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Standard Guide for Designing Systems for Oxygen Service[1]

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ε[1] NOTE—Keywords were added editorially in March 1998.

1. Scope

1.1 This guide applies to the design of systems for oxygen or oxygen-enriched service but is not a comprehensive document. Specifically, this guide addresses system factors that affect the avoidance of ignition and fire. It does not address the selection of materials of construction for which Guides G 63 and G 94 are available, nor does it concern mechanical, economic or other design considerations for which well-known practices are available.

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.

1.2 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

G 63 Guide for Evaluating Nonmetallic Materials for Oxygen Service[2]

G 72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment[2]

G 74 Test Method for Ignition Sensitivity of Materials to Gaseous Fluid Impact[2]

G 93 Practice for Cleaning Methods for Material and Equipment Used in Oxygen-Enriched Environments[2]

G 94 Guide for Evaluating Metals for Oxygen Service[2]

2.2 ASTM Adjuncts:

Oxygen Safety Video[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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

3.1.2 *indirect oxygen service*—service in which oxygen is not normally contacted but in which it 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.

3.1.3 *oxygen-enriched atmosphere*—a fluid mixture (gas or liquid) that contains more than 25 mol % oxygen.

3.1.4 *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.

4. Significance and Use

4.1 The purpose of this guide is to furnish qualified technical personnel with pertinent information to use in designing oxygen systems. It emphasizes factors that cause ignition and enhance propagation throughout a system's service life so that the occurrence of these conditions may be avoided or minimized. It is not intended as a specification for the design of oxygen systems.

5. Factors Affecting the Design for an Oxygen or Oxygen-Enriched System

5.1 *General*—An oxygen system designer should understand that oxygen, fuel, and heat (source of ignition) must be present to start and propagate a fire. Since combustible materials and oxygen are usually present, the design of a system for oxygen or oxygen enriched service is primarily a matter of understanding the factors that are potential sources of ignition or which aggravate consequential propagation. The goal is to eliminate these factors or compensate for their presence. Preventing fires involves both minimizing system environments that enhance fire and maximizing the use of system materials with properties that resist ignition and combustion.

5.2 *Factors Recognized as Causing Fires*:

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[2] *Annual Book of ASTM Standards,* Vol 14.02.

[3] Available from ASTM Headquarters, Order PCN 12-700880-31.

5.2.1 *Temperature*—As the temperature of a material increases, the amount of energy that must be added to produce ignition decreases. Operating a system at unnecessarily elevated temperatures, whether locally or generally elevated, reduces this safety margin. The ignition temperature of the most easily ignited material in a system is related to that temperature measured by Test Method G 72 but is also a function of the system pressure, configuration and operation, and the thermal history of the material. Elevated temperature also facilitates sustained combustion of materials that might otherwise be self-extinguishing.

5.2.2 *Pressure*—As the pressure of a system increases, the ignition temperatures of its components typically decrease, and the rates of fire propagation increase. Therefore, operating a system at unnecessarily elevated pressures increases the probability and consequences of a fire. It should be noted that pure oxygen, even at lower than atmospheric pressure, may still pose a significant hazard with noncompatible materials such as hydrocarbon pump oils.

5.2.3 *Concentration*—As oxygen concentration decreases from 100 % with the balance being inert gases, there are progressive decreases in the likelihood and intensity of a potential reaction. Greater latitude may therefore be exercised in the design of a system for dilute oxygen service.

5.2.4 *Contamination*—Contamination can be present in a system because of inadequate initial cleanness, introduction during assembly or service life, or generation within the system by abrasion, flaking, etc. Contaminants may be liquids, solids, or gases. Such contamination may be highly flammable and readily ignitable, for example, hydrocarbon oils. Accordingly, it is likely to ignite and promote consequential system fires. However, even normally inert contaminants, such as rust, may produce ignition through particle impact (see 5.2.5) or friction (see 5.2.7) or through augmenting of resonance heating effects (see 5.2.8).

5.2.5 *Particle Impact*—Collisions of inert or ignitable solid particles entrained in an oxidant stream are associated with potential ignition. Such ignition may result from the particle being flammable and igniting upon impact and, in turn, igniting other system materials. Ignition may also result from heating of the particle and subsequent contact with system plastics and elastomers, from fine flammable particles produced during the collision, or from the direct transfer of kinetic energy during the collision. Absolute removal of particles is not possible, and systems can self-regenerate particles. Hence, a system must be designed to tolerate at least some particle presence. The hazard associated with particles increases with both the particles' heat of combustion and their kinetic energies. The quantity of particles in a system will tend to increase with the age of the system.

5.2.6 *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.) The elevated temperatures produced can ignite contaminants or elevate system components above their ignition temperature. The hazard of heat of compression increases with system pressure and with pressurization rates.

TABLE 1 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
10000	1450	98.6	815	1499
13790	2000	136.1	920	1688
27579	4000	272.1	1181	2158
34474	5000	340.1	1277	2330
100000	14500	986.4	1828	3322
1 000 000	145000	9863.9	3785	6845

[A] See 5.2.6.

5.2.6.1 *Equation*—A formula for the theoretical maximum temperature that can be developed when pressurizing a gas rapidly without heat dissipation 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

$$n = \frac{C_p}{C_v} = 1.40 \text{ for oxygen} \tag{2}$$

where:
C_p = specific heat at constant pressure, and
C_v = specific heat at constant volume.

5.2.6.2 Table 1 gives the theoretical temperatures which could be obtained by compressing oxygen adiabatically from 20°C and one standard atmosphere to the pressures shown.

5.2.7 *Friction*—The rubbing together of two surfaces can produce heating and can generate particulates. Such heating may elevate a system component above its ignition temperature. Particulates can participate as contaminants (see 5.2.4) or in particle impacts (see 5.2.5). The hazard associated with friction generally increases with the loading and rubbing rates.

5.2.8 *Resonance*—Acoustic oscillations within resonant cavities are associated with rapid heating. The temperature rises more rapidly and achieves higher values where particles are present or where there are high gas velocities. Resonance phenomena in oxygen systems are well documented **(1)**,[4] but there are few design criteria.

[4] The boldface numbers in parentheses refer to the references listed at the end of this guide.

5.2.9 *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 ground piping.

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

6. Test Methods

6.1 *Gaseous Impact, Test Method G 74*—This is a material test, but it can also be used with modification to stress whole components and system designs. The test repeatedly exposes the system to rapid cyclic pressurization with gaseous oxygen, and any combustion is noted.

7. System Design Method

7.1 *Overview*—To design a system for oxygen service, the designer observes good mechanical design principles and incorporates the factors below to a degree consistent with the severity of the application. Mechanical failures are undesirable since rupture, friction, etc. can produce heating, particulates, etc. which in turn are associated with ignition as discussed in the following sections.

7.2 *Final Design* **(2)**—In the final analysis, the system design involves a complex interplay of the various factors that promote ignition and of the ability of the materials of construction to resist such ignition. There are many subjective judgements, external influences, and compromises involved. While each case must be ultimately decided on its own merits, the generalizations below apply. In applying these principles, the designer should consider the system's normal operating conditions and, in addition, indirect oxygen exposure that may result from system upsets and failure modes. The system should be designed to fail safely. To this end, failure effect studies are recommended to identify components subject to indirect oxygen exposure or for which an oxygen exposure more severe than normal is possible. Not every principle can be applied in the design of every system. However, the fire resistance of a system will improve with the number of principles that are followed.

7.3 *Avoid unnecessarily elevated temperatures*.

7.3.1 Locate systems a safe distance from heat or radiation sources (such as furnaces).

7.3.2 Design for efficient dissipation of heat.

7.3.3 Provide monitoring equipment and automatic shutdown devices where practical on heaters, bearings, etc.

7.4 *Avoid unnecessarily elevated pressures*.

7.4.1 Reduce pressure near the supply point rather than near the use point so that intermediate equipment is at minimum pressure.

7.5 *Design for System Cleanness*:

7.5.1 Design a system that is easy to clean and easy to maintain clean **(3)**. The system should be capable of disassembly into elements capable of thorough cleaning. Cleaning is discussed in Practice G 93.

7.5.2 Avoid the presence of unnecessary sumps, dead-ends and cavities likely to accumulate debris.

7.5.3 Filters should be used to limit the introduction of particles and to capture particles generated in service.

7.5.3.1 Filter use should be considered at oxygen entry points into a system, at points where particles are likely to be generated and at critical points where particle presence produces the greatest risk, such as at the suction side of compressors or inlets to throttling valves.

7.5.3.2 Filters should not be fragile or prone to breakage. If complete blockage is possible, the filter should be able to withstand full differential pressure.

7.5.3.3 Preventive maintenance of filters should be adequate to limit the hazard associated with flammable debris collected on the filter element.

7.5.3.4 Provision should be made for preventive maintenance of filters. Such provision may include pressure gages to indicate excessive pressure drop and a bypass line to allow cleaning. When bypass lines are used, they should not tend to accumulate debris.

7.5.3.5 Since many filters have high surface-area/volume ratios, a highly fire resistant material is desirable (see Guides G 63 and G 94).

7.5.3.6 Consider dual filters if the system cannot be shut down to change elements.

7.6 *Avoid particle impacts*.

7.6.1 Filters should be used to limit particle presence as described in 7.5.3.

7.6.2 Limit gas velocities to limit particle kinetic energies.

7.6.2.1 For carbon steel or stainless steel pipelines, CGA Pamphlet G-4.4 **(4)** may be consulted for an industry approach to the limiting of oxygen velocities.

7.6.3 Use highly fire resistant materials (see Guide G 94) where velocities cannot be minimized, such as in throttling valves.

7.6.4 Use highly fire resistant materials at particle impingement points, such as gas streams into the side ports of tees. Local impingement plates of highly fire resistant alloys are also acceptable.

7.6.5 Minimize pressurization rates.

7.6.6 Do not impinge gas streams onto seats, seals, or other plastics or elastomers.

7.7 *Minimize heat of compression*.

7.7.1 Avoid rapid pressurization of components.

7.7.1.1 Avoid the use of fast opening valves, such as standard ball valves, unless specifically designed to enable slow pressurization.

7.7.1.2 Select automatic valve operators that are slow opening.

7.7.1.3 Install line restrictors, such as an orifice plate, to limit system pressurization rates.

7.7.1.4 Use small bypass valves across rapid opening valves to equalize pressure across fast valve prior to its operation.

7.7.2 Do not compress gas volumes against easily ignited components.

7.7.2.1 Use "distance pieces" to isolate polymers from end points that experience heat of compression **(5).**

7.8 *Avoid friction and galling*.

7.8.1 Avoid rubbing components.

7.8.2 Design rotating machinery so that clearances are adequate and verifiable.

7.8.3 Use highly fire resistant materials where friction cannot be limited.

7.8.4 Sensors may be used to shut down rotating equipment if rubs or instabilities develop.

7.9 *Avoid corrosion*.

7.9.1 Avoid dissimilar metal joints where practical.

7.9.2 Avoid crevices, sumps, etc. that may accumulate particles (for example, corrosion products, metal fines, etc.) contributing to corrosion.

7.10 *Avoid resonance*.

7.10.1 Avoid unnecessary blind, unswept passages that can serve as resonant cavities.

7.11 *Use proven hardware*.

7.11.1 Use hardware that has a significant trouble-free history in oxygen service under similar operating conditions.

7.11.2 Pretest components or systems in controlled situations.“ Techniques Employed by the NASA White Sands Test Facility to Ensure Oxygen System Component Safety” in STP 812, **(6)**, discusses one procedure for stress-testing of components that has been used with the basic apparatus specified for gaseous impact testing in Test Method G 74. An elaboration of one philosophy for this type of testing is given in NASA Reference Publication 1113, “Design Guide for High-Pressure Oxygen Systems” **(7)**.

7.12 *Design to manage fires* **(8, 9)**.

7.12.1 Provide an automatic remote shutoff to isolate critical components from all bulk oxygen supplies. The shutoff may be activated by a fire or other sensor and may, if advantageous, simultaneously vent the oxygen in the system.

7.12.2 Locate bulk oxygen storage away from the system and flammable materials.

7.12.3 Shields, barriers, or distance may be used to isolate potentially hazardous apparatus.

7.12.4 Fire extinguishment equipment, such as nitrogen flooding systems, may be installed.

7.12.5 Fire-break sections of highly-fire-resistant materials may be installed in pipelines, tubing runs, equipment, etc. Changes in flow direction, such as elbows, may enhance fire-break performance.

7.13 *Anticipate indirect oxygen exposure*.

7.13.1 Vents should discharge to areas capable of dissipating the oxygen or resisting ignition.

7.13.2 The effect of leaks or releases on surrounding areas and equipment should be evaluated; for example, to avoid cryogens on carbon surfaces.

7.13.3 Mechanical failures, such as leaks through control valve seats, may result in an oxygen exposure exceeding system design limits.

7.14 *Minimize available fuel/oxygen* **(10)**.

7.14.1 If seals, seats, etc. are of polymeric materials they should be small and well shielded.

7.14.2 Minimize the volume of internal volume of components to reduce the oxygen they contain.

7.15 *Miscellaneous*:

7.15.1 Eliminate internal mechanical collisions.

7.15.2 Ensure that every portion of the system is properly grounded to prevent internal arcing or sparking.

7.15.3 Consider lightning protection. Protection against lightning arcing across insulated flanges of cathodic corrosion-prevention systems of pipelines is particularly important. One method is the use of fusing spark gaps.

7.15.4 Remove sharp edges and burrs exposed to oxygen because they are more easily ignited than bulkier base materials.

7.15.5 Avoid exposing to oxygen thin walls that are easily ignited or prone to mechanical failure.

7.15.6 Provide the capability to start-up the system on inert gases as a means to seat surfaces, displace particulates, prove mechanical integrity, leak-test system, etc. Following inert gas use in rotating machinery, precautions are required prior to oxygen exposure in the event that an accumulation of pyrophoric materials may have been formed by wear.

7.15.7 Eliminate valve chatter and fretting throughout the operating range.

8. Examples

8.1 There are few detailed examples of system design procedures. One detailed procedure is found in “Selection of Metals for Gaseous Oxygen Service” in STP 812 **(5)**. Numerous examples of individual design aspects are found in NASA Reference Publication 1113, “Design Guide for High Pressure Oxygen Systems” **(6)**. A video illustrating the hazards when using oxygen and the selection of components for oxygen service is available as an adjunct (2.2).

9. Keywords

9.1 contamination; combustion; fire; fire resistant materials; heat of compression; ignition; particle impact; propagation; system cleanness; oxygen service; oxygen system; oxygen-enriched atmosphere

REFERENCES

(**1**) Phillips, B. R. and DeWitt, K. J.," Resonance Tube Ignition of Aluminum," *Combustion and Flame* 35, 1979, pp. 249–258.

(**2**) NASA Handbook 8060.1 B, "Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion," National Aeronautics and Space Administration, Washington, DC.

(**3**) CGA Pamphlet G-4.1, "Cleaning Equipment for Oxygen Service," Compressed Gas Association, Arlington, VA.

(**4**) CGA Pamphlet G-4.4, "Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems," Compressed Gas Association, Arlington, VA.

(**5**) Flamability and Sensitivity of Materials in Oxygen Enriched Atmospheres, Vol 3, ASTM STP 986, 1988, pp. 289–309.

(**6**) *Flammability and Sensitivity of Materials in Oxygen Enriched Atmospheres, ASTM STP 812*, 1983, pp. 97–107.

(**7**) Bond, Alek C., et al, *Design Guide for High Pressure Oxygen Systems*, NASA Reference Publication 1113, National Aeronautics and Space Administration, Washington, DC, August 1983, (NTIS N83-32990).

(**8**) CGA Pamphlet G-4.0," Oxygen," Compressed Gas Association, Arlington, VA.

(**9**) NFPA Booklet 50-1979, "Standard for Bulk Oxygen Systems at Consumer Sites," National Fire Protection Agency.

(**10**) NFPA Booklet 53M-1979, "Manual on Fire Hazards in Oxygen-Enriched Atmospheres," National Fire Protection Agency.