Standard Guide for
Control of Hazards and Risks in Oxygen Enriched Systems[1]

1. Scope

1.1 This guide covers an overview of the work of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen-Enriched Atmospheres. It is a starting point for those asking the question: "What are the risks associated with my use of oxygen?" This guide is 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. All fluid systems require design considerations, such as adequate strength, corrosion resistance, fatigue resistance, and pressure safety relief. In addition to these design considerations, one must also consider the ignition mechanisms that are specific to an oxygen-enriched system. This guide outlines these ignition mechanisms and the approach to reducing the risks.

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 G63, G88, Practice G93, and Guide G94. Useful documentation from other resources and literature is also cited.

NOTE 1—This guide is an outgrowth of an earlier (1988) Committee G04 videotape adjunct entitled *Oxygen Safety* and a related paper by Koch[2] 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 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *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.

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]

D2512 Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques)

D2863 Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)

D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

G63 Guide for Evaluating Nonmetallic Materials for Oxygen Service

G72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment

G74 Test Method for Ignition Sensitivity of Nonmetallic Materials and Components by Gaseous Fluid Impact

G86 Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments

G88 Guide for Designing Systems for Oxygen Service

G93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments

G94 Guide for Evaluating Metals for Oxygen Service

G124 Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres

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[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.

[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.

[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.

G126 Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres

G175 Test Method for Evaluating the Ignition Sensitivity and Fault Tolerance of Oxygen Pressure Regulators Used for Medical and Emergency Applications

2.2 *ASTM Adjuncts:*

Video: Oxygen Safety[4]

2.3 *ASTM CHETAH Analytical Computer Software Program:*

CHETAH Chemical Thermodynamic and Energy Release Evaluation[5]

2.4 *Compressed Gas Association (CGA) Standards:*[6]

G-4.1 Cleaning Equipment for Oxygen Service

G-4.4 Oxygen Pipeline and Piping Systems

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

33/XX/E Cleaning of Equipment for Oxygen Service

13/XX/E Oxygen Pipeline and Piping Systems

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

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

55 Compressed Gases and Cryogenic Fluids Code

99 Health Care Facilities Code

2.7 *Military Specifications:*[9]

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

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

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology G126 for the terms listed in this section.

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

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

3.1.4 *ignition mechanisms, n*—These are the specific physical attributes and system conditions that cause the initial fire within a system. A system designer must evaluate an oxygen-enriched system for all possible ignition mechanisms. A common ignition mechanism for metals is particle impact. A common ignition mechanism for non-metals is adiabatic compression.

3.1.5 *ignition temperature, n*—the temperature at which a material will ignite under specific test conditions.

3.1.6 *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.

3.1.7 *nonmetal, n*—a class of materials consisting of polymers, certain composite materials (polymer matrix and brittle matrix composites in which the most easily ignited component is not a metallic constituent), ceramics, and various organic and inorganic oils, greases, and waxes. **nonmetallic**, adj.

3.1.8 *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.

3.1.9 *oxygen-enriched, adj*—containing more than 23.5 mol percent oxygen.

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

3.1.10 *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.

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

3.1.12 *system conditions, n*—the physical parameters of a specific system. These can include local and system-wide pressure, temperature, flow, oxygen concentration, and others.

3.1.13 *wetted material, n*—any component of a fluid system that comes into direct contact with the system fluid.

4. Significance and Use

4.1 The purpose of this guide is to introduce the hazards and risks associated with oxygen-enriched systems. This guide explains common hazards that often are overlooked. It provides an overview of the standards and documents produced by ASTM Committee G04 and other knowledgable sources as well as their uses. It does not highlight standard test methods that support the use of these practices. Table 1 provides a graphic representation of the relationship of ASTM G04 standards. Table 2 provides a list of standards published by ASTM and other organizations.

4.2 The standards discussed here focus on reducing the hazards 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 program[5]) 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

TABLE 1 Relationship of ASTM Standards for Oxygen-Enriched Systems
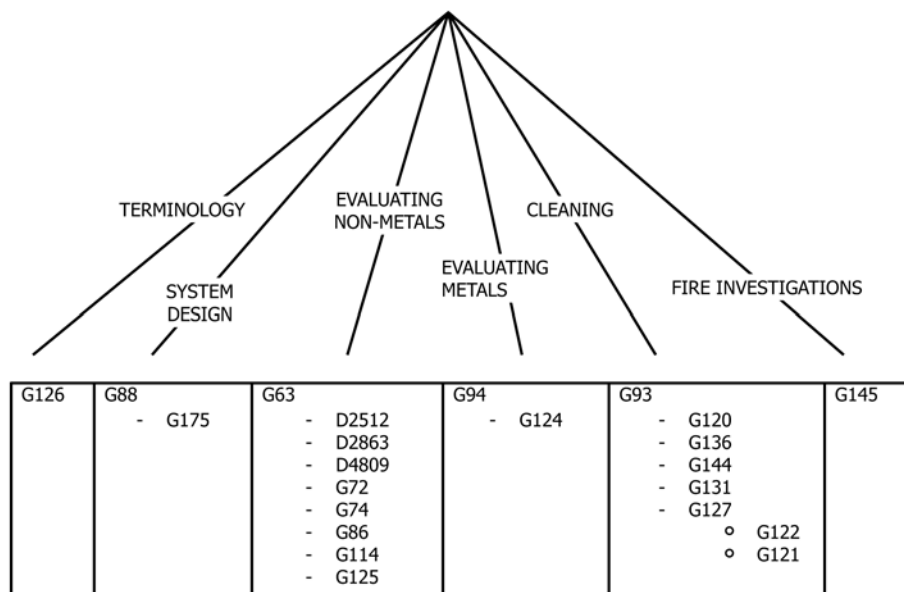
here do not purport to contain all the information needed to design and operate an oxygen-enriched system safely. The control of oxygen hazards has not been reduced to handbook procedures, and the tactics for using oxygen are not simple. Rather, they require the application of sound technical judgment and experience. Oxygen users should obtain assistance from qualified technical personnel to design systems and operating practices for 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 reduce those hazards are reviewed. Applicable ASTM standards from Committee G04 and how these standards are used to help mitigate oxygen-enriched 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] under ambient pressure.

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, deep-sea diving, 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 demand for ultrahigh purity within the semiconductor industry has led to a 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 detailed below. 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 gaseous oxygen 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 other large-volume users, who utilize liquid storage tanks, then vaporize the liquid, and distribute the gas (Fig. 1 and Fig. 2).

FIG. 1 Skid-Mounted Cryogenic Oxygen Storage
Image courtesy of Essex Industries

FIG. 2 Cryogenic Oxygen Storage
Image courtesy of Air Liquide America

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.

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-enriched systems present definite hazards.

8.2 Oxygen 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 these fires cause can be devastating. Fires and explosions that occur in oxygen-enriched atmospheres can be even more devastating due to the intensity of the combustion.

8.3 Oxygen is not flammable by itself, but it supports combustion. Fire typically occurs when an oxidant such as oxygen is combined chemically with a fuel in the presence of an ignition source or sufficient heat (Fig. 3). Hence, although oxygen is not flammable, its contribution to the production of fire is otherwise comparable to that of the fuel. If there is no fuel, there is no fire. If there is no oxygen, there is no fire.

8.4 The ability to support and enhance combustion after ignition is the hazard associated with an oxygen-enriched atmosphere. 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 developed to minimize the risk. The overall concepts of hazard and risk have been lumped into the term "oxygen compatibility."

8.4.1 ASTM Committee G04 first codified its interpretation of the concept of "oxygen compatibility" in its Technical and

FIG. 3 The Fire Triangle
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Professional Training course textbook *Manual 36, Safe Use of Oxygen and Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation*:[10] Oxygen compatibility is 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 burn 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 51, NFPA 55, 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 guide is an overview of such sources, 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 G63 and G94 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 G88 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 G93 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 G04 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 G04 members at least twice a year at a variety of locations. This course introduces participants to the fire risk in oxygen-enriched 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*,[10] 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-enriched 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-enriched 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 *Particle Impact*—This ignition mechanism is typically found to ignite metals. Particle impact ignition occurs when a particle at high linear velocity strikes a flammable target. The high linear velocity can occur within several components in the system. Flow control valves, orifices, regulators, check valves and other fluid components can all provide flow restrictions that result in high linear velocity. The kinetic energy of the particle creates heat at the point of impact, which can ignite the particle, the target, or both.

10.2 *Adiabatic Compression*—This ignition mechanism is typically found to ignite non-metals. Adiabatic compression ignition occurs when there is rapid pressurization of a system volume with an exposed non-metal. The rapid pressurization results in heating that causes the temperature to rise above the

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

auto-ignition temperature of the non-metal material and the material starts to burn.

10.3 *Mechanical Impact*—This ignition mechanism is typically found to ignite non-metals. Mechanical impact ignition occurs when a material experiences impacts that generate heat in excess of the auto-ignition temperature and the material starts to burn.

10.4 *Galling and Friction (Frictional Heating)*—This ignition mechanism can be found to ignite both metals and non-metals. Frictional heating ignition in non-metals occurs when two surfaces are rubbing in a way that the non-metal material heats above the auto-ignition temperature. Frictional heating ignition in metals occurs when the two surfaces are rubbing and the metal oxide layer is removed, which exposes the active, bare metal to the enriched oxygen.

10.5 *Electric Arc*—This ignition mechanism can be found to ignite both metals and non-metals. Electric arc ignition occurs when powered components are ungrounded or otherwise build an electrical charge that once released provides sufficient heat to ignite the material.

10.6 *Static Discharge*—This ignition mechanism can be found to ignite both metals and non-metals. Static discharge ignition is similar to electric arc ignition. It occurs when electrical charge builds and is released providing sufficient heat to ignite the material.

10.7 *Resonance*—This ignition mechanism can be found to ignite both metals and non-metals. Resonance ignition occurs when particles or the gas molecules vibrate with increasing amplitude inside a cavity. The resonance generates sufficient heat to ignite the particles or nearby material.

10.8 *Promoted Ignition/Kindling Chain*—This ignition mechanism can be found to ignite both metals and non-metals. Promoted ignition/kindling chain ignition occurs when a burning material has a heat of combustion sufficient to ignite a nearby material. The fire continues to ignite nearby components due to either the components' inability to transmit the heat or the components' low heat of combustion.

10.9 *Thermal Ignition*—This ignition mechanism is typically found to ignite non-metals. Thermal ignition occurs when

an outside heat source raises the temperature of a material above its auto-ignition temperature and ignites the material.

10.10 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 G04 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-enriched system fires are recognized and well understood. For a more detailed explanation of these ignition mechanisms please refer to the other standards published through the ASTM G04 committee.

11. Hazards

11.1 *Recognized Hazards*—Within any system, a number of conditions 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 linear gas velocity at restrictions such as valves, regulators, and intersections which increases particle impact and compression heating effects.

11.1.3 *Temperature*—Temperatures most often encountered in oxygen-enriched 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.
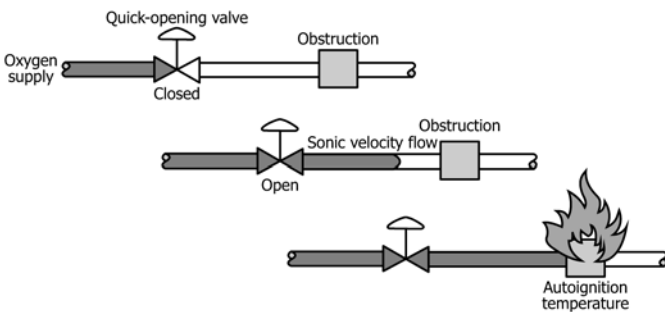

FIG. 4 Adiabatic Compression Can Occur When Oxygen Under High Pressure is Released Quickly into a Low-pressure System. The Gas Flow Can Reach the Speed of Sound, and if it Encounters an Obstruction, the Temperature Can Rise High Enough to Initiate Ignition and Cause a Fire

11.1.5 *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-enriched 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-enriched 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 open air, which 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-enriched 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-enriched 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 Like in air systems, there is a series 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, all wetted material including lubricants, metals, and non-metals must be selected more carefully.

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-enriched systems can enjoy a certainty that fires are not possible. There is a strong empirical influence in the approach to oxygen-enriched 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 G04 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 G63, G88, and G94, and Practice G93 describe many factors affecting oxygen-enriched systems and describe how to reduce the hazards associated with these systems.

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

13. System Design

13.1 Oxygen-enriched 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 G63, G88, G94, and G128/G128M, and Practice G93 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-enriched system design.

13.2 Oxygen-enriched 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-enriched 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 Linear velocity is a hazard that is controlled primarily by overall system design. Line sizes should be selected to follow guides for oxygen-enriched system velocity. System velocity is generally 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 impact and compression heating ignition mechanisms, especially near polymers. CGA G-4.4 recommends that linear velocities should be limited wherever possible and means should be provided to increase the resistance to ignition at locations where high linear 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 G88, CGA G-4.4, NFPA 51 and 55, and many others provide excellent guidelines for system design, although these references are not handbooks. The ASTM G04 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.[10] This course introduces participants to the fire risk in oxygen-enriched 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 G04 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 (G63, G88, G93, or G94). Clearly, the thrust of these standards is to provide guidelines to qualified technical personnel who can 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, and 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-enriched system. Only the oxygen-enriched 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-enriched 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 adiabatic compression.

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 linear 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-enriched 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 G88, 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 a high linear velocity when opened, whereas needle valves are designed to open slowly (Fig. 5). If a quick-opening 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.

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, adiabatic compression ignition can occur at the polymer seat of a closed valve and initiate the kindling chain which leads to a system fire.

14.5.4 Valve construction methods and techniques can be as important as valve design. In some applications, the system designer may require the manufacturer to provide a quality plan with hold points for customer inspection. These hold points may include:

14.5.4.1 Confirming Bill of Materials,

14.5.4.2 Confirming components are free of burrs, sharp edges and mechanical damage,

14.5.4.3 Confirming application of the proper amount and type of lubricant.

14.5.4.4 Inspecting for oxygen cleanliness (e.g. free of oil, grease, lubricants, sealant anti-seizing paste or preservatives). This inspection may be done by visual inspection under UV-light or white light.

15. System Operation

15.1 Perhaps the most neglected aspect of controlling oxygen-enriched 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-enriched 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 adiabatic compression. 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 adjunct,[4] 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-enriched system by the selection and placement of components, for example, and not rely solely on operator compliance with procedures to prevent oxygen fires.
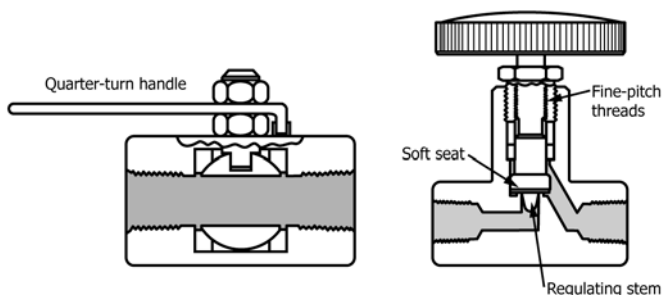

FIG. 5 Ball Valves and Plug Valves (left) Are Quick-Opening, Requiring Only a Quarter Turn to Go from Fully Closed to Fully Open. Needle Valves (right) Are Designed to Open Slowly, with Fine-pitch Threads for Gradual Opening, and Soft Seats for Gas-Tight Shut-off

16. Cleaning

16.1 Cleaning is a primary safeguard for an oxygen-enriched system. Any such system must be evaluated carefully for cleanliness, and must be cleaned thoroughly to the required levels. 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 must be avoided.

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 G93, CGA G-4.1, and EIGA 33/XX/E. Practice G93 provides special guidance for cleaning components in its Section on Interferences.

16.3.1 *Disassembly:*

16.3.1.1 It is imperative that oxygen-enriched systems be cleaned as individual articles, prior to assembly. Assembled systems that have not been cleaned prior to assembly or that may have become contaminated during storage or handling must be disassembled for cleaning before being placed into service. Flushing an assembled system can deposit and concentrate contaminants in stagnant areas.

16.3.1.2 Manufactured products (for example, valves, regulators, and pumps) must be cleaned by the manufacturer or manufacturer's subcontractor prior to final assembly and testing. The cleaned equipment must be packed in clean packaging and labeled with the corresponding cleanliness level. Subsequent assembly and testing procedures shall be carefully controlled to prevent recontamination. 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. The purchaser should follow the manufacturer's instructions for disassembly, inspection for damage, reassembly, and testing. If the product cannot be dissembled completely, the manufacturer should be consulted to determine whether the cleaning procedure will remove contaminants adequately, particularly lubricants, and will not leave contaminants or solvents in trapped areas or crevices.

16.4 Practice G93 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 compatible with the application. An inert gas may be used for system testing. Ensure that the system testing does not generate particles or otherwise increase the risk of conditions that contribute to ignition mechanisms. Numerous incidents have been reported where medical oxygen-enriched systems in healthcare facilities were contaminated with toxic solvent residues which resulted in injuries and fatalities.

17. 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-enriched 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 Lubricants shall be used sparingly and shall never be used on moving parts exposed to liquid oxygen or cold gaseous oxygen. Any lubricants used in an oxygen-enriched system should be evaluated for use in oxygen service.

17.2.1 Several halogenated oils and greases have been tested and used widely with success in gaseous 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, linear velocity, and component or system design. Guide G63 includes test data on many lubricants, thread compounds, seats, and gaskets. Specifications MIL-PRF-27617 and DOD-PRF-24574(2) may also be consulted for selecting greases and lubricants.

17.3 Practice G93, 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 Lubricants should be selected in accordance with Guide G63. The component manufacturer should also be consulted to ensure that the selected lubricant provides adequate lubrication for component performance. These lubricants may have different lubricating properties from conventional lubricants.

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

17.5 Scrupulous cleaning combined with the use of properly evaluated lubricants may be the only special precautions needed in moderate services. Lubricants should be evaluated and selected following the guidance contained in Guide G63. However, all lubricants should be used sparingly.

18. 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 properly evaluated lubricants are necessary, the next hazard is that of polymers.

18.2 Most polymers burn in pure oxygen, usually violently. Polymers 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.

18.2.1 Polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE) are commonly used in oxygen service. Yet, even these materials begin to decompose at 200 to 300°C [400 to 600°F] and can ignite at higher temperatures.

18.2.2 As emphasized in Guide G63, 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. 6). The use of PTFE-lined hose in high-pressure oxygen may require special provisions in the system design, such as a distance-volume piece.[11]

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 G63. Chlorine-based and fluorine-based polymers, such as polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE) which often are selected for oxygen service, yield particularly haz-

ardous products of combustion. The hazard is most pronounced when a polymer ignites in an oxygen-enriched 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-enriched 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.

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 finish 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 many 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-enriched systems are generally dry, external moisture can initiate corrosion which can cause hidden damage.

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[11] 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.
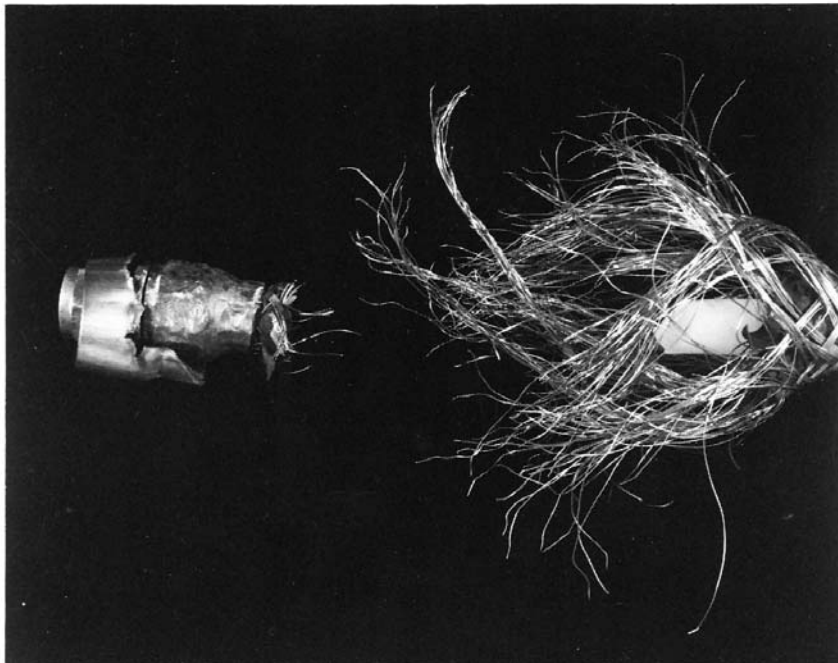

FIG. 6 PTFE Fluorocarbon-lined Hose Ignited and Consumed by Adiabatic Compression

18.5 All nonmetals should be tested and evaluated carefully before being used in a particular oxygen system application. Guide G63 presents a systematic approach to selecting nonmetallic 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. 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. 7). 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-enriched piping systems (Fig. 8).

19.2 Typically, the last hazard threshold crossed as the severity of the hazards in an oxygen-enriched system increases is that for which compatible metals are required.

19.3 Metals should be evaluated and selected following the guidance contained in CGA G-4.4 and Guide G94, which provide extensive data on metal ignition in oxygen-enriched systems, guidance for metals selection, and several practical examples. Any system that requires special metals to reduce 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 materials, or when a system cannot be modified to reduce the hazard to an acceptable level, 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 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 Some 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 behind panels may 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 United States Department of Defense, NFPA, BG Chemie, and EIGA publications describe some currently used shields.
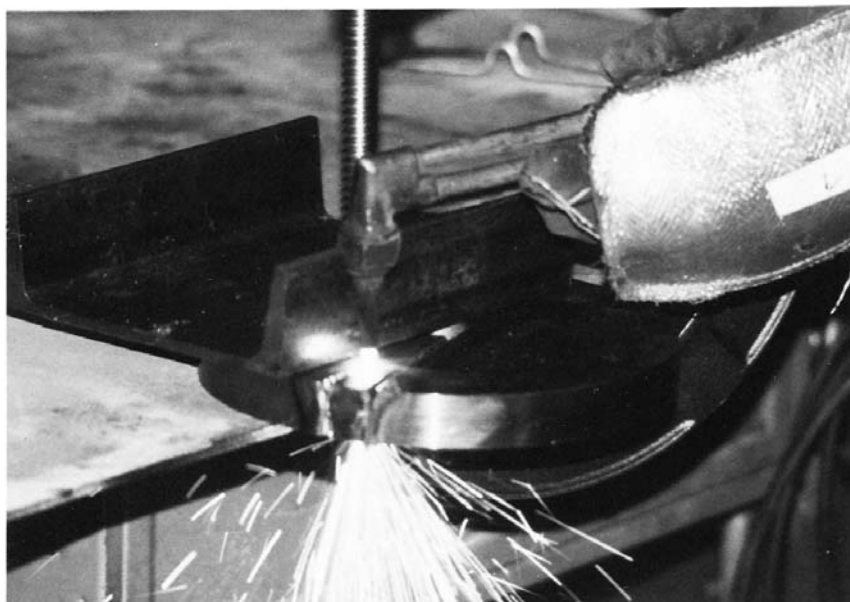

FIG. 7 An Oxygen Torch Can Cut Even Thick Steel Plate; the Torch Ignites the Metal, and the Oxygen Keeps it Burning
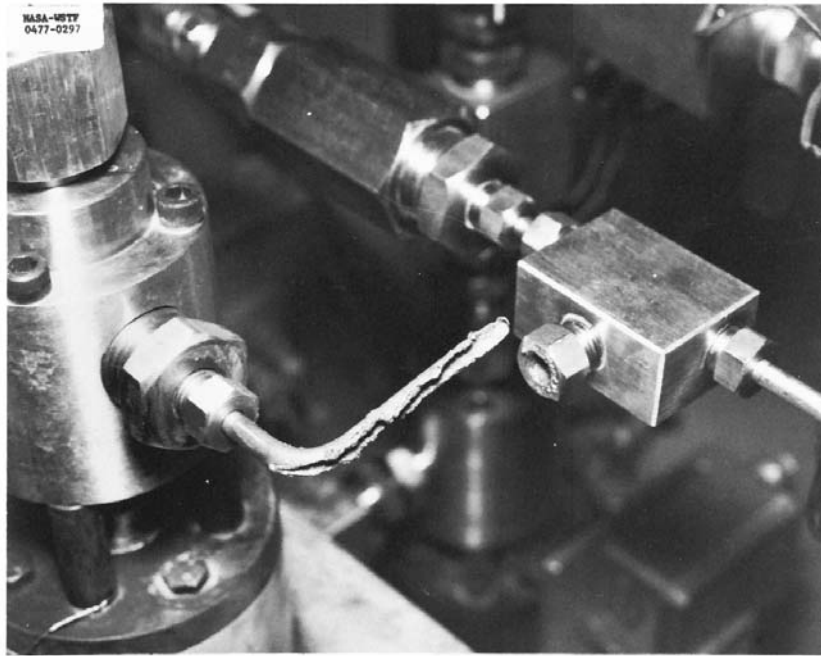
FIG. 8 Damage to Stainless Steel Tubing Caused by a Fire Initiated by Adiabatic Compression Initiated

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

Method/Practice etc.	BAM[A]	ASTM International	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-AIR822-Oxygen Systems for General Aviation
Design of systems for oxygen service	...	Guide G88; Committee G.04[E] STT Course, Manual 36[F]	EIGA-IGC Document 13/XX[G] ; BS 3N 100[H]	VBG 62	CGA[C] G4.4	NFPA[D] 55	NASA-WSTF Test Plan No. TP-WSTF-713[I]
Evaluation of nonmetallic materials for oxygen service	...	Guide G63	EIGA-IGC Document 13/XX[G]	VBG 62	...	...	...
Evaluation of metals for oxygen service	...	Guide G94	EIGA-IGC Document 13/XX[G]	VBG 62	...	...	...
Cleaning methods for material and equipment	...	Practice G93	EIGA-IGC 33/XX[G]	VBG 62	CGA G4.1	...	...
Pneumatic Impact Test (PIT)—Materials	BAM PIT; see "Liste"[J]	Test Method G72	...	...	...	...	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 G74	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[I] ; Mil-V-5027D[L]
Auto Ignition (AIT) high pressure	BAM AIT	Test Method G72	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 D4809	DIN 51900[N]	...	...	...	...
Oxygen Index (OI)	BAM OI	Test Method D2863	ISO 4589[M] (DIN 22117[N])	...	...	...	...
Mechanical Impact Test (MIT)-LOX	BAM MIT	NFPA 51 Test Method G86 Test Method D2512	BS 3N 100[H] (LOX Impact Test)	...	...	...	NASA-STD 6001[K] Test 13A

TABLE 2 *Continued*

Method/Practice etc.	BAM[A]	ASTM International	Other European Standards/ Documents	VBG[B]	CGA[C]	NFPA[D]	Other North American Standards/ Documents
MIT-pressurized LOX and GOX	...	Test Method G86	...	...	...	...	NASA-STD 6001[K] Test 13B
Test determining the combustion behavior of metals	...	Test Method G124	...	...	...	...	NASA-STD 6001[K] Test 17
Aging of polymeric material	Practice briefly described in "Liste"[J]	Standard Guide (under preparation)	ISO 188[M] DIN 53508[N] IEC 493[Q] IEC 610[Q]	...	...	...	...[RS]
Evaluating the Ignition Sensitivity and Fault Tolerance of Oxygen Regulators Used for Medical and Emergency Applications		Test Method G175					

[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 (VGB 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 entitled "The Transportation and Distribution of Oxygen by Pipelines," provides recommendations for design, construction operating, and maintenance of oxygen systems. Several additional documents concerning O_2 handling are available from EIGA-IGC. The documents are 6, 8, 10, 11, 16, 20, 21, 27, TN 28, and TN 32.

[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-Technishche 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 Genéve, 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-enriched 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 International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.
D2512 Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass/Fail Technique[3]

D2863 Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index)[5]

D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Intermediate Precision Method)[6]

G72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment.

G74 Test Method for Ignition Sensitivity of Materials to Gaseous Fluid Impact[3]

G86 Test Method for Determining the Ignition Sensitivity of Materials to Mechanical Impact in Pressurized Oxygen Environments[7]

G124 Test Method for Determining the Combustion Behavior

of Metallic Materials in Oxygen-Enriched Atmospheres

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

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Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, Sixth Volume, STP 1197, D. D. Janoff and J. M. Stoltzfus, Ed., 1993.

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

VBG 62 Unfallverhütungsvorschrift 62 Sauerstoff

Compressed Gas Association, Inc., 4221 Walney Riad, 5th Floor, Chantilly, VA 20151.

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

EIGA 6/XX Oxygen Fuel Gas Cutting Machine Safety.

EIGA 8/XX/E Prevention of Accidents Arising from Enrichment or Deficiency of Oxygen in the Atmosphere.

EIGA 12/XX/E Pipelines Distributing Gases and Vacuum Services to Medical Laboratories.

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

Data Sheet 7-52 Loss Prevention Data, Oxygen, 1975.

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

NFPA 51B Cutting and Welding Processes.

SAE A-10 Aircraft Oxygen Equipment Committee

Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, IL 60062

UL 252 Compressed Gas Regulators.

UL 407 Manifolds for Compressed Gases.