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Guide for Oxygen Hazards Analyses on Components and Systems

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Abstract

Because most materials, including metals, will burn in an oxygen-enriched environment, hazards are always present when using oxygen. Most materials will ignite at lower temperatures in an oxygen-enriched environment than in air, and once ignited, combustion rates are greater in the oxygen-enriched environment. Many metals burn violently in an oxygen-enriched environment when ignited. Lubricants, tapes, gaskets, fuels, and solvents can increase the possibility of ignition in oxygen systems. However, these hazards do not preclude the use of oxygen. Oxygen may be safely used if all the materials in a system are not flammable in the end-use environment or if ignition sources are identified and controlled. These ignition and combustion hazards necessitate a proper oxygen hazards analysis before introducing a material or component into oxygen service.

The objective of this test plan is to describe the White Sands Test Facility oxygen hazards analysis to be performed on components and systems before oxygen is introduced and is recommended before implementing the oxygen component qualification procedure. The plan describes the NASA Johnson Space Center White Sands Test Facility method consistent with the ASTM documents for analyzing the hazards of components and systems exposed to an oxygen-enriched environment. The oxygen hazards analysis is a useful tool for oxygen-system designers, system engineers, and facility managers. Problem areas can be pinpointed before oxygen is introduced into the system, preventing damage to hardware and possible injury or loss of life.

1. Introduction

Because most materials, including metals, will burn in an oxygen-enriched environment, hazards are always present when using oxygen. Most materials will ignite at considerably lower temperatures in an oxygen-enriched environment than in air, and once ignited, combustion rates are greater in the oxygen-enriched environment. Many metals burn violently in an oxygen-enriched environment when ignited. Lubricants, tapes, gaskets, fuels, and solvents can increase the possibility of ignition in oxygen systems. However, these hazards do not preclude the use of oxygen. Oxygen may be safely used if all the materials in a system are not flammable in the end-use environment or if ignition sources are identified and controlled. Ignition and combustion hazards necessitate a proper oxygen hazards analysis before introducing a material or component into oxygen service.

This test plan describes the NASA Johnson Space Center White Sands Test Facility (WSTF) method (consistent with the most current versions of ASTMs G 63, G 88, and G 94) for analyzing the hazards of components and systems exposed to oxygen-enriched environments. The oxygen hazards analysis is a useful tool for oxygen-system designers, system engineers, and facility managers. Problem areas can be pinpointed before oxygen is introduced into the system, preventing damage to hardware and possible injury or loss of life. Further information on the safe design of oxygen systems can be found in the most current versions of ASTMs G 63, G 88, and G 94; NHB 8060.1C (1991); NFPA 50 (1990) and 53M (1990); and CGAs G-4.0 (1987), G-4.1 (1984), and G-4.4 (1984).

2. Objective

The objective of this test plan is to describe the WSTF oxygen hazards analysis to be performed on components and systems before oxygen is introduced. The analysis should be performed before implementing the oxygen component qualification procedure (Bamford and Rucker, 1992).

3. Approach

An oxygen hazards analysis of an oxygen component or system is usually approached as shown in Figure 1 (Christianson and Stoltzfus, 1993). The oxygen application and the scope of the investigation are first determined, and then a team is assembled to conduct the analysis. Information is collected on the components and the worst-case operating conditions.

Usually, a fire will not occur in any environment unless the construction materials of the system or component are flammable **and** a credible ignition mechanism is present. The flammability of the material is first reviewed to determine if any fire hazards exist at the worst-case operating conditions. If the material is flammable, then the possible ignition mechanisms are surveyed to determine which are credible. If data for the particular ignition mechanism and the material(s) under consideration are not available, appropriate materials tests are conducted. Finally, the secondary and reaction effects are evaluated to determine what effect an ignition and possible combustion would have on the system and the facility (Christianson and Stoltzfus, 1993).

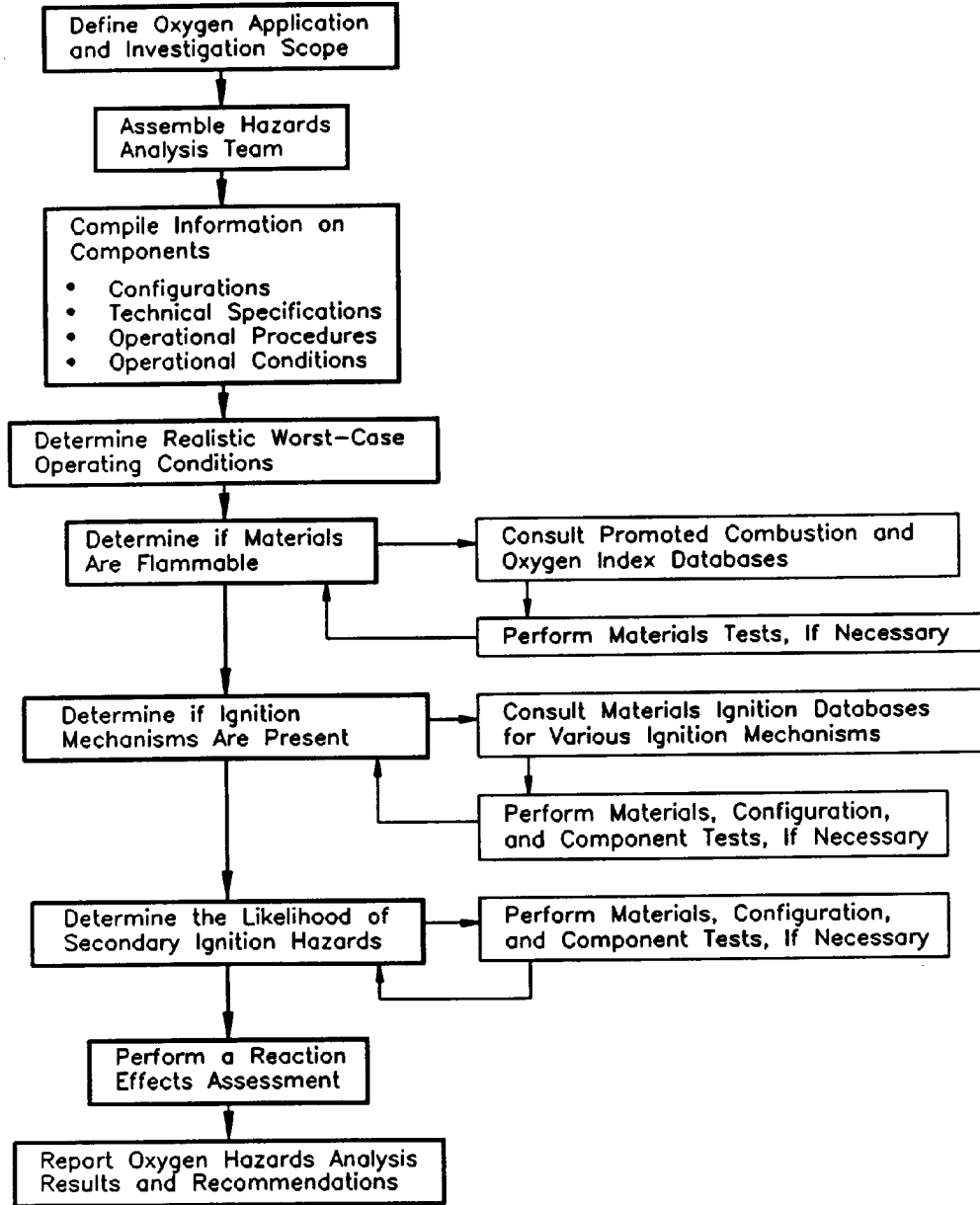


Figure 1 Approach to oxygen hazards analysis (Christianson and Stoltzfus, 1993).

To use an oxygen hazards analysis as a tool, it should be properly documented from the beginning. A typical oxygen hazards analysis chart (Figure 2) contains the component designation (which indicates the materials of construction including soft goods), the possible ignition mechanisms, the probability of each ignition mechanism, and the results of the secondary effects analysis and the reaction effects assessment. The documentation also includes any recommendations or limitations from the oxygen hazards analysis team, including recommendations of further testing if needed, stipulations of use, and any additional safety precautions. If component tests are required, they may be performed according to the *Guide for Oxygen Component Qualification Tests* (Bamford and Rucker, 1992).

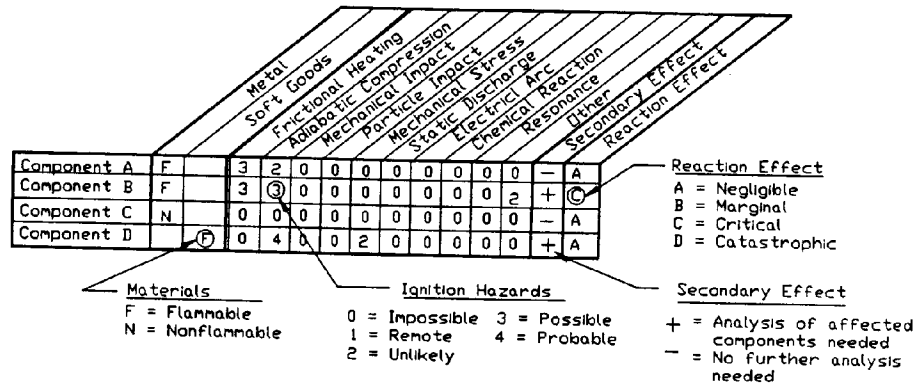


Figure 2 Oxygen Hazards Analysis Chart.

4. Procedures

The procedures for performing an oxygen hazards analysis on a component or a system are shown in Figure 1 and discussed in the following paragraphs.

4.1 Oxygen Application and Investigation Scope

The oxygen application and investigation scope should first be determined to provide the basis for choosing the oxygen hazards analysis team and for conducting the analysis.

4.2 Oxygen Hazards Analysis Team

An oxygen hazards analysis team is assembled including, at a minimum, personnel with expertise in mechanical design, metals ignition and combustion, nonmetals ignition and combustion, and component testing (with emphasis on oxygen systems). Depending on the system, personnel may also be included with expertise in electrical design, cryogenic fluids, materials, and chemistry.

4.3 Component/System Information

Information is obtained on each component in the system: materials of construction (including soft goods and lubricants), drawings showing the cross-sectional view of each component (particularly fluid flow paths and the location of the soft goods), and a system

fluid schematic. The cross section of the component is used to locate and identify all the soft goods. If the cross-sectional view of a component is poor quality or unclear, a disassembled component complete with soft goods is sometimes useful. All materials of construction are identified. The flow path is also identified, along with all oxygen-wetted materials. A list of some common high-risk components is in the appendix.

4.4 Worst-Case Operating Conditions

The worst-case operating conditions that the component may undergo are now determined. This information includes maximum use pressures, temperatures, and flow rates and is used to evaluate the materials of construction for resistance to ignition and combustion. Pressures and temperatures are important because material flammability is often a function of these two parameters. Flow rates are important because they affect the particle impact and adiabatic compression ignition mechanisms.

4.5 Material Flammability

The materials are evaluated to determine if they are flammable at the worst-case operating conditions. A large material flammability database at WSTF contains flammability data from previous and ongoing tests of both metals and polymers. If information on a material for the worst-case operating conditions cannot be located in the database, tests may be conducted to obtain this information. The oxygen hazards analysis chart is updated with the results, using N (nonflammable) or F (flammable). If the materials of a component are determined nonflammable, the ignition mechanisms need not be analyzed for that component.

4.6 Ignition Mechanisms

Next, an ignition mechanism survey is performed. For each component found to have flammable materials, nine ignition mechanisms must be evaluated: adiabatic compression (pneumatic impact), frictional heating, mechanical impact, particle impact, mechanical stress or vibration, static discharge, electric arc, chemical reaction, and resonance. Each ignition mechanism must be evaluated to determine if it exists in the component and the likelihood that it will cause an ignition. The results of the analysis for each ignition mechanism are documented on the oxygen hazards analysis chart. Ratings for the ignition mechanisms are 0 (impossible), 1 (remote), 2 (unlikely), 3 (possible), and 4 (probable).

4.6.1 Frictional Heating

Parts of a component or system can rub against each other with enough force or velocity to raise any one part to its ignition temperature at the given oxygen pressure and concentration (examples: rotating or oscillating equipment and chattering relief valves).

4.6.2 Adiabatic Compression

A quantity of any gas can generate a considerable amount of heat if rapidly compressed. This heat can readily ignite polymers or flammable contaminants (examples: a downstream valve or flexible hose with a polymer liner in a dead-ended high-pressure oxygen manifold).

4.6.3 Mechanical Impact

An object with a relatively large mass or momentum striking a material can cause mechanical deformation and expose fresh surfaces (example: a poppet of a solenoid-operated valve impacting the polymer seat).

4.6.4 Particle Impact

Combustible particles impinging on materials at velocities greater than 50 m/s in oxygen-enriched environments can cause ignition (example: high-velocity particles from a dirty pipeline striking a valve plunger).

4.6.5 Mechanical Stress or Vibration

Materials that are poor heat conductors (such as plastics) can reach their ignition temperatures when stressed or vibrated (example: unanchored joints that protrude inside piping).

4.6.6 Static Discharge

Discharges of static electricity can produce high temperatures, sometimes high enough to cause a material to reach its ignition temperature (example: the accumulation of electrostatic charges created by the friction of dry oxygen flowing over nonmetals).

4.6.7 Electric Arc

Electric arcs can provide the energy to ignite materials in the presence of oxygen (example: an insulated electrical heater short-circuiting and arcing through its sheath to the oxygen).

4.6.8 Chemical Reaction

An unrelated chemical reaction can produce sufficient heat to ignite materials in the presence of oxygen (example: a chemical process that generates elevated temperatures).

4.6.9 Resonance

Acoustic oscillations within resonant cavities can cause a rapid gas temperature rise. The rise is more rapid and achieves higher values when particles are present. Ignition can result if the heat generated is not rapidly dissipated (example: gas flow into a tee and out of a branch port so that the remaining closed port forms a resonant chamber).

4.7 Secondary Effects Analysis

After the ignition mechanisms have been surveyed, the secondary effects are analyzed. This analysis addresses the effects of failures that are not ignition-related, but may create an ignition hazard in a nearby component, such as an external leak caused by normal seal wear. The leaking oxygen could build up and allow an ignition by the static discharge ignition mechanism in some nearby component. Ratings for the secondary effects analysis are + (further analysis of affected components necessary) and - (no further analysis needed).

4.8 Reaction Effects Assessment

Finally, a reaction effects assessment is performed and documented. This is an assessment of the effect if a component fails or is ignited and is useful for making judgments on the safe use of a component. The reaction effects assessment would then help determine if the component may be used safely. The ratings are *A* (negligible, no loss of equipment or life), *B* (marginal, equipment is damaged, but no lives are lost), *C* (critical, loss of test data and damage to equipment, but no loss of life), and *D* (catastrophic, loss of equipment and life).

5. References

ASTM G 63, "Guide for Evaluating Nonmetallic Materials for Oxygen Service," American Society of Testing and Materials, Philadelphia, Pennsylvania (most current version).

ASTM G 88, "Guide for Designing Systems for Oxygen Service, American Society of Testing and Materials, Philadelphia, Pennsylvania (most current version).

ASTM G 94, "Guide for Evaluating Metals for Oxygen Service," American Society of Testing and Materials, Philadelphia, Pennsylvania (most current version).

Bamford, L. B. and M. A. Rucker, "Guide for Oxygen Component Qualification Tests," TP-WSTF-712, NASA Johnson Space Center White Sands Test Facility, Las Cruces, New Mexico (1992).

CGA G-4.0, *Oxygen*, Compressed Gas Association, Eighth edition, Arlington, Virginia (1987).

CGA G-4.1, *Cleaning Equipment for Oxygen Service*, Compressed Gas Association, Eighth edition, Arlington, Virginia (1987).

CGA G-4.4, *Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems*, Compressed Gas Association, Second edition, Arlington, Virginia (1984).

Christianson, R. and J. M. Stoltzfus, "Oxygen Hazards Analysis of Composite Liquid Oxygen Tanks," WSTF-IR-93-0024, NASA Johnson Space Center White Sands Test Facility, Las Cruces, New Mexico (1993).

NHB 8060.1C, "Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion," NASA Office of Safety and Mission Quality (1991).

NFPA 50, *Standard for Bulk Oxygen Systems at Consumer Sites*, National Fire Protection Association, Quincy, Massachusetts (1990).

NFPA 53M, *Fire Hazards in Oxygen-Enriched Atmospheres: 1990 Edition*, National Fire Protection Association, Quincy, Massachusetts (1990).

Appendix

High-Risk Components

Many of the typical components found in oxygen systems are particularly susceptible to one or more of the 10 possible ignition mechanisms. The following is a list of some of these components and the associated ignition mechanisms.

Ball Valve:	Particulate generation (<i>particle impact</i>) and quick-opening (<i>adiabatic compression</i>)
Relief Valve:	Chattering (<i>mechanical impact or frictional heating</i>)
Globe Valve:	Impingement even when fully open (<i>particle impact</i>)
Butterfly Valve:	Impingement even when fully open (<i>particle impact</i>)
Flex Hose:	Susceptible to <i>adiabatic compression</i> when dead-ended
Regulator:	<i>Mechanical impact</i> and high velocities generated (<i>particle impact</i>)
Check valve:	Chattering (<i>mechanical impact/frictional heating</i>)
Filter:	<i>Pneumatic impact</i> of contaminants on the filter element and possible <i>particle impact</i> if poorly located within the system
Fittings:	Particulate introduced into the system during assembly (<i>particle impact</i>)
Soft goods:	Impingement on polymers in gas stream (<i>pneumatic impact, mechanical impact, and particle impact</i>)

Most ignition mechanisms for the above components can be eliminated or minimized by proper material selection, system design, and operating constraints.