ASTM INTERNATIONAL

Designation: G128 – 02(Reapproved 2008)

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

This standard is issued under the fixed designation G128; 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 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 G-4 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 *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]
G63 Guide for Evaluating Nonmetallic Materials for Oxygen Service
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
G126 Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres
G128 Guide for Control of Hazards and Risks in Oxygen Enriched Systems

2.2 *ASTM Adjuncts:*
Video: Oxygen Safety[4]

2.3 *ASTM CHETAH 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 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems

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

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2.7 *Military Specifications:*[9]

2.8 *NASA Documents:*[10]

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.

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

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

3.1.5 *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.

3.1.6 *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.

3.1.7 *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.

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

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

3.1.9 *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.

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

3.1.10.1 *Discussion*—The magnitude of a risk relates to how likely a hazard is to cause harm. **G128**

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 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 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).

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.

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
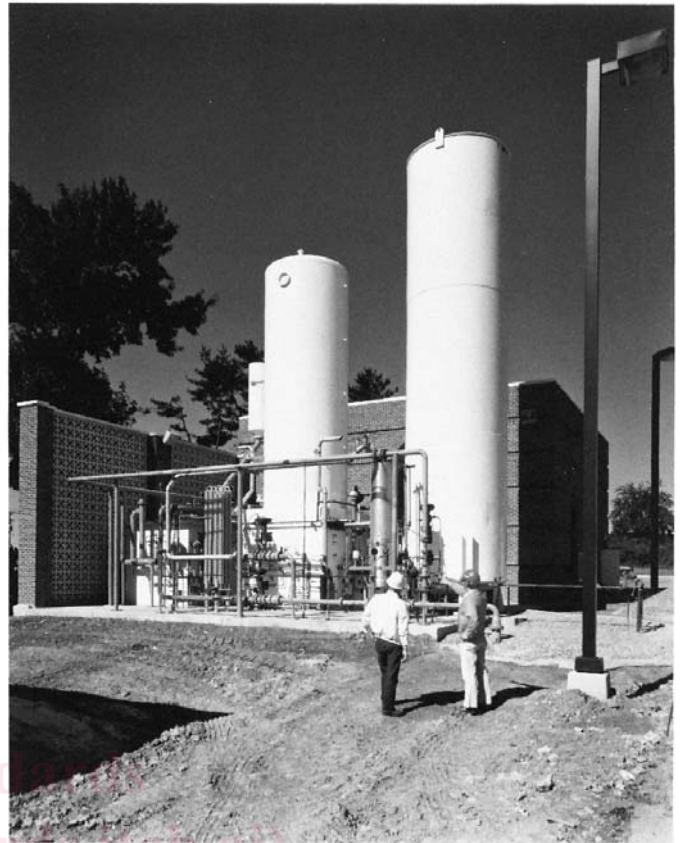

FIG. 1 High-volume Oxygen Users Buy the Gas in Bulk, Storing It in an Adjacent Facility

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 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 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 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

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[11] 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.

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 G63. 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 G63 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.

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
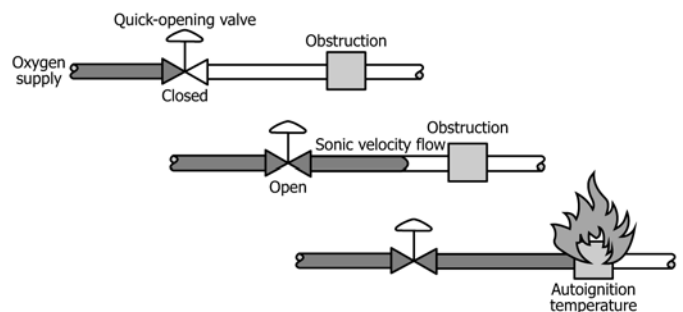

FIG. 2 Near-adiabatic Compression Can Occur When Oxygen Under High Pressure Is Released Quickly into a Low-pressure System. The Gas Flow Can Reach the Speed of Sound, and if It Encounters an Obstruction, the Temperature Can Rise High Enough to Initiate Ignition and Cause a Fire

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