valve. Each connection to the main distribution system shall be provided with a check valve or other suitable device to prevent contamination of the system through reversal of flow. This can occur either through loss of inert gas pressure or by excessive pressure in an inerted unit.

442. Cross-connections. Cross-connections between the inert gas distribution system and any other utility system, such as compressed air, shall be prohibited. Emergency connections to individual inerted units shall be made only on the downstream side of the check valve required in paragraph 441. Any such connection should be made with a temporary hose connection rather than with permanent piping. In all cases, such connections shall be protected against contamination by a double valve and vent arrangement.

45. Application of Inert Gas at Points of Usage.

451. General. Facilities for introducing inert gas into the area or enclosure to be protected shall be arranged to insure effective distribution. Multiple outlets in the enclosure may be necessary.

4511. High velocity inert gas streams into the enclosure should be avoided to prevent agitation of product and generation of static electricity.

4512. Piping connections and regulating devices shall be of adequate size for the maximum required rates of application.

452. Fixed or permanently piped inert gas connections. Flame arresters, if used should never be installed between the inert gas connection and the container, because of the danger of plugging the arrester bank with rust and scale from the inert gas system.

4521. A positive means for electrically bonding and grounding the inert gas system shall be provided. Refer to the pamphlet entitled "Static Electricity."*

4522. Suggested locations for inert gas connections to storage tanks are shown in Figure 4.

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*NFPA No. 77. See Appendix B, page 69–45, for availability.

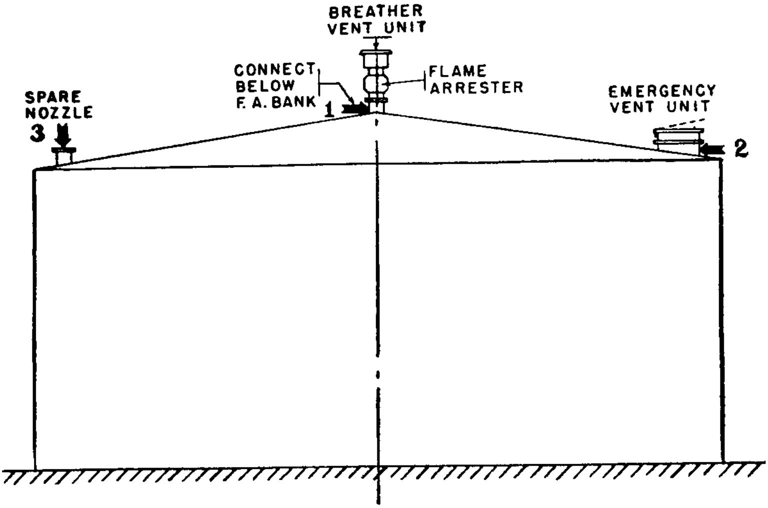

Figure 4. Positions where inert gas may be introduced into vessel (indicated by arrows).

453. Temporary Connections. Flexible hose designed for the maximum inert gas pressure may be used to connect the inert gas system to the enclosure to be inerted.

4531. If the flexible hose terminates in a metal pipe or tip, positive means shall be provided for electrically bonding the metal to the container being inerted.

46. Instruments and Control Devices for Distribution of Inert Gas.

461. Regulators. Regulators or motor valves used to control the flow of inert gas shall be of sufficient capacity to satisfy peak demand requirements.

462. Analyzers. Wherever contamination might result in the creation of a hazardous situation or in offgrade products, and elsewhere as necessary, suitable recording or indicating analyzers should be provided to continuously record the proportion of such contaminants in the inert gas.

463. Sample Points. The instruments shall be arranged to draw their samples from as many points within the enclosure as is practical. The point at which the highest oxygen reading is obtained should be the one used in controlling the hazard.

464. High Oxygen Alarm. Where a process or equipment in which inert gas is used for fire and explosion prevention is not under the direct control of an operator who can observe regularly the instruments indicating the amount of oxygen present, automatic apparatus which signal increases in the oxygen percentage should be installed.

465. High Oxygen Shut-off. When a dangerous increase in the oxygen percentage occurs, the equipment creating the hazard shall be shut down unless the operator is able to reduce the oxygen to a safe level promptly.

466. Portable Oxygen Indicators. Portable oxygen indicators of the Orsat or Pauling types should be used to determine the completeness of purging. A representative sampling may be obtained by closing in the container for sufficient time to allow the gases to diffuse. Samples should then be taken at intervals until no appreciable increase in oxygen content is noted.

4661. When commercially available carbon dioxide is used to inert or purge, the results may be determined by analyzing for carbon dioxide rather than oxygen. The minimum carbon dioxide concentration shall be based on the maximum allowable oxygen concentration assuming an air and carbon dioxide atmosphere.

$$\text{Minimum } \% \ CO_2 = \frac{(21 - O_2)}{21} \times 100$$

Where O_2=the maximum permissible percentage of oxygen in Table 1, 2 or 3.

Should oxygen from any source other than air be present, the carbon dioxide analysis method cannot be used.

467. Restriction Orifices. Restriction orifices should be installed in manually operated inerting systems to limit the maximum flow available. In instrument controlled systems where rust and scale are problems, restriction orifices should also be installed to prevent wastage if controls stick in the wide-open position.

468. Pressure Gauges. Pressure gauges shall be provided as necessary throughout the system.

469. Combustible Gas Indicators. Combustible gas indicators are not reliable when used in the presence of some of the inerting gases, particularly nitrogen, and therefore are generally not suitable for use in determining the completeness of inerting.

APPENDIX A, EXPLANATORY

A–2. Rock Dusting. Rock dusting as performed in coal mining operations is an example of the use of inert solids for preventing the development of widespread coal dust explosions. Normally the rock dust, generally pulverized limestone of specified fineness and other characteristics, is distributed by machine on the floor, sides and roof surfaces of mine entries. When an explosion starts, this dust together with any coal dust present, is thrown into suspension by the pressure wave preceding the explosion flame. The rock dust thus dilutes the coal dust in suspension and absorbs a large proportion of the heat produced by the combustion, acting to limit the spread of the explosion. The Federal Mine Safety Code requires that "sufficient rock dust be used in bituminous and lignite mines, so that the total noncombustible content of the dust present should be not less than 65 per cent."

A–4(a). Flash Point. The flash point of the liquid is the temperature at which it gives off vapor sufficient to form an ignitable mixture with the air near the surface of the liquid or within the vessel used. By "ignitable mixture" is meant a mixture within the explosive range (between upper and lower limits) that is capable of the propagation of flame away from the source of ignition. Some evaporation takes place below the above temperature, when vapor does not go off freely enough to meet flash point classification requirements. This term applies mostly to flammable liquids, although there are certain solids, such as camphor and naphthalene, that slowly evaporate or volatilize at ordinary room temperature and therefore have flash points.

Open cup flash points are usually somewhat higher than the closed cup flash point figures for the same substances. Closed cup flash point figures are commonly used in determining the classification of liquids which flash in the ordinary temperature range, but for certain materials which have relatively high flash points, the open cup flash point testing is often preferred. (Reference: NFPA Handbook of Fire Protection.)*

For flash point data on a large number of flammable liquids, gases and combustible solids see NFPA Pamphlet No. 325. Similar data for many trade name products will be found in NFPA Pamphlet No. 325A.*

A–4(b). Ignition Temperature. Ignition temperature of a substance, whether solid, liquid, or gaseous, is the minimum temperature required to initiate or cause self-sustained combustion independently of the heat source.

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*See Appendix B, page 69-45, for availability.

The figures on ignition temperature may vary, depending upon the test method, as the ignition temperature varies with the size, shape and material of the testing container and other factors. (Reference: NFPA Handbook of Fire Protection.)

A-4(c). Explosive or Flammable Limits. In the case of gases or vapors which form flammable mixtures with air or oxygen, there is a minimum concentration of vapor in air or oxygen below which propagation of flame does not occur on contact with a source of ignition. There is also a maximum proportion of vapor or gas in air above which propagation of flame does not occur. These boundary-line mixtures of vapor or gas with air, which if ignited will just propagate flame, are known as the "lower and upper explosives or flammable limits," and are usually expressed in terms of percentage by volume of gas or vapor in air. (Reference: NFPA Handbook of Fire Protection.)

A-4(d). Flammable Range. The difference between the lower and upper explosive or flammable limits, expressed in terms of percentage of vapor or gas in air by volume, is known as the "explosive range," also often referred to as the "flammable range." For example, the lower limit of flammability of a gasoline at ordinary ambient temperatures is approximately 1.4 per cent vapor in air by volume, while the upper limit of flammability is about 7.6. By difference, the explosive or flammable range of gasoline is therefore 6.2. No attempt is made to differentiate between the terms "flammable" and "explosive" as applied to the lower and upper limits of flammability. In the case of most vapors and gases there is no basis for sharp distinctions between "flammable limits" and "explosive limits." (Reference: NFPA Handbook of Fire Protection.)

A-4(e). Specific Gravity. The ratio of the mass of a substance to the mass of an equal volume of water at 4° C. or other specified temperature. (Reference: Handbook of Chemistry and Physics.)

A-4(f). Molecular Weight. The sum of the atomic weights of all the constituent atoms in the molecule of an element or compound. (Reference: Handbook of Chemistry, Lange.)

A-4(g). Vapor Density. Vapor density is the relative density of the vapor (with no air present) as compared with air, a figure less than 1 indicating a vapor lighter than air, and a figure greater than 1 a vapor heavier than air. (Reference: NFPA Handbook of Fire Protection.)

A-4(h). Vapor Pressure. The pressure exerted by a vapor when a state of equilibrium has been reached between a liquid, solid, or solution, respectively, and its vapor is called the vapor pressure of a liquid, solid, or solution. When the vapor pressure of a liquid exceeds that of the confining atmosphere, the liquid commonly is said to be boiling. (Reference: Handbook of Chemistry, Lange.)

A-4(i). Thermal Capacity. Thermal capacity of a substance is the quantity of heat necessary to produce unit change of temperature in unit mass. It is ordinarily expressed as calories per gram per degree Centigrade. Numerically equivalent to specific heat. (Reference: Handbook of Chemistry and Physics.)

A-4(j). Rate of Diffusion. The speed at which vapors or gases spread through a given gaseous medium. The rates at which gases diffuse vary inversely as the square roots of their densities, irrespective of the fluid in which diffusion occurs. The diffusion coefficient for one gas in another varies inversely as the pressure and directly as the 1.7 to 2.0 power of the absolute temperature. It is slightly dependent on the composition of the gaseous mixture. Diffusion coefficients may be calculated according to the kinetic gas theory; for methods, consult Gilliland, Ind. Eng. Chem. 26, 681 (1934).

A-4(k). Heat of Combustion. The total amount of heat evolved when a definite quantity of a substance is completely burned (oxidized). It is expressed variously as in calories per gram or gram molecules or (especially for fuel) in British thermal units (Btu) per pound. (Ref.: Handbook of Chemistry, Lange.)

A-4(l). Latent Heat of Vaporization. The quantity of heat required to convert a unit quantity of liquid at a definite temperature to a vapor at the same temperature. It is usually expressed in Btu per pound. (Ref.: Handbook of Chemistry, Lange.)

A-5. Listed below are some of the more common ignition sources with examples of enclosures which may be protected by inerting.

a. Lightning Effects or Induced Charges — Example, flammable liquids storage tanks.

b. Spontaneous Combustion — Example, coal bins.

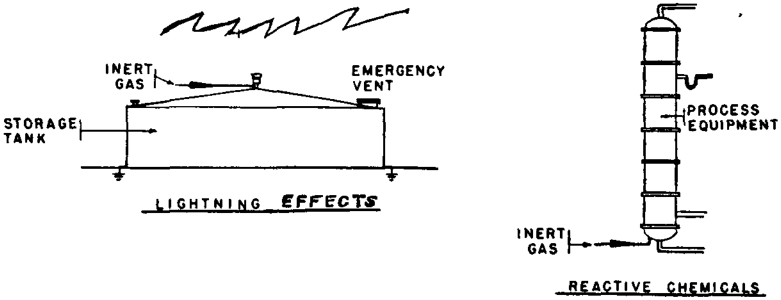
c. Mechanical sparks due to friction and impact — Example, resin mills.

d. Reactive Chemicals (pyrophoric materials, peroxides, acetylides) — Example, processing equipment.

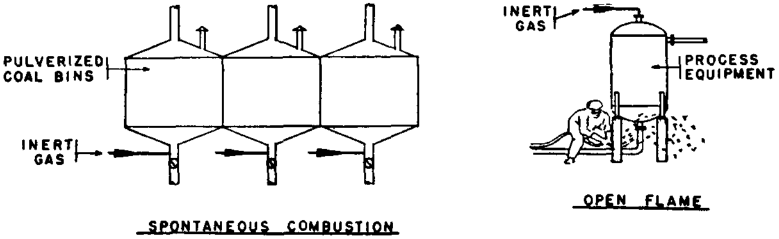
e. Open Flame (welding hot work) — Example, tanks, processing equipment. See paragraph 312.

f. Hot surfaces — Example, ovens.

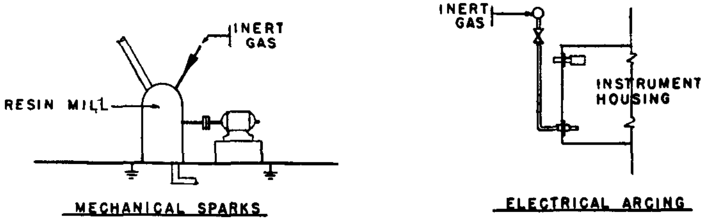
g. Electrical arcing, including static — Example, synchronous motor collector rings, instrument enclosures, areas of static discharge.


LIGHTNING EFFECTS

REACTIVE CHEMICALS


SPONTANEOUS COMBUSTION

OPEN FLAME


MECHANICAL SPARKS

ELECTRICAL ARCING

Figure 5. Examples of enclosures which may be protected by inerting.

A-1334

TABLE 1.

MAXIMUM PERMISSIBLE OXYGEN PERCENTAGE TO PREVENT IGNITION OF FLAMMABLE GASES AND VAPORS USING NITROGEN AND CARBON DIOXIDE FOR INERTING.

	N-Air		CO$_2$-AIR	
	O_2 Per Cent Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent	O_2 Per Cent Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent
Butadiene	10	8	13	10½
Butane	12	9½	14½	11½
Carbon Monoxide	5½	4½	6	5
Cyclopropane	11½	9	14	11
Ethane	11	9	13	10½
Ethylene	10	8	11½	9
Hydrogen	5	4	6	5
Isobutane	12	9½	15	12
Methane	12	9½	14½	11½
Pentane	11½	9	14	11
Natural Gas (Pittsburgh)	12	9½	14	11
Propane	11½	9	14	11
Propylene	11½	9	14	11
Acetone	13½	11	15½	12½
Benzene (Benzol)	11	9	14	11
Carbon Disulfide	—	—	8	6½
*Ether	—	—	13	10½
Ethyl Alcohol	10½	8½	13	10½
Gasoline	11½	9	14	11
Hexane	12	9½	14½	11½
Kerosene	11	9	14	11
Methyl Alcohol	10	8	13½	11

Notes to Table 1.

1. Data in this Table were obtained from publication of the U. S. Bureau of Mines unless specifically designated otherwise.
2. Data were determined by laboratory experiments conducted at atmospheric temperature and pressure. Vapor-air inert-gas samples were placed in explosion tubes and exposed to a small electric spark or open flame.
3. In the absence of reliable data, the U. S. Bureau of Mines or other recognized authority should be consulted.
4. The "Maximum Recommended O_2 Per Cent" applies only to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Much higher factors of safety are required for conditions where sources of ignition are deliberately applied such as hot work. See Purging, Paragraph 223.

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* Values obtained from NFPA Handbook of Fire Protection.

A-1334 continued

TABLE 2.

MAXIMUM PERMISSIBLE OXYGEN CONTENT TO PREVENT IGNITION OF COMBUSTIBLE DUSTS USING NITROGEN AND CARBON DIOXIDE FOR INERTING.

	N_2-AIR		CO_2-AIR	
	O_2 Percentage Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent	O_2 Percentage Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent
Aluminum (Atomized)	9	7	3	2½
Antimony	—	—	16	13
Iron, hydrogen reduced	—	—	13	10½
Iron, Carbonyl	—	—	10	8
Magnesium	2	1½	3	2
Manganese	—	—	15	12
Silicon	—	—	13	10½
Tin	—	—	16	13
Vanadium	—	—	13	10½
Zinc	10	8	10	8
Dowmetal	3	2½	0	0
Ferrotitanium	—	—	13	10½
Ferrosilicon	—	—	19	15
Magnesium-Aluminum	6	5	0	0
Thorium	2½	2	0	0
Thorium Hydride	5	4	6	5
Titanium	6	5	0	0
Titanium Hydride	10	8	13½	11
Uranium	1½	1	0	0
Uranium Hydride	2½	2	½	0
Zirconium	4	3	0	0
Zirconium Hydride	8	6½	11	9

Notes to Table 2.

1. Data in this Table were obtained from publications of the U. S. Bureau of Mines unless specifically noted otherwise.

2. In the furnace test dust clouds of Zr, Th, U, and UH_3 also ignited in CO_2. During heating for several minutes, undispersed layers of samples of the following metal powders ignited (glowed) in CO_2: Stamped Al, Mg, Zn Mg-Al, Dowmetal, Ti, TiH_2, Zr, ZrH_2, Th, ThH_2, U, and UH_3. Visible burning of dust layers was also observed in N_2 with powders of Mg, Sn, Mg-Al, Dowmetal, Ti, TiH_2, Zr, Th, ThH_2, U and UH_3.

3. In the absence of reliable data for combustible dusts, the U. S. Bureau of Mines or other recognized authority should be consulted.

4. Data were obtained by laboratory experiments conducted at atmospheric temperature and pressure. An electric spark was the ignition source.

5. The "Maximum Recommended O_2 Per Cent" applies only to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Much higher factors of safety are required for conditions where sources of ignition are deliberately applied such as hot work. See Purging, Paragraph 223.

A-1334 continued

TABLE 3.

MAXIMUM PERMISSIBLE OXYGEN CONTENT TO PREVENT IGNITION OF COMBUSTIBLE DUSTS USING CARBON DIOXIDE FOR INERTING.

	HOT SURFACE (1560° F.) IGNITION		SPARK IGNITION	
Resins	O_2 Percentage Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent	O_2 Percentage Above Which Ignition Can Take Place	Maximum Recommended O_2 Per Cent
Allyl Alcohol	7	5½	—	—
Cellulose Acetate	5	4	13	10½
Coumarone-Indene	11	9	14½	11½
Lignin	7	5½	17	13½
Phenolic	9	7	14½	11½
Pine-Rosin Base	5	4	—	—
Polyethylene	8	6½	13	10½
Polystyrene	7	5½	14½	11½
Polyvinyl Acetate	11	9	17	13½
Shellac, Rosin, Gum	9	7	14½	11½
Urea	11	9	17	13½
Vinyl Butyral	5	4	14½	11½
Molding Compositions				
Cellulose Acetate	7	5½	11½	9
Methyl Methacrylate	7	5½	14½	11½
Phenolic	7	5½	14½	11½
Polystyrene	9	7	14½	11½
Synthetic Rubber	11	9	15	12
Urea	9	7	17	13½
Vinyl	15	12	—	—
Resin Ingredients				
Hexamethylenetetramine	11	9	14½	11½
Pentaerythritol	7	5½	14½	11½
Phthalic Anhydride	11	9	14½	11½
Rennet Casein	7	5½	17	13½
Resin Stabilizer	13	10½	15	12
Sodium Carboxymethylcellulose	6½	5	—	—
Fillers for Molding Compositions				
Alpha Pulp, ground	7	5½	17	13½
Cotton Flock, ground	7	5½	17	13½
Wood Flour	7	5½	17	13½

(*Table 3 continued next page*)

Miscellaneous Dusts				
Cork	—	—	14	11½
Cornstarch	5	4	11	9
Cotton in bulk to prevent smoldering and ignition	—	—	8	6½
Cotton lint and dust in air	—	—	15	12
Ground oat hulls	—	—	13½	11
Jute	—	—	8	6½
Pyrethrum flower	—	—	15½	12½
Phenothiazine	—	—	16	13
Rubber, hard crude	12½	10	15	12
Sulphur	—	—	11	9
Wheat, corn or oat elevator dust	—	—	14	11
Wheat starch	—	—	12	9½
White dextrin	—	—	12	9½
Coal dust:				
Semi-anthracite	11½	9	—	—
Low-volatile	10½	8½	—	—
Medium-volatile	10½	8½	18½	15
High-volatile A	10½	8½	16	13
High-volatile C	10½	8½	15	12
Lignite	7½	6	15	12
Coal tar pitch	—	—	15–17½	12–14
Water gas tar pitch	—	—	16½	13
Petroleum pitch	—	—	11	9

Notes to Table 3.

1. Data in this Table were obtained from publications of the U. S. Bureau of Mines unless specifically noted otherwise.
2. To prevent ignition of dust clouds of cellulose acetate by dilution of the atmosphere with N_2, the limiting oxygen percentages were determined to be 3 per cent in the furnace test and 9.5 per cent in the spark test.
3. In the absence of reliable data for combustible dusts, the U. S. Bureau of Mines or other recognized authority should be consulted.
4. Data (with spark ignition) were obtained by laboratory experiments conducted at atmospheric temperature and pressure.
5. The "Maximum Recommended O_2 Per Cent" applies only to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Much higher factors of safety are required for conditions where sources of ignition are deliberately applied such as hot work. See Purging, Paragraph 223.
6. Data for cork, cotton in bulk, cotton lint, ground oat hulls, jute, pyrethrum flower, wheat, corn or oat elevator dust, and white dextrin were taken from Table 1189 of NFPA Handbook of Fire Protection, 11th Ed. Pg. 1189.

A–1334. Figure 6, from Bureau of Mines Bulletin 503, "Limits of Flammability of Gases and Vapors," shows the limits of flammability of gasoline in the presence of various inert gases.

The following is a partial list of references from which maximum permissible oxygen concentration data were obtained:

Bureau of Mines Report of Investigations 3722 — Inflammability and Explosibility of Metal Powders, by Irving Hartmann, John Nagy, and H. R. Brown, 1943, 44 pp.

R. I. 3751 — Inflammability and Explosibility of Powders Used in the Plastics Industry, by Irving Hartmann and John Nagy, 1944, 38 pp.

R. I. 4835 — Explosive Characteristics of Titanium, Zirconium, Thorium, Uranium and Their Hydrides, by Irving Hartmann, John Nagy, and Murray Jacobson, 1951, 16 pp.

R. I. 5052 — Laboratory Explosibility Study of American Coals, by Irving Hartmann, Murray Jacobson and R. P. Williams, 1954, 8 pp.

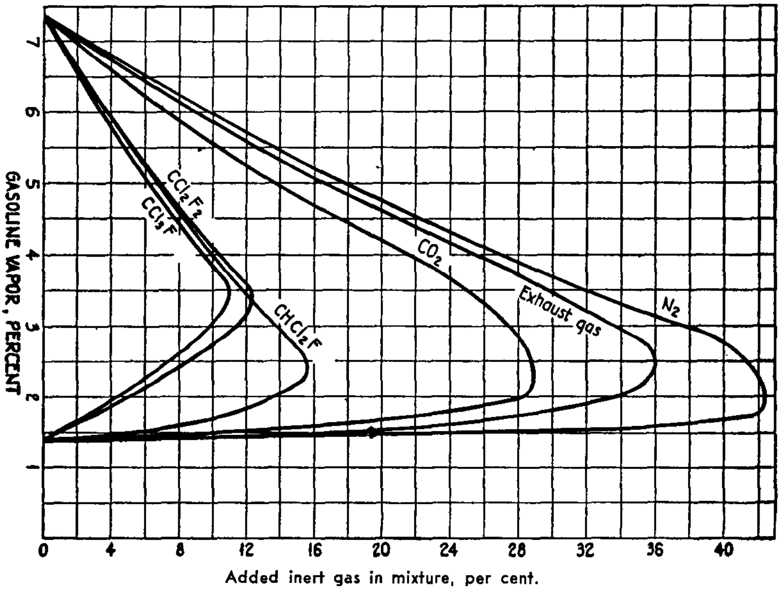

Figure 6. Limits of flammability of gasoline in the presence of various inert gases. Reprinted from Bulletin 503, U. S. Bureau of Mines.

Bureau of Mines Technical Paper 617 — Characteristics of Fuel Pitches and Their Explosibility in Pulverized Form, by Irving Hartmann, H. C. Howarth, and H. P. Greenwald, 1940, 45 pp.

Marks' Mechanical Engineers' Handbook, Rev. 5th ed., 1951 — Explosion Characteristics of Various Dusts, by Irving Hartmann, Table — Page 798.

Recent Research on the Explosibility of Dust Dispersions, by Irving Hartmann: Industrial and Engineering Chemistry, Vol. 40, pp. 752–758, April 1948.

The Explosibility of Starch Dust, by Irving Hartmann and John Nagy; Chemical and Engineering News, Vol. 27, pp. 2071–2072, July 18, 1949.

A–2211. The quantity of inert gas required under paragraphs 2211 and 2212 may be calculated as follows:

Volume of inert gas required for one inerting cycle:

$$V_2 = \frac{(P_1 - P_2)V_1}{P_1}$$

Oxygen content of enclosure after one inerting cycle, using an oxygen free inert gas:

$$O_1 = O_2 \frac{(P_2)}{(P_1)}$$

Oxygen content of enclosure after one inerting cycle, using a non-oxygen free inert gas:

$$O_1 = O_2 \frac{(P_2)}{(P_1)} + O_3 \frac{(P_1 - P_2)}{P_1}$$

where

P_1=pressure in enclosure (psia), after introduction of inert gas.

P_2=pressure in enclosure (psia), prior to introduction of inert gas.

V_1=total volume of enclosure, cu. ft.

V_2=volume of inert gas required, measured in standard cu. ft. (68° F., 14.7 psia).

O_1=proportion of oxygen in enclosure at end of inerting cycle.

O_2=proportion of oxygen in enclosure at start of inerting cycle.

O_3=proportion of oxygen in inert gas.

A–2211. Sample Calculation. Assume a 1,230 gal. vessel (total capacity) normally operating at a vacuum of 15 in. mercury:

$P_2=15$ in. Hg vacuum
7.37 psi vacuum

$P_2=14.7-7.37=7.33$ psia

$P_1=$atmospheric pressure (14.7 psia)

$V_1=\frac{1230}{7.48}=164.5$ cu. ft.

Volume inert gas required for one cycle:

$$V_2=\frac{(14.7-7.37)\text{ x }164.5}{14.7}=\frac{7.33\text{ x }164.5}{14.7}$$

$=82$ std. cu. ft.

Since the vessel initially contained no oxygen, the final oxygen content would depend on the oxygen in the venting gas. Assume an inert gas containing 3 per cent oxygen:

Final oxygen content:

$$O_1=O_2\frac{(P_2)}{(P_1)}+O_3\frac{(P_1-P_2)}{P_1}$$

$$=0.0+\frac{.03\ (14.7-7.37)}{14.7}=.015$$

$O_1\%=1.5\%$

A–2212. Sample Calculation. Assume a 1,230 gal. vessel designed to withstand full vacuum. A vacuum pump is available which will reduce the pressure in the vessel to 21 in. mercury.

$P_2=21$ in. Hg vacuum
10.3 psi vacuum

$P_2=14.7-10.3=4.4$ psia

$P_1=$Atmospheric,$=14.7$ psia

$V_1=\frac{1230}{7.48}=164.5$ cu. ft.

Volume inert gas required for one cycle:

$$V_2=\frac{(14.7-4.4)\ 164.5}{14.7}=\frac{10.3\text{x}164.5}{14.7}$$

$=115.3$ std. cu. ft.