



Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service¹

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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 aging, shredding, or sloughing of particles, 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 G 94 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 and health 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.

2. Referenced Documents

2.1 ASTM Standards:²

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.

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² 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.

D 217 Test Methods for Cone Penetration of Lubricating Grease

D 566 Test Method for Dropping Point of Lubricating Grease

D 1264 Test Method for Determining the Water Washout Characteristics of Lubricating Greases

D 1743 Test Method for Determining Corrosion Preventive Properties of Lubricating Greases

D 1748 Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet

D 2512 Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques)

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

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

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

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

G 86 Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments

G 88 Guide for Designing Systems for Oxygen Service

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

G 94 Guide for Evaluating Metals for Oxygen Service

2.2 *Federal Standard:*

Fed. Test Method Std. 91B Corrosion Protection by Coating: Salt Spray (Fog) Test³

2.3 *Other Standard:*

BS 3N:100:1985 Specification for General Design Requirements for Aircraft Oxygen Systems and Equipment⁴

³ Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

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

2.4 Other Documents:

- CGA Pamphlet G4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping System⁵
 NSS 1740.15 NASA Safety Standard for Oxygen and Oxygen Systems⁶

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 (see Guide **G 88**).

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. Thus considered: the material's minimum ignition temperature, and the energy sources that will produce a sufficient increase in the temperature of the material. These should be viewed in the context of the *entire system design* so that the specific factors listed below will assume the proper relative significance. To summarize: *it depends on the application*.

5.2 Properties of the Material:

5.2.1 *Factors Affecting Ease of Ignition*—Generally, in 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 are relative resistance to impact, geometry, configuration, specific heat, relative porosity, thermal conductivity, preoxidation or passivity, and "heat-sink effect." The latter is the heat-transfer aspect of the material to the mass in intimate contact with it, with respect to both the amount and the physical arrangement of each and to their respective physical properties. 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 material, such as a hydrocarbon oil or a grease film, can promote the ignition of the base material. Accordingly, cleanliness is vital to minimize the risk of ignition (**1**).⁷ See also Practice **G 93** and Refs. **2–3**.

5.2.2 *Factors Affecting Propagation*—After 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 pressure, initial temperature, the geometric state of the matter, and whether the available oxygen will be consumed or the accumulation of combustion products reduce the availability of oxygen sufficiently to stop the reaction. Combustion may also be interrupted by the presence of a heat sink.

5.2.3 *Properties and Conditions Affecting Potential Resultant Damage*—A material's heat of combustion, its mass, the oxygen concentration, flow conditions before and after ignition, and the flame propagation characteristics affect the potential damage if ignition should occur and should be taken into account in estimating the reaction effect in **7.5**.

5.3 *Operating Conditions*—Conditions that affect the suitability of a material include the other materials of construction and their arrangement in the equipment and pressure, temperature, concentration, flow, and velocity of the oxygen. 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 Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.

⁶ National Aeronautics and Space Administration, Office of Safety and Mission Assurance, Washington, DC.

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

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

NOTE 3—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
- (6) An increase in the likelihood of adiabatic compression 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 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. 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.

5.4.3 *Heat From Mass Impact*—Heat is generated from the transfer of kinetic energy when an object having relatively large mass or momentum strikes a material. Example: hammer striking oxygen-saturated macadam.

5.4.4 *Heat from Particle Impact*—Heat is generated from the transfer of kinetic and possibly thermal energy when small particles (sometimes incandescent), moving at high velocity, strike a material. Example: dirt particles striking a valve seat in an inadequately cleaned high-velocity pipeline.

5.4.5 *Static Electric Discharge*—Electrical discharge from static electricity, possibly generated by high fluid flow under certain conditions, may occur, especially where particulate matter is present. Example: arcing in poorly cleaned, inadequately grounded piping.

5.4.6 *Electrical Arc*—Electrical arcing may occur from motor brushes, electrical control equipment, instrumentation, lightning, etc. Example: defective pressure switch.

TABLE 2 Theoretical Maximum Temperature Obtained When Compressing Oxygen Adiabatically from 20°C and One Standard Atmosphere to the Pressures Shown^A

Final Pressure, P_f		Pressure Ratio P_f/P_i	Final Temperature, T_f	
kPa	psia		°C	°F
345	50	3.4	143	289
690	100	6.8	234	453
1000	145	9.9	291	556
1379	200	13.6	344	653
2068	300	20.4	421	789
2758	400	27.2	480	896
3447	500	34.0	530	986
5170	750	51.0	628	1163
6895	1000	68.0	706	1303
10 000	1450	98.6	815	1499
13 790	2000	136.1	920	1688
27 579	4000	272.1	1181	2158
34 474	5000	340.1	1277	2330
100 000	14 500	986.4	1828	3322
1 000 000	145 000	9883.9	3785	6845

^ASee 5.4.2.

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