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## Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service<sup>1</sup>

This standard is issued under the fixed designation G63; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide applies to nonmetallic materials, (hereinafter called materials) under consideration for oxygen or oxygen-enriched fluid service, direct or indirect, as defined below. It is intended for use in selecting materials for applications in connection with the production, storage, transportation, distribution, or use of oxygen. It is concerned primarily with the properties of a material associated with its relative susceptibility to ignition and propagation of combustion; it does not involve mechanical properties, potential toxicity, outgassing, reactions between various materials in the system, functional reliability, or performance characteristics such as physical aging, degradation, abrasion, hardening, or embrittlement, except when these might contribute to an ignition.

1.2 When this document was originally published in 1980, it addressed both metals and nonmetals. Its scope has been narrowed to address only nonmetals and a separate standard Guide G94 has been developed to address metals.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—The American Society for Testing and Materials 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.

NOTE 2—In evaluating materials, any mixture with oxygen exceeding atmospheric concentration at pressures higher than atmospheric should be evaluated from the hazard point of view for possible significant increase in material combustibility.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations*

*issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

- D217 Test Methods for Cone Penetration of Lubricating Grease
- D566 Test Method for Dropping Point of Lubricating Grease
- D1264 Test Method for Determining the Water Washout Characteristics of Lubricating Greases
- D1743 Test Method for Determining Corrosion Preventive Properties of Lubricating Greases
- D1748 Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet
- 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)
- 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 Guide for Cleanliness Levels and Cleaning Methods for Materials and Equipment Used in Oxygen-Enriched Environments
- G94 Guide for Evaluating Metals for Oxygen Service

<sup>1</sup> 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.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

## 2.2 Federal Standard:

**Fed. Test Method Std. 91B Corrosion Protection by Coating: Salt Spray (Fog) Test<sup>3</sup>**

## 2.3 Other Standard:

**BS 3N:100: 1985 Specification for General Design Requirements for Aircraft Oxygen Systems and Equipment<sup>4</sup>**

## 2.4 Other Documents:

**CGA Pamphlet G4.4 Oxygen Pipeline and Piping System<sup>5</sup>**

**EIGA IGC 13-12 Oxygen Pipeline and Piping Systems**

**NSS 1740.15 NASA Safety Standard for Oxygen and Oxygen Systems<sup>6</sup>**

## 3. Terminology

### 3.1 Definitions:

3.1.1 *autoignition temperature*—the temperature at which a material will spontaneously ignite in oxygen under specific test conditions.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *direct oxygen service*—in contact with oxygen during normal operations. Examples: oxygen compressor piston rings, control valve seats.

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

3.2.3 *indirect oxygen service*—not normally in contact with oxygen, but which might be as a result of a *reasonably* foreseeable malfunction, operator error, or process disturbance. Examples: liquid oxygen tank insulation, liquid oxygen pump motor bearings.

3.2.4 *maximum use pressure*—the maximum pressure to which a material can be subjected due to a *reasonably* foreseeable malfunction, operator error, or process upset.

3.2.5 *maximum use temperature*—the maximum temperature to which a material can be subjected due to a *reasonably* foreseeable malfunction, operator error, or process upset.

3.2.6 *nonmetallic*—any material, other than a metal, or any composite in which the metal is not the most easily ignited component and for which the individual constituents cannot be evaluated independently.

3.2.7 *operating pressure*—the pressure expected under normal operating conditions.

3.2.8 *operating temperature*—the temperature expected under normal operating conditions.

3.2.9 *oxygen-enriched*—applies to a fluid (gas or liquid) that contains more than 25 mol % oxygen.

3.2.10 *qualified technical personnel*—persons such as engineers and chemists who, by virtue of education, training, or

experience, know how to apply physical and chemical principles involved in the reactions between oxygen and other materials.

3.2.11 *reaction effect*—the personnel injury, facility damage, product loss, downtime, or mission loss that could occur as the result of an ignition.

## 4. Significance and Use

4.1 The purpose of this guide is to furnish qualified technical personnel with pertinent information for use in selecting materials for oxygen service in order to minimize the probability of ignition and the risk of explosion or fire. It is not intended as a specification for approving materials for oxygen service.

## 5. Factors Affecting Selection of Material

5.1 *General*—The selection of a material for use with oxygen or oxygen-enriched atmospheres is primarily a matter of understanding the circumstances that cause oxygen to react with the material. Most materials in contact with oxygen will not ignite *without a source of ignition energy*. When an energy-input rate, as converted to heat, is greater than the rate of heat dissipation, and the temperature increase is continued for sufficient time, ignition and combustion will occur. A material's minimum ignition temperature and the ignition sources that will produce a sufficient increase in the temperature of the material must therefore be considered. Ignition temperatures and ignition sources should be viewed in the context of the *entire system design* so that the specific factors listed below will assume the proper relative significance. Therefore: *material suitability for oxygen service is application-dependent*.

NOTE 3—For the safe use of materials in oxygen, in addition to the flammability and ignitability properties of the material, it is necessary to consider other physical and chemical properties such as mechanical properties, potential toxicity, etc. Consequently, because ignition and physical (or chemical) properties may be conflicting for selecting a material, it may be necessary in such cases to perform component tests simulating the most probable ignition mechanisms (e.g., a rapid pressurization test on a valve if heat of compression is analyzed as severe).

### 5.2 Properties of the Material:

5.2.1 *Factors Affecting Ease of Ignition*—Generally, when considering a material for a specific oxygen application, one of the most significant factors is its minimum ignition temperature in oxygen. Other factors that will affect its ignition include relative resistance to various ignition energies, geometry, configuration, specific heat, relative porosity, thermal conductivity, preoxidation or passivity, and “heat-sink effect.” Heat-sink effect is the heat-transfer capacity of the material relative to that of the material in intimate contact with it, considering the mass, physical arrangement, and physical properties of each. For instance, a gasket material may have a relatively low ignition temperature but be extremely resistant to ignition when confined between two steel flanges. The presence of a small amount of an easily ignitable contaminant, such as a hydrocarbon oil or a grease film, can promote the

<sup>3</sup> Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

<sup>4</sup> Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., <http://www.bsi-global.com>.

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

<sup>6</sup> National Aeronautics and Space Administration, Office of Safety and Mission Assurance, Washington, DC.

ignition of the base material. Accordingly, cleanliness is vital to minimize the risk of ignition (1).<sup>7</sup> See also Practice G93 and Refs. 2–3.

5.2.2 *Factors Affecting Propagation*—Once a material is ignited, combustion may be sustained or may halt. Among the factors that affect whether fire will continue are the basic composition of the material, the presence of heat-sink effects, the pressure, the initial temperature, the geometric state of the matter, and whether there is oxygen available to sustain the reaction. Combustion may also be interrupted by the presence of a heat sink.

5.2.3 *Properties and Conditions Affecting Potential Resultant Damage*—The material properties and system conditions that could affect the damage potential if ignition occurs should be taken into account when estimating the reaction effect in 7.5. These properties and conditions include the material’s heat of combustion, its mass, the oxygen concentration, flow conditions before and after ignition, and the flame propagation characteristics.

5.3 *Operating Conditions*—Conditions that affect the suitability of a material include pressure, temperature, concentration, flow, and gas velocity, and the ignitability of surrounding materials. Pressure and temperature are generally the most significant, and their effects show up in the estimate of ignition potential (5.4) and reaction effect (5.5), as explained in Section 7.

5.3.1 *Pressure*—The operating pressure is important, not only because it generally affects the generation of potential ignition mechanisms, but also because it affects the destructive effects if ignition should occur. While generalizations are difficult, approximate reaction effects would be as given in Table 1.

TABLE 1 Reaction Effect Assessment for Typical Pressures

kPa	psi	Reaction Effect Assessment
0–70	0–10	relatively mild
70–700	10–100	moderate
700–7000	100–1000	intermediate
7000–20 000	1000–3000	severe
Over 20 000	over 3000	extremely severe

NOTE 4—While the pressure generally affects the reaction as indicated in Table 1, tests indicate that it has varying effects on individual flammability properties. For example, for many materials, increasing pressure results in the following:

- (1) An increase in propagation rate, with the greatest increase in rate at lower pressures but with significant increases in rate at high pressures;
- (2) A reduction in ignition temperature, with the greatest decrease at low pressure and a smaller rate at high pressure, however, it should be noted that increasing autoignition temperatures with increasing pressures have been reported for selected polymers, due to competing kinetics (4);
- (3) An increase in sensitivity to mechanical impact;
- (4) A reduction in oxygen index, as measured in an exploratory study (5), with sharper initial declines in materials of high oxygen index but with only slight relative declines in general above 10 atmospheres and up to at least 20 atmospheres;
- (5) A negligible change in heat of combustion; and

<sup>7</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

(6) An increase in the likelihood of compression heating ignition, with the greatest likelihood at the highest pressures.

In the case of friction, increased pressure may improve heat dissipation and make ignition at constant frictional energy input less likely than at lower pressure. Increased pressure also reduces the likelihood of spark generation at constant electric field strength through increased breakdown voltage values.

5.3.2 *Temperature*—Increasing temperature obviously increases the risk of ignition but does not generally contribute to the reaction effect. The material should have a minimum ignition temperature, as determined by an acceptable test procedure, that exceeds the maximum use temperature (as defined in 3.2.5) by a suitable safety margin.

5.3.3 *Concentration*—As oxygen concentration decreases from 100 %, the likelihood and intensity of a potential reaction also decrease; therefore, greater latitude may be exercised in the selection of materials.

5.4 *Ignition Mechanisms*—For an ignition to occur, it is necessary to have three elements present: oxidizer, fuel, and ignition energy. The oxygen environment is obviously the oxidizer, and the material under consideration is the fuel. Several potential sources of ignition energy are listed below. The list is neither all-inclusive nor in order of importance nor in frequency of occurrence.

5.4.1 *Friction*—The rubbing of two solid materials results in the generation of heat. Example: the rub of a centrifugal compressor rotor against its casing.

5.4.2 *Heat of Compression*—Heat is generated from the conversion of mechanical energy when a gas is compressed from a low pressure to a high pressure. This can occur when high-pressure oxygen is released into a dead-ended tube or pipe, quickly compressing the residual oxygen that was in the tube ahead of it. As the ratio of final pressure to initial pressure increases, so, too, does the final theoretical temperature generated from the compression event. Example: a downstream valve in a dead-ended high-pressure oxygen manifold.

5.4.2.1 *Equation*—An equation that can be used to estimate the theoretical maximum temperature that can be developed when pressurizing oxygen rapidly from one pressure and temperature to an elevated pressure is as follows:

$$T_f/T_i = [P_f/P_i]^{(n-1)/n} \tag{1}$$

where:

- $T_f$  = final temperature, abs,
- $T_i$  = initial temperature, abs,
- $P_f$  = final pressure, abs,
- $P_i$  = initial pressure, abs, and
- $n = \frac{C_p}{C_v} = 1.40$  for oxygen.

where:

- $C_p$  = specific heat at constant pressure, and
- $C_v$  = specific heat at constant volume.

Table 2 gives the theoretical temperatures which could be obtained by compressing oxygen from one atmosphere (absolute) and 20 °C to the pressures shown.

NOTE 5—The final temperature calculated by Eq 1 is conservative because the equation assumes instantaneous pressurization with no heat loss (adiabatic). The equation is also conservative because it treats oxygen