



Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems¹

This standard is issued under the fixed designation G 128; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers an overview of the work of ASTM Committee G-4 on Compatibility and Sensitivity of Materials in Oxygen-Enriched Atmospheres. It is a starting point for those asking the question: “Are there any problems associated with my use of oxygen?” An introduction to the unique concerns that must be addressed in the handling of oxygen. The principal hazard is the prospect of ignition with resultant fire, explosion, or both. This hazard requires design considerations beyond those that apply to all systems, such as adequate strength, corrosion resistance, fatigue resistance, and pressure safety relief.

1.2 This guide also lists several of the recognized causes of oxygen system fires and describes the methods available to prevent them. Sources of information about the oxygen hazard and its control are listed and summarized. The principal focus is on Guides G 63, G 88, Practice G 93, and Guide G 94. Useful documentation from other resources and literature is also cited.

NOTE 1—This guide is an outgrowth of an earlier (1988) Committee G-4 videotape adjunct entitled *Oxygen Safety* and a related paper by Koch² that focused on the recognized ignition source of adiabatic compression as one of the more significant but often overlooked causes of oxygen fires. This guide recapitulates and updates material in the videotape and paper.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements see Sections 8 and 11.

¹ This guide is under the jurisdiction of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and is the direct responsibility of Subcommittee G04.02 on Recommended Practices.

Current edition approved Sept. 1, 2008. Published October 2008. Originally approved in 1995. Last previous edition approved in 2002 as G 128–95(2002) ^{ϵ 1}.

² Koch, U. H., “Oxygen System Safety,” *Flammability and Sensitivity of Materials In Oxygen-Enriched Atmospheres*, Vol 6, ASTM STP 1197, ASTM, 1993, pp. 349–359.

NOTE 2—ASTM takes no position respecting the validity of any evaluation methods asserted in connection with any item mentioned in this guide. Users of this guide are expressly advised that determination of the validity of any such evaluation methods and data and the risk of use of such evaluation methods and data are entirely their own responsibility.

2. Referenced Documents

2.1 ASTM Standards:³

G 63 Guide for Evaluating Nonmetallic Materials for Oxygen Service

G 88 Guide for Designing Systems for Oxygen Service

G 93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments

G 94 Guide for Evaluating Metals for Oxygen Service

G 126 Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres

G 128 Guide for Control of Hazards and Risks in Oxygen Enriched Systems

2.2 ASTM Adjuncts:

Video: Oxygen Safety⁴

2.3 ASTM CHETAH Program:

CHETAH Chemical Thermodynamic and Energy Release Evaluation⁵

2.4 Compressed Gas Association (CGA) Standards:⁶

G-4.1 Cleaning Equipment for Oxygen Service

G-4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁴ Available from ASTM International Headquarters. Order Adjunct No. ADJG0088.

⁵ Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428, Order # DSC 51C, Version 7.2.

⁶ Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.



2.5 *European Industrial Gas Association (EIGA) Standards*:⁷

33/97/E Cleaning of Equipment for Oxygen Service

2.6 *National Fire Protection Association (NFPA) Standards*:⁸

50 Standard for Bulk Oxygen Systems at Consumer Sites

51 Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting and Allied Processes

53 Recommended Practice on Material, Equipment, and Systems Used in Oxygen Enriched Atmospheres

99 Standard for Health Care Facilities

2.7 *Military Specifications*:⁹

MIL-PRF-27617 Performance Specification, Grease, Aircraft and Instrument, Fuel and Oxidizer Resistant

DOD-L-24574 (SH) Military Specification, Lubricating Fluid for Low and High Pressure Oxidizing Gas Mixtures

2.8 *NASA Documents*:¹⁰

KSC 79K22280 Specification for 1,000-GPM LO₂ Pump Bearings

3. Terminology

3.1 *Definitions*— See Terminology G 126 for the terms listed in this section.

3.1.1 *autoignition temperature (AIT)*, *n*—the lowest temperature at which a material will spontaneously ignite in an oxygen-enriched atmosphere under specific test conditions.

3.1.2 *hazard*, *n*—source of danger; something that could harm persons or property.

3.1.2.1 *Discussion*—The magnitude of a hazard relates to the severity of the harm it could cause.

3.1.3 *ignition temperature*, *n*—the temperature at which a material will ignite in an oxidant under specific test conditions.

3.1.4 *impact-ignition resistance*, *n*—the resistance of a material to ignition when struck by an object in an oxygen-enriched atmosphere under a specific test procedure.

3.1.5 *nonmetal*, *n*—any material, other than a metal, non-polymeric alloy, or any composite in which the metallic component is not the most easily ignited component and for which the individual constituents cannot be evaluated independently, including ceramics, such as glass; synthetic polymers, such as most rubbers, thermoplastics, and thermosets; and natural polymers, such as naturally occurring rubber, wood, and cloth. **nonmetallic**, *adj.*

3.1.6 *oxidant compatibility*, *n*—the ability of a substance to coexist at an expected pressure and temperature with both an oxidant and a potential source(s) of ignition within a risk parameter acceptable to the user.

3.1.7 *oxygen-enriched*, *adj.*—containing more than 25 mol percent oxygen.

3.1.7.1 *Discussion*—Other standards such as those published by NFPA and OSHA differ from the definition in their specification of oxygen concentration.

3.1.8 *qualified technical personnel*, *n*—persons such as engineers and chemists who, by virtue of education, training, or experience, know how to apply the physical and chemical principles involved in the reactions between oxidants and other materials.

3.1.9 *risk*, *n*—probability of loss or injury from a hazard.

3.1.9.1 *Discussion*—The magnitude of a risk relates to how likely a hazard is to cause harm. **G 128**

4. Significance and Use

4.1 The purpose of this guide is to introduce the hazards and risks involved with the handling of oxygen, cautioning the reader about the limitations of present practices and technology and about common hazards that often are overlooked. It then provides an overview of the standards produced by ASTM Committee G-4 and their uses, as well as similar documents available from other knowledgeable sources. It does not highlight standard test methods that support the use of these practices from this or other committees.

4.2 The standards discussed here focus on reducing the hazards and risks associated with the use of oxygen. In general, they are not directly applicable to process reactors in which the deliberate reaction of materials with oxygen is sought, as in burners, bleachers, or bubblers. Other ASTM Committees and products (such as the CHETAH program⁵) and other outside groups are more pertinent for these.

4.3 This guide is not intended as a specification to establish practices for the safe use of oxygen. The documents discussed here do not purport to contain all the information needed to design and operate an oxygen system safely. The control of oxygen hazards has not been reduced to handbook procedures, and the tactics for using oxygen are not unique. Rather, they require the application of sound technical judgement and experience. Oxygen users should obtain qualified technical expertise to design systems and operating practices to ensure the safe use of oxygen in their specific applications.

5. Summary

5.1 Oxygen and its practical production and use are reviewed. The recognized hazards of oxygen are described. Accepted and demonstrated methods to diminish those hazards are reviewed. Applicable ASTM standards from Committee G-4 and how these standards are used to help mitigate oxygen system hazards are discussed. Similar useful documents from the National Fire Protection Association, the Compressed Gas Association, and the European Industrial Gas Association also are cited.

6. Oxygen

6.1 Oxygen is the most abundant element, making up 21 % of the air we breathe and 55 % of the earth's crust. It supports plant and animal life. Oxygen also supports combustion, causes iron to rust, and reacts with most metals. Pure oxygen gas is colorless, odorless, and tasteless. Liquid oxygen is light blue and boils at −183 °C (−297 °F).

⁷ Available from European Industrial Gas Association, Publication de la Soudure Autogene, 32 Boulevard de la Chapelle, 75880 Paris Cedex 18, France.

⁸ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

⁹ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

¹⁰ Available from NASA, Engineering Documentation Center, John F. Kennedy Space Center, FL 32899.



6.2 Oxygen has many commercial uses. For example, it is used in the metals industry for steel making, flame cutting, and welding. In the chemical industry it is used for production of synthetic gas, gasoline, methanol, ammonia, aldehydes, alcohol production, nitric acid, ethylene oxide, propylene oxide, and many others. It is also used for oxygen-enriched fuel combustion and wastewater treatment. For life support systems it is used in high-altitude flight, clinical respiratory therapy or anesthesiology, and emergency medical and fire service rescues.

7. Production and Distribution

7.1 Most oxygen is produced cryogenically by distilling liquid air. The recent demand for ultrahigh purity within the semiconductor industry has led to much more thorough distillation of cryogenic oxygen. Further, noncryogenic production has become significant in recent years. The principal difference among these sources of oxygen is the resulting oxygen purity. The hazards of oxygen are affected greatly by purity and, in general, higher purity is more hazardous. However, fire events can and do occur in any oxygen-enriched atmosphere.

7.2 *Cryogenic Production*—Cryogenically produced oxygen is distilled in a five-step process in which air is: (1) filtered to remove particles; (2) compressed to approximately 700 kPa (100 psig) pressure; (3) dried to remove water vapor and carbon dioxide; (4) cooled to -160°C (-256°F) to liquefy it partially; and (5) distilled to separate each component gas. The end products are oxygen, nitrogen, and inert gases such as argon and neon; the principal secondary products are nitrogen and argon. Commercial oxygen is produced to a minimum 99.5 % purity, but typical oxygen marketed today is more likely to be near 99.9 % purity.

7.2.1 For high-volume bulk users, such as steel or chemical plants, the oxygen plant is often adjacent to the user's facility, and gas is delivered by pipeline at low to medium pressures, usually 700 to 5500 kPa (100 to 800 psig).

7.2.2 Cryogenic liquid oxygen is delivered by trailer to large-volume users, who utilize storage tanks and equipment to pump, vaporize, and distribute the gas (Fig. 1).

7.2.3 Most users buy oxygen in small amounts, usually in 20-MPa or 2500-psig cylinders, and use it directly from the cylinders or through manifolds and a piping distribution system. Usually, the pressure is reduced with a regulator at the cylinder or manifold.

7.3 *Ultrahigh-Purity Oxygen*—There are a few markets that require high- and ultrahigh-purity oxygen. High-purity oxygen typically delivers >99.99 % purity, whereas the demands of the semiconductor industry have resulted in the marketing of >99.999 % purity oxygen.

7.4 *Noncryogenic Production*—Noncryogenic oxygen production processes include pressure swing adsorption (PSA), vacuum swing adsorption (VSA), and membrane separation. In general, these methods produce oxygen less pure than cryogenically produced oxygen—typically < 97 %, with the balance being nitrogen, argon, and carbon dioxide. However, these processes use less power and offer a cost advantage for high-volume users who do not need higher purity.

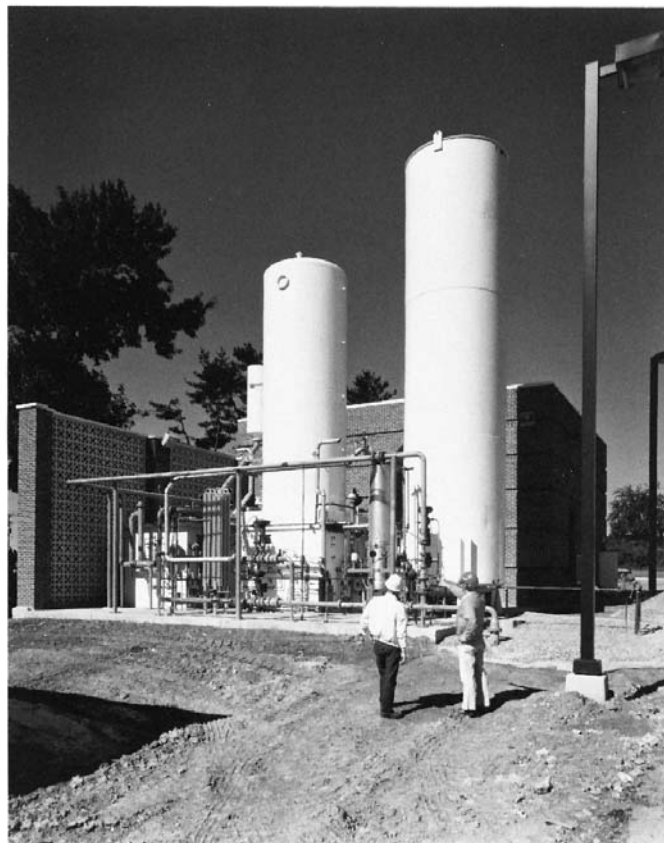


FIG. 1 High-volume Oxygen Users Buy the Gas in Bulk, Storing It in an Adjacent Facility

The equipment for these systems is typically large and is located on site. However, small medical-oxygen generators used in the home also are included in this category.

8. Hazards and Risks

8.1 How can oxygen be hazardous? It is all around us. It supports life and is used to support or resuscitate a person with oxygen deficiency (hypoxemia). It may have been used in a common familiar system for years without a problem. Could it be that oxygen is not hazardous? No, oxygen presents definite hazards.

8.2 Despite its apparent innocence in many instances, oxygen is a serious fire hazard. It makes materials easier to ignite and their subsequent combustion more intense, more complete, and more explosive than in air alone. Fires in air, which contain just 21 % oxygen, are common. The injuries, loss of life, and property damage they cause can be devastating. Fires and explosions that occur in oxygen-enriched atmospheres can be even more devastating, whether involving a patient in an oxygen-enriched environment or someone at an industrial site that uses oxygen.

8.3 Oxygen is not flammable by itself, but it supports combustion. In most instances, a fire occurs when an oxidant such as oxygen is combined chemically with a fuel. Hence, although oxygen is not flammable, its contribution to the production of fire and heat is otherwise comparable to that of the fuel. If there is no fuel, there is no fire. If there is no oxidant, there is no fire.



8.4 The ability of an oxygen-enriched atmosphere to support and enhance combustion after ignition occurs is its hazard. The risk to people and property that accompanies this hazard is variable. Sometimes the human risk is grave; sometimes the economic risk is severe. In these instances, the need to prevent combustion is imperative. Occasionally the risk is small enough that it can be accepted and other tactics may be used to minimize the risk. The overall concepts of hazard and risk have been lumped into the term “oxygen compatibility.”

8.4.1 ASTM Committee G-4 first codified its interpretation of the concept of “oxygen compatibility” in its Technical and Professional Training course textbook *Manual 36, Safe Use of Oxygen and Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation*.¹¹

“The ability of a substance to coexist with both oxygen and a potential source(s) of ignition within the acceptable risk parameter of the user [at an expected pressure and temperature].”

8.4.1.1 In this definition, a system is oxygen compatible if it cannot or is unlikely to burn, if the occurrence of fires is adequately infrequent, or even if potential fires can be isolated and their effects can be tolerated.

8.5 Other organizations have a similar respect for the hazards of oxygen. NFPA 53 is a concise, readable booklet that describes oxygen, its uses and hazards, design guidelines, aids to material selection, and references. Significantly, NFPA 53 presents more than 40 case studies of accidents with oxygen that shows just how serious, yet subtle, the hazard can be. Further, in most of its publications (NFPA 50, NFPA 51, NFPA 99), the NFPA view of oxygen compatibility is given as:

“Compatibility involves both combustibility and ease of ignition. Materials that burn in air will burn violently in pure oxygen at normal pressure and explosively in pressurized oxygen. Also many materials that do not burn in air will do so in pure oxygen, particularly under pressure. Metals for containers and piping must be carefully selected, depending on service conditions. The various steels are acceptable for many applications, but some service conditions may call for other materials (usually copper or its alloys) because of their greater resistance to ignition and lower rates of combustion.

“Similarly, materials that can be ignited in air have lower ignition energies in oxygen. Many such materials may be ignited by friction at a valve seat or stem packing or by adiabatic compression produced when oxygen at high pressure is rapidly introduced in a system initially at low pressure.”

9. Sources of Information

9.1 Despite the hazards inherent with pure oxygen and its mixtures, the risk of injury and economic loss can largely be controlled using methods documented in ASTM publications and many other sources. This is an overview of such sources,

by no means complete, intended only to assist the reader in finding additional information.

9.1.1 Designing equipment and systems to function safely in oxygen-enriched environments requires information about the behavior of materials in such environments. ASTM standard test methods have been developed to measure the ignition and combustion properties of materials in gaseous and liquid oxygen, at various concentrations and pressures, by tests that relate to the common ignition mechanisms.

9.1.2 Guides G 63 and G 94 provide the designer with compilations of data obtained by the above ASTM test methods and present a structured approach to using that data in practical applications. Guide G 88 presents a systematic approach to system design with emphasis on the special factors that should be considered to minimize the risk of ignition and fire.

9.1.3 Practice G 93 covers the selection of methods and materials to clean equipment for oxygen service. Examples are provided for specific materials and applications.

9.1.4 ASTM Committee G-4 sponsors an international Symposium on the Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres every two to three years. The papers presented at these symposia cover topics from combustion theory to practical applications and fire experiences. They are published in Special Technical Publications, which, along with their extensive list of references, represent the largest existing collection of published work on this subject.

9.1.5 A two-day Technical and Professional Training Course, Fire Hazards in Oxygen Handling Systems, is presented by ASTM G-4 members at least twice a year at a variety of locations. This course introduces participants to the fire risk in oxygen systems and presents a systematic approach to reducing the fire risk through the application of relevant ASTM and other industry standard publications. The textbook, *Fire Hazards in Oxygen Systems*,¹¹ teaches how to apply the many resources available to reduce the risk of oxygen fires. The video used in the course, *Oxygen Safety*,⁴ is a brief introduction to some of the hazards present in oxygen systems, particularly those often overlooked.

9.2 Industry associations such as the Compressed Gas Association, National Fire Protection Association, and European Industrial Gas Association have developed product standards, design guides, codes, and training aides to assist in reducing the risk of oxygen system fires.

9.3 Government agencies serving aerospace programs, the military, and national research laboratories, offer oxygen system safety information. In some countries, product testing and approval services are available through national laboratories.

9.4 Most oxygen producers provide their users with safety publications and offer resources to assist in design, operation, and training for personnel. A few examples of such publications are listed in Appendix X1. That list is neither complete nor is it an endorsement of those publications.

10. Causes of Fires in Oxygen

10.1 There is a considerable body of useful information that can aid in understanding the principles of ignition and flammability in oxygen-enriched environments. New theories are under development, as frequently reported at Committee G-4

¹¹ For more information regarding Standards Technology Training Courses and corresponding text material, contact ASTM Headquarters, Standards Technology Training, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

symposia. These developments are expanding our knowledge of oxygen safety. Indeed, some oxygen fires have not been explained fully and their causes are not known. However, many common ignition mechanisms and causes of oxygen system fires are recognized and well understood.

10.2 Kindling Chain—Ignition usually begins as a small event and grows into a fire through the kindling chain sequence. A small amount of energy ignites a material with a low ignition temperature or a particle with a large surface area and small mass. Once ignited, the material gives off enough heat to ignite bulk materials with higher ignition temperatures, which generate more heat, until the process is self-sustaining.

10.3 Ignition Mechanisms—Oxygen fires require a source of energy to trigger ignition, as do most fires. The most common ignition energy sources are: (1) mechanical impact; (2) particle impact; (3) friction; and (4) pneumatic impact or compression heating. The risk of ignition by these mechanisms, and others less often encountered, increases as the severity of the operating conditions in the oxygen system increases. This is discussed below.

10.3.1 Mechanical Impact—When one object strikes another, as with a hammer blow, the absorbed energy appears as heat. In an oxygen-enriched environment, that heat can be sufficient to ignite materials at the point of impact. Such an impact can occur in mechanical equipment used in oxygen service. Testing the resistance of materials to ignition by mechanical impact is one method used to compare candidate materials for use in oxygen systems.

10.3.2 Particle Impact—Small particles carried by flowing gas in the oxygen system strike surfaces of the system, such as piping intersections or valve seats. The kinetic energy of the particle creates heat at the point of impact, which can ignite either the particle or the target material.

10.3.3 Friction—The rubbing of two solid materials results in the generation of heat.

10.3.4 Pneumatic Impact or Compression Heating—A common but easily overlooked cause of ignition is the rapid pressurization of a system, resulting in compression heating of the oxygen, ignition of contaminants or polymers, and fire or system rupture, which may be violent. Compression heating has caused an ignition in a new system the first time it is pressurized with oxygen, usually because of contamination or a system design error. In other cases, compression heating has caused ignition in a system after months or years of successful operation. Such delayed events are often attributed to unsuspected changes such as the gradual accumulation of contaminants, introduction of combustible particles, component wear, system alterations made during maintenance, or changes in operating procedures.

10.3.4.1 When a gas flows from high to low pressure, it often reaches sonic velocity, usually at the seat of a valve or regulator. When the high-velocity gas suddenly stops flowing at an obstruction, it compresses the oxygen downstream to the original pressure and the temperature rises. This results in nearly adiabatic compression. (Complete adiabatic compression would occur if the gas were compressed so rapidly that no heat is lost to the surroundings.) The higher the pressure differential, the higher the final temperature. Anyone who has

inflated a tire with a hand pump recognizes the effect; the pump gets hot as air is compressed in it. Diesel engines use the same principle. The pistons compress air in the cylinders to high pressure, the air gets hot, and injected fuel ignites without a spark plug.

10.3.4.2 Near-adiabatic compression occurs in a piping system when a valve is opened quickly and the high-velocity gas stream compresses the oxygen downstream against an obstruction, such as the seat of the next closed valve or regulator (**Fig. 2**). When that happens, the gas temperature can rise to well over 540 °C (1000 °F), as noted in **Guide G 63**. The gas temperature can reach the autoignition point of plastics, organic contaminants, or small metal particles, whose combustion can add enough heat to ignite the metal in a valve or fitting. Other particles which will not burn, such as dirt or scale, generate friction when carried at high velocity by the gas stream and retain the heat of compression at the point of impact, thereby aiding ignition of the kindling chain. **Guide G 63** contains a technical discussion of these ignition mechanisms.

11. Hazards

11.1 Recognized Hazards—Within any system, a number of key parameters are recognized that can increase the hazard and make ignition more likely: (1) oxygen concentration and associated diluents; (2) pressure; (3) temperature; (4) phase; (5) velocity; (6) time and age; and (7) mechanical failure.

11.1.1 Oxygen Concentration and Associated Diluents—Higher oxygen concentrations increase the hazards of ignition and fire intensity because more oxygen is available to mix with the fuel. The nature of the diluent gases can have a significant effect on the overall hazard. Inert diluents of large molecular weight are most effective at reducing the hazard. In a few extreme cases, even small amounts of diluents (tenths of a percent) can reduce the flammability of some materials.

11.1.2 Pressure—Higher pressures increase the hazards of ignition and fire intensity. Pressure increases the density of the gas, with the same effect as increasing the concentration: more oxygen is available to the fuel, so materials ignite easier and burn faster. Pressure also increases the gas velocity at restrictions such as valves, regulators, and intersections which increases particle impact and compression heating.

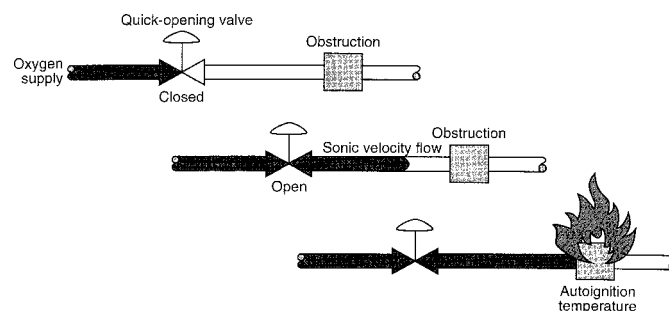


FIG. 2 Near-adiabatic Compression Can Occur When Oxygen Under High Pressure Is Released Quickly into a Low-pressure System. The Gas Flow Can Reach the Speed of Sound, and if It Encounters an Obstruction, the Temperature Can Rise High Enough to Initiate Ignition and Cause a Fire



11.1.3 Temperature—Temperatures most often encountered in oxygen systems have relatively little effect on the intensity of combustion and resulting damage. However, higher temperatures tend to increase the likelihood of ignition. They may enable combustion to occur in a system that is not otherwise flammable because less energy must be added to reach the ignition temperature of a material. In addition, high temperatures can accelerate the aging of polymers and thereby reduce their compatibility with oxygen.

11.1.4 Phase—Liquid oxygen exists at cryogenic temperatures, and low temperatures generally result in a decreased likelihood of ignition, fire intensity, and resulting damage. However, the density of liquid oxygen is hundreds of times greater than that of gas and it is 100 % pure, making far more oxygen available to the fuel than does high pressure gaseous oxygen. Further, combustion generates enormous pressures as the liquid changes to a gas. If liquid oxygen is mixed with high-surface-area flammable materials the resulting fire can be explosive. Indeed, liquid oxygen in combination with carbon particles has been used as a high explosive. For this reason, liquid oxygen containing fine particles represents an exceptionally severe hazard.

11.1.5 Velocity—Increased oxygen velocities in flowing systems lead to higher particle velocities, which increase the likelihood of ignition by particle impact.

11.1.6 Time and Age—Time and age are important hazards. Many fires in oxygen-enriched atmospheres occur the first time the system is used or the first time it is operated after a shutdown. Contributing factors include poor design, incorrect operation, inadequate cleaning, and foreign objects left in the system. Systems fabricated with materials not considered compatible, based on the guidance of ASTM standards, may operate successfully for extended periods. However, with time, polymers in the system may age and become brittle or porous, contamination may increase, and mechanical failures may become more likely. Thus, it becomes easier to initiate the kindling chain that results in a system fire.

11.1.7 Mechanical Failure—Mechanical failures in oxygen systems frequently lead to ignition and become more likely as the system becomes older. The mechanical impact of broken parts can ignite components. Rubbing, in a compressor, for example, can generate heat to ignite parts and can shed particles that could be ignited as they are generated or from impact as they are carried elsewhere in the system. Particles also can be generated as polymers wear and age and lead to a mechanical failure. Failed seals can lead to rapid pressurization. Hence, every oxygen system component should be designed for high mechanical reliability and special attention should be given to the potential effect of mechanical failures.

12. Fire Prevention

12.1 Combustion in air that contains about 21 % oxygen is a familiar hazard. Well-known fire prevention methods focus on separating the three elements essential to creating a fire: (1) the oxidant; (2) the fuel; and (3) the ignition sources. Preventive measures are applied progressively, depending on the severity of the fire hazard.

12.1.1 For example, in an area where combustible materials of minimal hazard are stored, it may be sufficient simply to

maintain good housekeeping practices, preventing accumulations of combustible trash and to prohibit open fires. In a flammable solvent storage area, the fire hazard is greater; consequently, prevention includes more strict housekeeping, elimination of all other combustible storage, and prohibition of all open flames and sparks. If flammable liquids are used in open containers, allowing the vapors to mix with air, one would do all of the above and add such measures as explosion-proof electrical systems to control ignition sources. Finally, if highly flammable materials are used in large quantities or in processes, it may become necessary to displace the air with an inert gas to eliminate the oxidant, in addition to taking all the preceding measures.

12.1.2 This example shows that as the severity of the fire hazard in air increases, progressively more stringent precautions are taken and prevention moves to the next higher level. In each instance, the preceding levels are not omitted, rather, they become even more strict to form the foundation on which the following levels are built.

12.2 Ordinary methods of preventing fires in air, separating the oxidant, fuel, and ignition sources, do not apply in oxygen systems because: (1) the process fluid is the oxidant and cannot be removed; (2) the materials used to build the system are flammable in oxygen under at least some conditions, hence the system is the fuel and cannot be eliminated; and (3) ignition sources exist within the system itself. Therefore, fire prevention in oxygen systems requires a new focus to control these inseparable elements. Combustible materials cannot be eliminated, but their selection can be controlled. Similarly, ignition sources in the system must be identified and controlled.

12.2.1 Just as in air, there is a progression of control measures that must be taken to prevent fires in oxygen services, depending on the severity of the fire hazard. Progressively more stringent practices are applied in this order: cleaning, compatible lubricants, compatible polymers and other nonmetals, and compatible metals. When oxygen concentration and pressures are low, the hazard is lowest and cleaning may be the only control necessary. As oxygen enrichment and pressure increase, careful cleaning is required and lubricants are selected more carefully. At higher pressures, careful cleaning, selection of lubricants, and selection of polymers and other nonmetals are all important. And finally, at the level of greatest severity, metals must be selected carefully in addition to all the preceding measures.

12.2.1.1 As each level of the oxygen service fire-prevention progression comes into play, the preceding levels must be maintained and strengthened to support the levels that follow. The levels at which these progressive measures must be applied are based on the relative flammability of the system elements. As oxygen concentration and pressure increase, various elements of a system become potentially flammable and must be either removed (as with contaminants) or upgraded (as with lubricants, polymers, and metals).

12.2.2 The measures used to reduce the hazard in oxygen systems may also be used to reduce the fire hazard in air. However, for the most part, they are used only on systems that are oxygen enriched or on high-pressure air systems, which are also more hazardous than low-pressure air systems.



12.3 Recognizing, identifying, and controlling potential sources of ignition and possible causes of fire is not simple. Present knowledge does not enable us to identify all potential ignition sources. Hence, few oxygen systems can enjoy a certainty that fires are not possible. There is a strong empirical influence in the approach to oxygen system safety practices. To a large extent, one does what has been successful in the past, provided it has been successful often, for long periods of time, and is based on sound principles. For this reason, ASTM Committee G-4 standards take a multi-pronged approach that attempts to align as many factors as possible toward reducing the likelihood of ignition and fire.

12.3.1 This approach is based on using the extensive body of information available on the ignition and flammability of materials and on methods with demonstrated ability to reduce the number and severity of fires in oxygen. Guides **G 63**, **G 88**, **G 94**, and Practice **G 93**, describe many factors affecting oxygen or oxygen-enriched systems and describe how to reduce the hazards associated with these systems.

12.3.2 Those discussions correlate control of oxygen system hazards with special attention to: (1) system design; (2) component selection; (3) system operation; (4) cleaning; (5) compatible lubricants; (6) compatible polymers and other nonmetals; (7) compatible metals; or (8) isolation and shielding. Each of these elements is discussed in detail below.

13. System Design

13.1 Oxygen system design should not be undertaken casually. These systems require careful and specialized design considerations. The first and most important rule is: Consult an expert! Guides **G 63**, **G 88**, Practice **G 93**, and Guides **G 94**, **G 128** define “qualified technical personnel” and provide vital information for use by these experts. Indeed in many companies, specific individuals are designated as specialists to acquire the expertise and assist others in oxygen system design.

13.2 Oxygen system design should begin with the same principles as conventional air or gas system design and follow the same nationally recognized codes and standards. There are no special codes that mandate how to design oxygen systems. The added hazards inherent in the use of oxygen should then be evaluated to modify conventional practices. In general, that leads to a more, not less, conservative design.

13.3 The severity of system operating conditions is defined by five of the seven hazards discussed in Section 11: concentration, pressure, temperature, phase, and time. As these factors increase the hazards, the system design must be modified to a greater extent. Oxygen concentration and phase are established by the system function, but the others can be influenced by design. For example, the hazard of high pressure can be minimized by placing a regulator as close as possible to the gas source. Temperatures can be limited, for example, by including protection from runaway heaters. The effects of time and age can be mitigated by designing for effective preventive maintenance.

13.3.1 Velocity is a hazard that is controlled primarily by overall system design. Line sizes should be selected to follow guides for oxygen system velocity, which generally are lower than the limits used in conventional systems. Abrupt size changes and the location of intersections and components can

be controlled by system design to minimize particle impingement and compression heating, especially near polymers. CGA **G-4.4** recommends that velocities should be limited wherever possible and means should be provided to increase the resistance to ignition at locations where high velocities may occur.

13.4 The considerations discussed below must be evaluated individually and also integrated into the overall design. For example, initial cleanliness is established as components are built and the system is fabricated. The system design must consider maintaining the required level of cleanliness thereafter, such as by preventing contamination during operation and maintenance and by providing for inspection and cleaning throughout the life of the system.

13.5 Guide **G 88**, CGA **G-4.4**, NFPA **50** and **51**, and many others provide excellent guidelines for system design, although these references are not handbooks. The ASTM G-4 Committee Technical and Professional Training course *Fire Hazards in Oxygen Handling System* teaches the fundamentals of oxygen safety for oxygen process designers and equipment specifiers and includes a textbook.¹¹ This course introduces participants to the fire risk in oxygen systems and presents a systematic approach to reducing the fire risk through the application of relevant ASTM and other industry standard publication.

14. Component Selection

14.1 ASTM Committee G-4 standards do not recommend specific products for oxygen service and do not imply that products can be marketed under a blanket claim of meeting any of the four applicable standards (**G 63**, **G 88**, **G 93**, or **G 94**). Clearly, the thrust of these standards is to enable qualified technical personnel to evaluate system needs in the context of a particular application. As the application changes, such as exposure to higher pressure, a host of conditions change, or hazard thresholds are crossed, that may render previously acceptable products unacceptable for further use. Therefore, although there may be a few products that are acceptable in any and all oxygen applications, one cannot consider products to be “approved for oxygen service” under the procedures of these standards without also specifying the conditions for which the approvals are intended.

14.2 Some products are marketed for oxygen service, but not every experienced designer will agree that every one of these products has adequate oxygen compatibility or even that a blanket approval is reasonable. Some companies do list materials approved across the board, but many others tie approval to specific applications and level of application hazard. The user must determine whether the properties of the particular products (whether or not they are marketed for oxygen service) actually meet the needs of the user’s specific application.

14.2.1 Performance tests conducted by hardware manufacturers generally do not simulate any specific application. Laboratory tests cannot duplicate the endless variety of actual operating conditions; such tests only indicate a predicted result in a controlled laboratory setting and cannot ensure the same result in a particular application or service.

14.2.2 Material qualification tests also are method specific and rarely afford blanket approval. The user should evaluate



the material test results along with the test method to determine if they correspond to the way the material will be used in a specific design.

14.3 It is also important to note that most common industrial components, such as valves, fittings, filters, regulators, gages, and other instruments, are not designed for specific applications. Rather, they are versatile, general-purpose products that can be used properly in many types of applications and systems. Hardware manufacturers in general have neither the experience nor expertise to select the most appropriate components for a specific use, such as an oxygen system. Only the oxygen system designer or user can have full knowledge of the entire system and each component's function, which must be considered when selecting the system components. Oxygen system designers and users both must be sensitive to product function, material compatibility, adequate ratings, and proper installation, operation, and maintenance.

14.4 Valve selection requires special attention by the system designer, because valves are one of the few mechanical items that are actuated routinely while the system is in use. The designer must determine the type of valve, its location, how it will be operated, and, often neglected, how it might be operated incorrectly. For example, a ball valve sometimes is included in a system as a quick-closing valve for emergency shut off in case of a system fire. However, such emergency shut off valves have been used improperly to pressurize or vent the system and thereby caused ignition by compression heating.

14.4.1 Particular attention should be directed to valve pressure and temperature ratings, internal materials of construction, and how readily the valve can be cleaned and kept clean. Valves often are selected with higher ratings, greater wall thicknesses, and more fire-resistant materials than the rest of the system because they are exposed to more severe service conditions.

14.5 As valves are opened and closed, they almost always generate localized high velocities near the valve seat or immediately downstream. This creates a local increase in the hazard level at the valve location and often requires that special consideration be given to the selection of seat materials and potential impingement areas nearby.

14.5.1 Oxygen system valves also pose a more serious risk of personal injury because many are opened and closed manually so that at the very moment they are most susceptible to the conditions that can cause a fire, someone is near them and is actuating the valve.

14.5.2 Guide G 88, CGA G-4.4, and NFPA 51 unanimously emphasize that valves under pressure must be opened slowly. Opening speed is controlled by valve design, as well as by operating procedures. Ball, plug, and butterfly valves are used in some low-pressure systems such as pipelines, because their straight-through design provides a lower pressure drop than a globe valve. However, ball and plug valves are quick opening and create high velocity when opened, whereas needle valves are designed to open slowly (Fig. 3). If a full-flow valve is used in a high-pressure service, the piping system must be designed with a small diameter equalization line across the valve before it is opened.

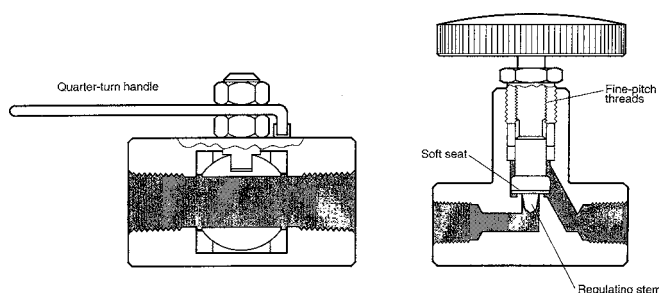


FIG. 3 Ball Valves and Plug Valves Are Quick-Opening (left), Requiring Only a Quarter Turn to Go from Closed to Wide Open. Needle Valves (right) Are Designed to Open Slowly, with Fine-pitch Threads, Regulating Stems for Gradual Opening, and Soft Seats for Gas-Tight Shut-off

14.5.3 Even while closed, valves require extra consideration. Valves used in gas services often have seats or stem tips made of polymers that are exposed to the system fluid when the valve is closed. If an upstream valve is opened rapidly the adiabatic compression heating can occur at the polymer seat of a closed valve and initiate the kindling chain which leads to a system fire.

15. System Operation

15.1 Perhaps the most neglected aspect of controlling oxygen system hazards involves system operation. Oxygen fires frequently are caused by systems whose safe operation depends so greatly on the operator's strict adherence to certain procedures that they cannot tolerate simple human error. In these poorly designed systems, a single mistake, such as actuating one of a series of valves in the wrong sequence, can lead to catastrophe. The following examples, documented in the ASTM video adjunct entitled, *Oxygen Safety*,⁴ illustrate several design errors that invited and then compounded operator errors, causing serious accidents.

15.1.1 In one instance, an operator opened a ball valve in a high-pressure manifold. The abrupt compression of the oxygen downstream at the inlet of a closed valve ignited the valve and destroyed the manifold.

15.1.2 In a second similar situation, a ball valve was located between a cylinder valve and a regulator. When the operator opened the ball valve, the regulator ignited and caused serious injuries to the operator.

15.2 Both systems previously had been used successfully for some time, probably because the operator always remembered to open the ball valve first, before opening the cylinder valve. And both examples illustrate how the design error of using quick-opening valves in high-pressure oxygen systems compounded the error of total reliance on operator attention to procedures for safe operation.

15.2.1 In addition, the seat of the closed ball valve in the first example and the seat of the regulator in the second case exposed a significant amount of polymer at the point of compression heating. In both instances, the polymer seat ignited and initiated the kindling chain that destroyed the rest of the system.

15.3 Still another design error increased the likelihood of fire in the second example: the function of the regulator and



ball valve assembly required frequently removing the assembly from and replacing it on the cylinder. The assembly's design did not protect it from contamination or provide means for routine maintenance and cleaning. Consequently, the accumulation of contaminants in the regulator may have contributed to its ignition.

15.4 As noted in the video adjunct⁴, thorough planning and careful monitoring of operating procedures and maintenance practices are important in oxygen fire prevention. However, safe operation should be engineered into the design of an oxygen system by the selection and placement of components, for example, and not rely solely on operator compliance with procedures to prevent oxygen fires.

16. Cleaning

16.1 Cleaning is the first measure required, even though it may be the last step accomplished in preparing a system for oxygen service. Any such system typically must be evaluated carefully for cleanliness, and most will be cleaned thoroughly. In fact, the extent of cleanliness used on a system exposed to only 25 % oxygen mixtures may be very similar to that applied to pure-oxygen, high-pressure systems.

16.2 Organic contaminants and fine particles burn violently in concentrated oxygen and are often the beginning of the kindling chain that starts a fire. Hydrocarbon oil or grease contamination is particularly undesirable. For low-pressure applications the particle impact hazard is not as severe and so it may be possible to relax the cleaning requirement as compared to that required for a high-pressure application.

16.2.1 The basis for determining the oxygen concentration and pressure at which more thorough cleaning is needed should be related to the flammability of the contaminants, lubricants, polymers, and metals. If the contaminants are unidentified, one must assume that they may be flammable and therefore must be eliminated at even a small increase in oxygen concentration or pressure.

16.3 Cleaning methods should be evaluated and selected following the guidance contained in Practice **G 93**, CGA **G-4.1**, EIGA **33/97/E**, and . Practice **G 93** provides special guidance for cleaning components in its Section on Interferences.

16.3.1 *Disassembly:*

16.3.1.1 It is imperative that oxygen systems be cleaned as individual articles, preferably prior to assembly. Assembled systems must be disassembled for cleaning if construction permits. Flushing an assembled system can deposit and concentrate contaminants in stagnant areas.

16.3.1.2 Manufactured products (for example, valves, regulators, and pumps) preferably should be cleaned by the manufacturer prior to final assembly and test. The purchaser should approve the cleaning procedure and packaging to ensure that they satisfy the system requirements.

16.3.1.3 Manufactured products that are cleaned by the purchaser must be disassembled for cleaning if construction permits. The purchaser should follow the manufacturer's instructions for disassembly, inspection for damage, reassembly, and testing. If the product cannot be disassembled completely the manufacturer should be consulted to determine that the cleaning procedure will remove contaminants adequately,

particularly lubricants, and will not leave contaminants or solvents in trapped areas or crevices.

16.4 Practice **G 93** contains additional information on cleaning methods, interferences with effective cleaning, packaging, and inspection, including examples of specific applications.

16.5 The gas delivered by the completed system and the oxygen used to fill the system should be tested for purity. An inert gas may be used for purity testing. Numerous incidents have been reported where medical oxygen systems in health-care facilities were contaminated with toxic solvent residues which resulted in injuries and fatalities.

17. Compatible Lubricants

17.1 If cleanliness is the first special measure that is necessary, the next concern is with lubricants, for two reasons. First, most common oils and greases are hydrocarbons, which are among the materials most necessary to remove from an oxygen system. Second, lubricants are fluids and pastes, which are more prone to migrate and collect within the piping system than are solid materials.

17.2 Any lubricants used in an oxygen system should be fire resistant. In most instances, even with mild oxygen exposures at low pressure and at oxygen concentrations as low as 25 %, fire-resistant lubricants or other fluids should be used.

17.2.1 Several halogenated oils and greases have been tested and used widely with success in oxygen service. Lubricant manufacturers should be consulted for chemical, physical, and functional use properties of lubricants for specific applications. Oxygen manufacturers should be consulted on the oxygen compatibility aspects of lubricants for specific applications taking into account all critical process parameters such as oxygen purity, pressure, temperature, velocity, and component or system design. Guide **G 63** includes test data on many lubricants, thread compounds, seats, and gaskets. Specifications MIL-G-27617, **DOD-L-24574(2)**, and **KSC 79K22280** may also be consulted for choosing oxygen-compatible greases and lubricants.

17.3 Practice **G 93**, Section on Interferences, provides special guidance for lubrication of components:

17.3.1 *Lubricants:*

17.3.1.1 Mechanical components are normally assembled with lubricants on seals, threads and moving surfaces. The manufacturer should be consulted to determine the kind of lubricant originally used on the article to ensure that the cleaning solutions and methods selected are effective in removing the lubricant and will not damage the component.

17.3.1.2 Oxygen-compatible lubricants should be selected in accordance with Guide **G 63**. The component manufacturer should also be consulted to ensure that the selected lubricant provides adequate lubrication for component performance. Oxygen-compatible lubricants often have markedly different lubricating properties from conventional lubricants.

17.4 The lubricant manufacturer should be consulted to ensure that the oxygen-compatible lubricant is compatible with the polymers and elastomers used in the components. Incompatible lubricants may change the properties of a sealing element and destroy its functional value.



17.5 Scrupulous cleaning combined with the use of fire-resistant lubricants may be the only special precautions needed in moderate services. Lubricants should be evaluated and selected following the guidance contained in Guide G 63. However, all lubricants should be used sparingly and with great caution.

18. Compatible Polymers and Other Nonmetals

18.1 As the severity of the hazards (such as higher pressure, temperature, or oxygen concentration) increases to elevate system operating conditions above the level at which both cleaning and compatible lubricants are necessary, the next hazard is that of compatible polymers. At room temperature and low pressures, below about 350 kPa (50 psig), and at oxygen concentrations between 30 and 100 %, most users switch to more fire-resistant polymers for gaskets, valve seats, packings, and other polymer parts.

18.2 Most polymers burn in pure oxygen, usually violently. They ignite more easily than metals and can initiate the kindling chain that ignites the system. These materials include the many polymers and elastomers used as seats, stem tips, packings, gaskets, seals, and thread sealants in pumps, valves, regulators, filters, instruments, and most other piping components.

18.2.2 As emphasized in Guide G 63, the successful use of even the best materials depends on the design of the component and where it is used. For example, PTFE-lined flexible hose has a large surface area-to-mass ratio, and many instances involving the ignition of such hoses have been reported (Fig. 4). The safe use of PTFE-lined hose in high-pressure oxygen may require special provisions in the system design.¹²

18.2.2.1 Most polymers produce toxic gases when they decompose, which can contaminate breathing gas systems even if there is no external fire, as noted in Guide G 63. Chlorine and fluorine based polymers, such as polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE) which often are selected for oxygen service, yield particularly hazardous products of combustion. The hazard is most pronounced when a polymer ignites in an oxygen system used for breathing gases. The ignition of a polymer component within a system may cause a transient fire that consumes the polymer element, but it is not noticed immediately because it does not ignite the surrounding metal and penetrate the system boundary. If the transient fire occurs in an oxygen system which provides a breathing gas mixture, the toxic combustion products may go undetected and result in personal injuries without warning and before the functional failure of the system is observed.

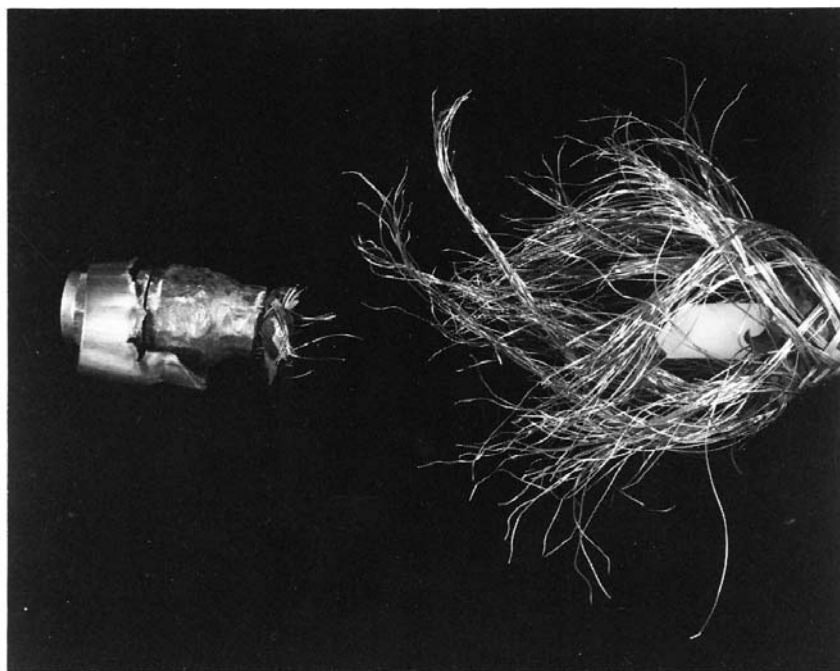


FIG. 4 Even PTFE Fluorocarbon-lined Hose Can Ignite and Burn Violently at the Temperatures Generated by Near-adiabatic Compression

18.2.1 Polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE) are listed by CGA G-4.4 as suitable for oxygen service and are used for many functions in piping components. Yet, even these materials begin to decompose at 200 to 300 °C (400 to 600 °F) and can ignite at higher temperatures.

¹² Barthelemy, H. and Vagnard, G., "Ignition of PTFE-Lined Hoses in High Pressure Oxygen Systems: Test Results and Considerations for Safe Design and Use," *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres*, Vol 3, ASTM STP 986, ASTM, 1988, pp. 289–304.



18.3 Operating conditions also must be considered in polymer selection. Continuous exposure to elevated temperatures or high oxygen concentrations can change a material into something quite different from what it was when new. With age, the material may become harder, softer, or brittle, or the surface may change. The molecular weight may decrease by scission or increase by cross-linkage. Such changes are accelerated by pressure and temperature and may decrease resistance to ignition and fire, as well as change performance properties.

18.4 For use at temperatures above the service limits of polymers, these materials sometimes are replaced by graphite, particularly in packings and gaskets. Being pure carbon, graphite will burn in an oxygen-enriched atmosphere. Although difficult to ignite in bulk form, graphite particles from packing wear may ignite more readily. Graphite introduces an additional concern because it is cathodic to most metals and causes corrosion in moist atmospheres. Although oxygen systems are generally dry, external moisture can initiate corrosion which can cause hidden damage.

18.5 All nonmetals should be tested and evaluated carefully before being used in a particular oxygen system application. Guide G 63 presents a systematic approach to selecting non-metallic materials, with numerous practical examples. It includes a compilation of test data for many nonmetallic materials frequently used in oxygen service. Chapter 3 of NFPA 53 also describes the ignition and combustion properties of materials commonly used in oxygen-enriched atmospheres.

19. Compatible Metals

19.1 Most common metals will burn in pure oxygen under at least some conditions of pressure and temperature. The most familiar example is cutting steel with an oxygen torch (Fig. 5). A torch ignites the steel, and then a stream of oxygen keeps it burning. The heat of the burning steel continues the cutting

action. The same process can happen accidentally in improperly designed oxygen piping systems (Fig. 6).

19.2 Typically, the last hazard threshold crossed as the severity of the hazards in an oxygen system increases is that for which compatible metals are required. It is difficult to ignite common steels at pressure below 1 mPa (150 psig) or at oxygen concentrations less than 40%. At higher concentrations and pressures, most users select more compatible metals.

19.3 NFPA 51 and CGA G-4.4 mention existing practices for the use of steel or stainless steel for oxygen systems, but only at 7 mPa (1000 psig) or less. Further, in regions of high velocity or impingement, such as valves, orifices, branch connections, and other critical areas, copper and nickel-based alloys (brass and alloy 400) are recommended, except for low pressures to 1.4 mPa (200 psig), where selected stainless steels may be used. For operating pressures above 7 mPa (1000 psig) CGA G-4.4 recommends asking the oxygen supplier to provide specific guidance.

19.4 Metals should be evaluated and selected following the guidance contained in CGA G-4.4 and Guide G 94, which provides extensive data on metal ignition in oxygen, guidance for metals selection, and several practical examples. Any system that requires special metals to cope with the oxygen hazard also requires special consideration be given to cleaning, lubricants, and nonmetals.

20. Isolation and Shielding

20.1 When there is a concern that the hazards of a system cannot be controlled to an acceptable level of risk with design, component selection, operating practices, and compatible materials, or when a system cannot be modified to improve its compatibility, then isolation or shielding should be considered.

20.1.1 Isolation implies that a worst-case fire event would be adequately remote from people or valuable materials so that the risk is acceptable. To apply this tactic, work stations may be

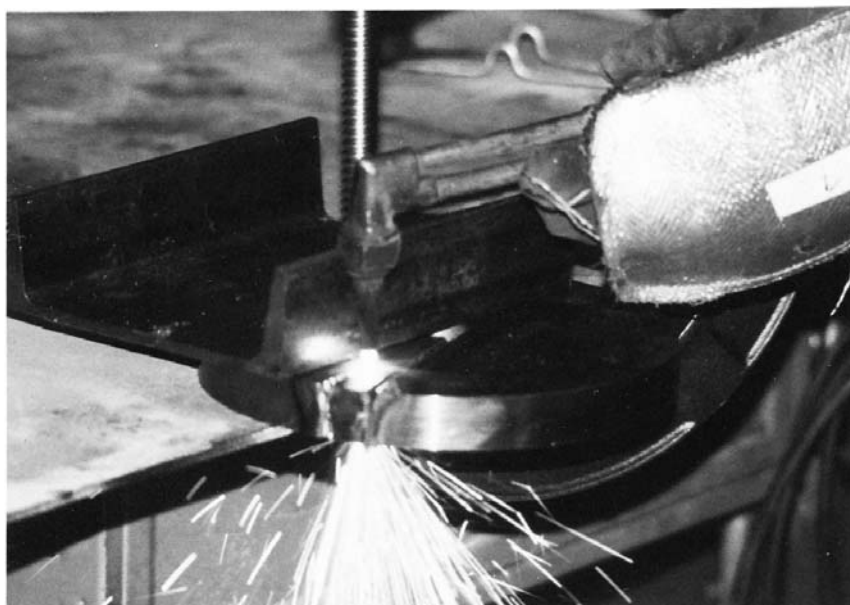


FIG. 5 An Oxygen Torch Can Cut Even Thick Steel Plate; the Torch Ignites the Metal, and the Oxygen Keeps it Burning

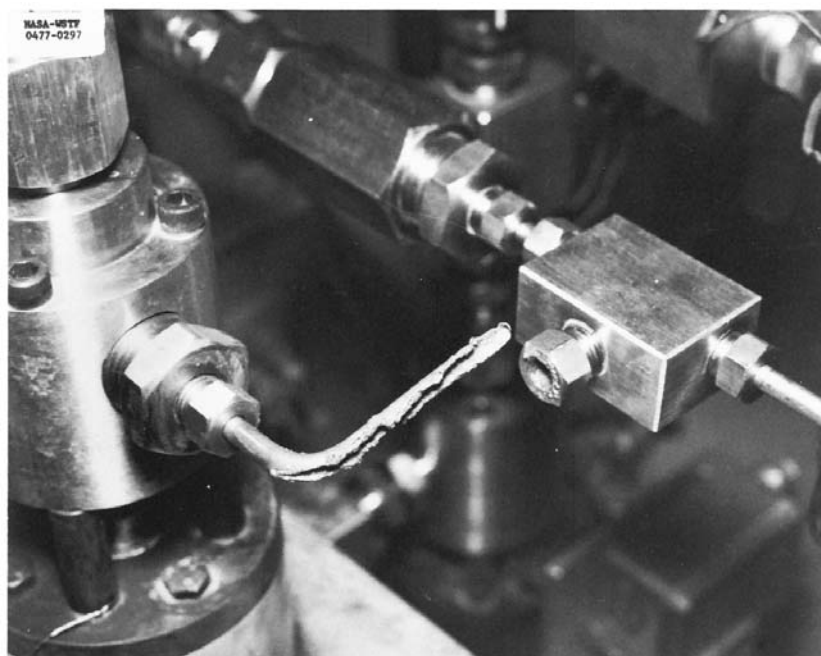


FIG. 6 Adiabatic Compression Initiated the Oxygen Fire that Burned Out this Stainless Steel Tubing

moved, portions of systems or entire systems may be relocated, or other measures taken to increase the distance between the system and those items whose loss would be unacceptable. This tactic presumes that the loss of the isolated system is an acceptable, unavoidable loss.

20.1.2 Shielding implies that a barrier can be provided around high-hazard or high-risk systems and that the barrier will contain or deflect a worst-case fire. This tactic also presumes that the loss of the shielded system is an acceptable, unavoidable loss.

20.1.2.1 At present, the only systems that apply this technique routinely are oxygen compressors, pumps, and some turbo-expanders. This machinery often cannot employ the optimum materials, and usually there is so much kinetic energy involved that a mechanical failure produces at least a transient fire. Therefore, such machinery is designed using materials and practices that optimize its reliability and performance to minimize the number of mechanical failures and the fire hazard. In addition, such machinery is shielded to contain any fires that may occur and avoid secondary damages.

20.1.2.2 Simple, inexpensive shields also can be effective. In small high-pressure systems, fires generally occur at components such as valves and regulators that are manually actuated and therefore exposed to operating personnel. Mounting such components and controls to operate pumps and other components on panels provide a simple, yet effective, local shield to protect nearby personnel.

20.2 There are no ASTM standards that provide help with the design of shields or the selection of adequate isolation distances. CGA, the Department of Defense, NFPA, BG Chemie, and EIGA publications describe some currently used shields.

21. Keywords

21.1 adiabatic compression; autoignition; barriers; cleaning; combustion; compression heating; contamination; explosion; fire; flammability; GOX; ignition; liquid oxygen; LOX; material evaluation; material selection; oxygen; oxygen compatibility; oxygen enriched; oxygen hazard; oxygen safety; oxygen service; oxygen systems; shielding

TABLE 1 Survey of North American and European Test Methods and Practices for Oxygen System Safety

Method/Practice etc.	BAM ^A	ASTM	Other European Standards/ Documents	VBG ^B	CGA ^C	NFPA ^D	Other North American Standards/ Documents
General information about oxygen and oxygen system hazards	...	...	...	...	CGA ^C G4.0	NFPA ^D 53	SAE-Aircraft Oxygen System Handbook
Design of systems for oxygen service	...	Guide G 88; Committee G.04 ^E STT Course, Manual 36 ^F	EIGA-IGC Document 13/97 ^G ; BS 3N 100 ^H	VBG 62	CGA ^C G4.4	NFPA ^D 50	NASA-WSTF Test Plan No. TP-WSTF-713 ^I



TABLE 1 Continued

Method/Practice etc.	BAM ^A	ASTM	Other European Standards/ Documents	VBG ^B	CGA ^C	NFPA ^D	Other North American Standards/ Documents
Evaluation of nonmetallic materials for oxygen service	...	Guide G 63	EIGA-IGC Document 13/97 ^G	VBG 62	...	...	...
Evaluation of metals for oxygen service	...	Guide G 94	EIGA-IGC Document 13/97 ^G	VBG 62	...	...	...
Cleaning methods for material and equipment	...	Practice G 93	EIGA-IGC 33/86 ^G	VBG 62	CGA G4.1	...	Mil-Std 1246
Pneumatic Impact Test (PIT)—Materials	BAM PIT; see “Liste” ^J	Test Method G 74	...	...	...	...	NASA-STD 6001 ^K Test 14; Mil-V-5027D ^L
PIT-components	BAM PIT; required for “approval” in Germany and several other European countries	Test Method G 74	ISO 2503 ^M ; DIN, 8545 ^N and 8546; TRG 770 ^O , Anlage 1, proposed European Norm 849, CEN/TC 23SC 2N 138 (not yet available)	...	...	...	NASA-WSTF Test Plan No. TP-WSTF-712 ^L ; Mil-V-5027D ^L
Auto Ignition (AIT) high pressure	BAM AIT	Test Method G 74	BS 3N 100 ^H (Bomb test); NF E29-763/91 ^P ; ISO TC58/WG7 ^M	...	...	...	...
AIT-atmospheric pressure	BAM AIT	...	BS 3N 100 ^H (Pot test) DIN 51794	...	...	...	...
Heat of Combustion (HoC)	BAM HoC	Test Method D 4809	DIN 51900 ^N	...	...	...	...
Oxygen Index (OI)	BAM OI	Test Method D 2863	ISO 4589 ^M (DIN 22117 ^M)	...	...	...	...
Mechanical Impact Test (MIT)-LOX	BAM MIT	Test Method G 86	BS 3N 100 ^H (LOX Impact Test)	...	...	...	NASA-STD 6001 ^K Test 13A
MIT-pressurized LOX and GOX	...	Test Method G 86	...	...	...	...	NASA-STD 6001 ^K Test 13B
Test determining the combustion behavior of metals	...	Standard Test Method (under preparation)	...	...	...	...	NASA-STD 6001 ^K Test 17 ^{RS}
Aging of polymeric material	Practice briefly described in “Liste” ^J	Standard Guide (under preparation)	ISO 188 ^M DIN 53508 ^N IEC 493 ^O IEC 610 ^O	...	...	...	...

^A BAM-Bundesanstalt für Materialforschung und Prüfung (Berlin, Germany). A brief description of each test method available from BAM. See ASTM STP 986 pp 268–278 for review of all BAM Methods. BAM PIT test methods are the primary methods used in Europe to establish suitability for oxygen service.

^B VBG-Die Unfallverhütungsvorschriften der Berufsgenossenschaft der chemischen Industrie (Heidelberg, Germany). See also Merkblatt M 034-6/2001–BGI 617 (ZHL/307 and VBG B7 (VBG 62)).

^C CGA-Compressed Gas Association (Chantilly, VA, USA)—see also CGA G4.1, G4.3, G4.5, P-14, SB-2, and SB-9.

^D NFPA-National Fire Protection Association (Quincy, MA, USA). See also NFPA 51, 99, 70, 90A, and 91.

^E ASTM Technical and Professional Training Course entitled “Fire Hazards in Oxygen-Handling Systems.”

^F ASTM Manual 36.

^G EIGA-IGC-European Industrial Gases Association-Industrial Gases Council (Bruxelles, Belgium). The document 13/97 entitled “The Transportation and Distribution of Oxygen by Pipelines,” provides recommendations for design, construction operating, and maintenance of oxygen systems. Several additional documents concerning O₂ handling are available from EIGA-IGC. The documents are 6/77, 8/76, 10/81, 11/82, 16/85, 20/83, 21/85, 27/82, TN 28/80, and TN 32/82.

^H British standard 3N 100: 1985 specifies the general design requirements for aircraft oxygen systems and equipment. It specifies three test methods: the bomb test, the pot test, and the LOX mechanical impact test.

^I NASA White Sands Test Facility (Las Cruces, NM, USA). TP-WSTF-712 “Guide for Oxygen Component Qualification Tests.” TP-WSTF-713 “Guide for Oxygen Hazards Analysis on Components and Systems.”

^J BAM “Liste”—test results published yearly and available through “Jedermann Verlag” in Heidelberg Germany.

^K NASA STD 6001: “Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion.”

^L Mil-USA Military standard “Valves, Check, Oxygen, High Pressure”. MIL Standards are issued by Department of Defence.

^M ISO-International Organization for Standardization (Geneva, Switzerland). Working group, WG7, is preparing a new ISO standard on oxygen compatibility of materials as of April 1993.

^N DIN-Deutsches Institut für Normung (Berlin, Deutschland).

^O TRG-Technische Regeln Druckgase.

^P French standard for valves and gas cylinders. Test method for determination of the spontaneous ignition temperature of nonmetallic material in pressurized gaseous oxygen, i.e. bomb test.

^Q IEC-International Electrotechnical Commission (registered office in Genève, Switzerland).

^R SAE-Society of Automotive Engineers, Inc. (Warrendale, PA, USA). 1993 SAE Aircraft Oxygen Equipment Handbook contains 30 references (Aerospace Standards, Recommended Practices, Information Reports, Technical Standards and Orders issued by FAA) and several other references. Also military standards used in UK.

^S NASA-National Aeronautics and Space Administration, Washington, D.C., USA. See published reports and technical memorandums.



APPENDIX

(Nonmandatory Information)

X1. REFERENCES

X1.1 The following are additional sources of information on oxygen systems, listed by publisher.

Air Products and Chemicals, Inc., 7201 Hamilton Blvd., Allentown, PA 18195-1501

Safetygram 1, Gaseous Oxygen, 1991.

Safetygram 6, Liquid Oxygen, 1989.

American National Standards Institute, 11 W. 42nd St., New York, NY 10036

ANSI B31.3 Chemical Plant and Petroleum Refinery Piping.

ANSI Z49.1 Safety in Welding and Cutting.

ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

D2512 Test Method for Compatability of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass/Fail Technique)³

D 2863 Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index)⁵

D 4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Intermediate Precision Method)⁶

G 72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment.

G 74 Test Method for Ignition Sensitivity of Materials to Gaseous Fluid Impact³

G 86 Test Method for Determining the Ignition Sensitivity of Materials to Mechanical Impact in Pressurized Oxygen Environments⁷

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, STP 812, B. L. Werley, Ed., 1983.

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, Second Volume, STP 910, M. A. Benning, Ed., 1986.

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American Welding Society, 550 N.W. Lejeune Rd., Box

351040, Miami, FL 33135

AWS C-4.2 Operator Manual for Oxy-fuel Gas Cutting. Berufsgenossenschaft der Chemischen Industrie (BG Chemie), Published by Jedermann-Verlag Dr. Otto Pfeffer oHG, Postfach 10 31 40, D-69021 Heidelberg, Germany

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CGA Video AV-8 Characteristics and Safe Handling of Cryogenic Liquid Gaseous Oxygen.

CGA E-2 Hose Line Check Valve Standards for Welding and Cutting.

CGA G-4 Oxygen.

CGA G-4.3 Commodity Specification for Oxygen.

CGA P-14 Accident Prevention in Oxygen-Rich and Oxygen-Deficient Atmospheres.

CGA P-2.5 Trans-filling of High Pressure Gaseous Oxygen Used for Respiration.

CGA TB-3 Hose Line Flashback Arresters.

European Industrial Gas Association (EIGA), Publication de la Soudure Autogene, 32 Boulevard de la Chapelle, 75880 Paris Cedex 18, France.

EIGA 5/75/E Code of Practice for Supply Equipment and Pipelines Distributing Non-Flammable Gases and Vacuum Services for Medical Purposes.

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Factory Mutual Engineering Corp., Box 9102, Norwood, MA 02062

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

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UL 252 Compressed Gas Regulators.

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