Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres

NINTH VOLUME

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ASTM STP 1395

STP 1395

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Ninth Volume

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ASTM Stock Number: STP1395

ASTM
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959

Printed in the U.S.A.

ISBN: 0-8031-2871-1
ISSN: 0899-6652

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Each paper published in this volume was evaluated by two peer reviewers and at least one editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were prepared "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. In keeping with long-standing publication practices, ASTM maintains the anonymity of the peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Saline, MI
August 2000

Foreword

This is the ninth in a series of Special Technical Publications produced by ASTM Committee G4 on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres. As with the eighth volume in this series, two of the papers in this volume were presented at seminars and workshops held in conjunction with the regular semi-annual meetings of Committee G4. The other papers contained in this volume were produced as a result of the Ninth International Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres held in Paris, France in September 2000.

This volume was edited by Theodore A. Steinberg, Department of Mechanical Engineering at the University of Queensland, Brisbane, Queensland, Australia; Barry E. Newton, Wendell Hull and Associates, Las Cruces, New Mexico; and Harold D. Beeson, NASA White Sands Test Facility, Las Cruces, New Mexico.

Overview

This is the ninth Special Technical Publication (STP) originating from ASTM Committee G4 focusing on Flammability and Sensitivity of Materials in Oxygen-Enriched Environments. As in past STPs, this ninth volume shares and expands upon the objectives that have been consistently carried forward since the first STP was published in 1983. These objectives include:

- Provision of a readily accessible reference addressing oxygen compatibility—a subject that is still not fully addressed in the open literature;
- Construction of a growing database on the most current risk management concepts, practices, and procedures used by individuals and organizations involved in the design, use, and maintenance of oxygen systems;
- Provision of valuable data used (1) by designers, manufacturers, and maintainers of oxygen components and systems; (2) in support of Committee G4's excellent Technical and Professional Training Course: *Fire Hazards in Oxygen Systems* and new short course: *Oxygen Systems Operation and Maintenance;* and (3) as an aid in interpreting the many ASTM Committee G4 guides, practices, test methods, and standards;
- Ability to guide Committee G4 in future efforts in many various areas related to the safety of oxygen (and high-pressure air) systems; and
- Provision of data necessary to aid in the ongoing effort to model the ignition, combustion, and sensitivity of materials, both metallic and nonmetallic, in oxygen-enriched atmospheres.

As with past STPs in this series, this volume is mainly the peer-reviewed publication of work presented at Committee G4's Ninth International Symposium held in Paris, France in September 2000. Similar to the eighth volume, however, two papers are included that were presented in conjunction with regular semi-annual Committee G4 meetings. All manuscripts included in this STP were subjected to the same rigid peer-review process, regardless as to where they may have been presented.

There has been a clear trend in the last several STPs toward an increase in the number of manuscripts modeling the ignition or combustion processes of metals and nonmetals in oxygen-enriched environments. This trend is continued and amplified upon in this publication. This type of work is clearly only possible due to the data generated and the greater understanding of this data which is directly attributable to Committee G4 activities and this STP series. Similarly, there is an increase in the number of manuscripts documenting and analyzing the results of forensic analyses of oxygen fires, post-event. This documentation process is highly encouraged by Committee G4 as it highlights specific situations, procedures, or materials that should be avoided in relation to oxygen systems and spotlights potential areas of future work for the committee.

This ninth volume contains 32 papers on topics that have been the mainstay of most past STPs. Included in these topics of this ongoing series are: ignition and combustion of metals, ignition and combustion of nonmetals, failure analysis and safety, material selection, test system development, and analysis of ignition and combustion. Additionally, due to the number of papers received specifically addressing issues associated with air-separation plants, a section on structured packings has been included in this STP. This ninth volume contains eight sections including the keynote address. The keynote address is given by Coleman Bryan, Chief, Test Division of the Materials Science Laboratory, at the NASA John F. Kennedy Space Center. Mr. Bryan has been an active participant in Committee G4 for two decades and has been involved in the safe use and selection of appropriate materials, procedures, and test method development associated with oxygen systems for four decades.

Mr. Bryan discusses, reviews, and compares the various test methods that are currently used in the selection of appropriate materials for use in oxygen service.

The first section of this STP, "Material Selection," investigates the appropriate use and selection of materials in oxygen-enriched atmospheres. Within this section, there are three papers addressing the proper selection of materials. The first paper presents the results of a very important investigation into the dimensional stability and potential changes in oxygen compatibility that have been observed for polychlorotrifluoroethylenes (PCTFE) plastics. Until 1995, PCTFE was sold as Kel-F®[1] and was widely used in many valve seat applications. Since 1995 Kel-F has been unavailable. A new PCTFE material is being produced by another manufacturer and is currently marketed as Neoflon®[2] PCTFE. The next paper presents a method used by Air Liquide to select and rank metals for use as an oxygen-valve material based upon gaseous impact testing (with particles) and estimated interface temperatures. The last paper presents the results of an experimental study on the oxygen compatibility of medical devices and materials.

The second section, "Ignition and Combustion of Nonmetals," also contains three papers. The first paper presents the results of a study looking at the effect of age on the mechanical and oxygen-compatibility (ignition and combustion) properties of six polymers. The second paper presents the results of an evaluation of the ignitability of polymers in various oxidizing environments. The last paper presents the results of the most comprehensive study to date on the ignition resistance of polymeric materials to particle impact in high-pressure oxygen.

As in the last two volumes, the third and largest dedicated section of this STP, "Ignition and Combustion of Metals," contains six papers. In the first paper, promoted ignition-combustion results at elevated temperatures for carbon steel, stainless steel, and nickel alloys are presented. This work is important as the use of metals at elevated temperatures in oxygen-enriched atmospheres are increasing. The second paper presents the results of liquid oxygen (LOX) mechanical impact tests on various size aluminum samples (and layered samples) that were contaminated by different hydrocarbons or by impurities in the LOX. The third work describes the heterogeneous burning process exhibited by metallic materials. Specifically addressed is the way in which the oxygen required for the combustion process is contained within the burning metal or oxide. Three systems are looked at as being representative of the type of chemical processes that are involved. The fourth paper presents a discussion on steel burning in oxygen given from the perspective of steel-making process metallurgy. The last two papers cover burning metals. One paper provides the community with promoted ignition-combustion data on Al-Si alloys, Al-SiC, selected binary alloys, and three stainless steels. Though some of this data is new, much of it was found to be unpublished during a comprehensive review of the metals combustion data at the NASA White Sands Test Facility. The other paper presents data and discusses the effects of the igniter wire chosen to initiate burning in the promoted ignition-combustion test, an area of investigation not addressed in the past.

The fourth section of this STP, "Analysis of Ignition and Combustion," contains five papers focusing on theoretical work related to the ignition and combustion of metals and nonmetals in oxygen-enriched atmospheres. The first paper presents a first-order analysis describing the ignition of a Buna-N O-ring contained between two metal flanges when impacted and exposed to oxygen. The next paper models the gaseous impact test using a numerical fluid dynamics model and compares the results to experimental observations. The third paper presents a model describing the smolder of cellulose-containing materials showing that, in the case of upholstery fabric, the combustion is controlled by oxygen diffusion to the reaction zone. Next the appropriate thermodynamic analysis that should be used to model the adiabatic compression of oxygen is presented. In the fourth paper, the author presents the analysis using the real equation of state and the implications of using simplifications to

[1] Kel-F® is a registered trademark of 3M, St. Paul, MN.

[2] Neoflon® is a registered trademark of Daikin America, Inc., Orangeburg, NY.

this equation of state with regard to the final temperature the compressed oxygen can reach. The final paper in this section presents a first-order model of the NASA/ASTM flammability test for metals burning in oxygen under reduced gravity. The work determines several combustion parameters that are valid for use in both reduced gravity and normal gravity.

The fifth section of this STP contain four papers related to failure analysis and safety. Two papers cover forensic analyses of regulator fires: the first in aluminum bodied medical regulators and the second in a welding regulator. The next paper discusses the training of emergency medical service personnel in the USA, Canada, and France and how to assure they are properly trained when using oxygen devices. This section concludes with a discussion of scuba systems and standard (contaminated) stainless steel tubes and their ignition potential by pneumatic impact in various nitrox environments. This work is highly relevant as the underwater dive industry continues to use higher concentrations of oxygen in recreational scuba systems.

"Structured Packings for Air Separation Plants," is the sixth section of this STP with four papers. The first paper presents results of a large experimental program investigating the flammability of brazed aluminum heat exchanger samples in both gaseous and liquid oxygen over a range of oxygen purities and pressures in an attempt to define a threshold above which a violent energy release occurs. Similarly, the next paper presents results on combustion tests of large aluminum packing and trayed columns in LOX are presented. The third paper is a study of flame spread and violent energy release processes of aluminum tubing in LOX and gaseous oxygen (GOX). A burning regime map defining the thresholds between no burning, normal burning, and violent energy release is presented as well as insight into the controlling mechanisms of the violent energy release. Finally, the last paper presents an analysis to determine the hydrocarbon adsorption on solid CO_2 and N_2O in LOX at ambient pressure.

The final section of this STP contains six papers that are a mix of topics relevant to the study of material compatibility in oxygen-enriched atmospheres. This section begins with a discussion of a new promoted-ignition combustion system being used to study the flammability of metallic materials in gaseous oxygen. Next work aimed at determining the oxidizing ability of gases and gas mixtures is presented. The third paper presents an analysis and discussion of flammability of materials in oxygen-enriched atmospheres. This is followed by a discussion of a new tester developed and used at NASA White Sands Test Facility to study the ignition of metals by polymers utilizing a CO_2 laser as the ignition source. The fifth paper presents and discusses the results, with particular emphasis on the statistical relevance of the data, of autoignition temperature round robin test results conducted by seven laboratories on eight polymeric materials. Finally, the last paper discusses the use of autoignition temperature data to statistically predict the ignition sensitivity of nonmetallics when subjected to a pneumatic gaseous impact.

This ninth volume on *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres,* provides a source of new information, highly relevant to individuals interacting with systems where the compatibility and sensitivity of materials due to their exposure to oxygen or oxygen-enriched atmospheres is of concern.

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