ASTM INTERNATIONAL
Selected Technical Papers

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: 15th Volume

STP 1626

Editors:
Theodore A. Steinberg
Gwenael J. Chiffoleau

SELECTED TECHNICAL PAPERS
STP1626

Editors: Theodore A. Steinberg and Gwenael J. Chiffoleau

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: 15th Volume

ASTM STOCK #STP1626
DOI: 10.1520/STP1626-EB

ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959
Printed in the U.S.A.

Library of Congress Cataloging-in-Publication Data

ISBN: 978-0-8031-7698-0

ISSN: 0899-6652

Peer Review Policy
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 International Committee on Publications.

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 International maintains the anonymity of the peer reviewers. The ASTM International Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM International.

Citation of Papers
When citing papers from this publication, the appropriate citation includes the paper authors, "paper title," in *STP title*, book editor(s) (West Conshohocken, PA: ASTM International, year), page range, paper doi, listed in the footnote of the paper. A citation is provided on page one of each paper.

Printed in Hanover, PA
October, 2021

Foreword

THIS COMPILATION OF Selected Technical Papers, STP1626, *Flammability and Sensitivity of Materials in Oxygen–Enriched Atmospheres: 15th Volume*, contains peer-reviewed papers that were submitted for presentation at a symposium planned for April 27–28, 2022, in Seattle, Washington, USA. The symposium was sponsored by ASTM International Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres.

Symposium Chairs and STP Editors:

Theodore A. Steinberg
Queensland University of Technology
Brisbane, Queensland, Australia

Gwenael J. Chiffoleau
WHA International
Las Cruces, NM, USA

Contents

Overview

STP1626 is the fifteenth Selected Technical Papers (STP) originating from ASTM International Committee G04 focusing on the *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres*. Committee G04 continues to grow in its international appeal due to its ongoing relevance in many diverse industries and uses. The fourteen previous STP volumes originating from the G04 committee, since 1983 when the first was published, are: STP812, 910, 986, 1040, 1111, 1197, 1267, 1319, 1395, 1454, 1479, 1522, 1561, and 1596. Copies of these valuable previous STPs are available from ASTM International.

The fifteenth symposium was scheduled to be held in Prague, Czech Republic, in 2020 but was cancelled due to the ongoing COVID-19 pandemic, which made it impossible for G04 members and other stakeholders to come together and meet in person. Due to this ongoing situation, G04 made the decision to move forward with this publication and attempt to meet in the future (tentatively scheduled for Seattle, Washington, USA, in 2022 at the time of this printing). As in the past STPs, the fifteenth volume expands upon the objectives that have been carried forward since the first STP was published. These objectives include:

- Review the current research on nonmetals and metals ignition and combustion,
- Overview principles of oxygen systems design and issues related to materials compatibility with oxygen; contribute to the knowledge on the most current risk management concepts, practices, approaches, and procedures used by individuals and organizations involved in the design, use, retrofitting, maintenance, and cleaning of oxygen systems,
- Review accident/incident case studies related to oxygen systems and oxygen handling procedures,
- Provide the most current data related to the flammability and sensitivity of materials in oxygen-enriched atmospheres to designers, users, manufacturers, and maintainers of oxygen components and systems and to support Committee G04's Technical and Professional Training Course on Fire Hazards in Oxygen Systems and Oxygen Systems Operation and Maintenance standards,

- Discuss enhancement, development, and use of standards sponsored by ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres, and
- Provide a readily accessible reference addressing oxygen compatibility.

The fifteenth volume consists of a group of 20 peer-reviewed publications presented in five sections on topics related to ignition and combustion of metals and non-metals, oxygen compatibility of components and systems, analysis of ignition and combustion, failure analysis and safety, and test methods/facilities.

Three papers focus on the ignition and combustion of nonmetals. The first paper presents the methodology applied by Kasch et al. to evaluate the compatibility of nonmetals for oxygen service that has been developed over 60 years of work. The next paper, by Newton et al., reviews approaches for assessing "safe-use" criteria and applying this criteria for evaluating the oxygen compatibility of nonmetals. The final paper in this section, by Odom et al., discusses the testing of nonmetallic materials (such as O-rings) that do not meet the requirements of ISO 21010:2017 in their actual operating configuration in a test fixture with a partial assembly of the in-use configuration.

Four papers are related to the ignition and combustion of metals. Coste et al. discuss the laser ignition and subsequent burning of metals while observing the process with optical pyrometry to provide a materials ignition temperature and minimum ignition energy, and investigate post-ignition combustion propagation. Results are compared to the standard test method used to evaluate metals (ASTM G124). The second paper in this section, by Hooser et al., presents an evaluation of a metals' flammability using the concept "extinguishment thickness." In this work, the authors prepare a test sample that is tapered with similar igniter as used in ASTM G124 to determine the thickness where a sample will extinguish. The results, for three proprietary alloys and stainless steel, are also compared to the standard (straight-rod) configuration data. The third paper, presented by Tylka and Johnson, describes supersonic particle impact testing on electroless nickel-coated SS304 in comparison with uncoated SS304 and Monel 405. The final paper in this section, also by Coste et al., discusses the laser ignition of metallic particles in oxygen at several pressures to provide the minimum ignition energy, ignition temperature, and burning characteristics of the particles (temperature and heat of combustion). A heat transfer model is developed and compared to the results obtained.

Four papers are presented on the analysis of ignition and combustion. The first, by Newton et al., provides a critical analysis of the various adiabatic compression test methods currently used as specified in ASTM G74, ASTM G175, ISO 10297, ISO 21010, and ISO 10524. A discussion of the thermodynamic energy developed by the test methods as compared to the adiabatic assumption typically made is provided. The second paper, by authors Ryan et al., presents a model developed to describe the thermal condition of a nonmetal when being subjected to rapidly compressed oxygen (as would be encountered in standard test methods noted above). The third paper, also by Ryan et al., presents the newly developed concept of "critical enthalpy" as the value where the enthalpy change available from a rapid compression of oxygen is greater than the enthalpy change required to take a nonmetal from ambient conditions up to its ignition point. The final paper of this section, by Ryan et al., discusses the kindling chain where a flammable nonmetal is (easily) ignited and then provides the energy required to ignite adjacent material. The work presents the burn rates and heat release rates for Nylon 6/6 and polytetrafluoroethylene and discusses the implications on the establishment of a kindling chain.

There are numerous significant oxygen system fires occurring across the globe that result in loss of system, loss of mission and/or loss of life. The fourth section presents five papers on failure analysis of specific events. The first paper by Wehr-Aukland et al. describes a failure analysis associated with a flash fire of a corrugated stainless steel hose as it was transferring LOX. Schumacher and Jason next present an investigation of a flash fire that occurred within an oxygen-enriched atmosphere within the cab of a moving passenger vehicle. Saha et al. present an analysis of a significant fire and explosion that occurred within an oxygen pressure reducing station at a steel plant. The next paper by Chiffoleau et al. describes a failure analysis of a LOX valve where the fire was contained internally to the device (and not noticed until a maintenance shutdown. This section finishes with another paper by Saha et al., where the authors present an analysis of the potential for a fire in an oxygen ball valve that is stuck closed during rapid opening (high torque) through frictional ignition of sealing gasket against the moving ball and trapped particles.

The final section of the STP contains four papers related to test methods or test facilities. The first paper by Gwynne et al. presents the results of evaluating the particles shed by two common bagging materials that are used to protect an oxygen cleaned component or part and compare the implications of these particles in relation to fire safety. The second paper by Woitzek et al. describes a new large high pressure (750 bar) oxygen pressure surge test facility developed within the German federal test agency (BAM) to support component testing. The facilities performance and technical specifications are provided. Gallus et al. present the third paper that describes a direct velocity measurement of particle impacts in flowing oxygen using photon doppler velocimetry. The final paper in this section is by Tapia-Harper et al., and it looks at the ambient and pressurized test methods described within the mechanical impact test, ASTM G86-17, and identifies variability between the two test methods which is described and discussed.

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifteenth Volume provides a diverse source of new information to the air separation industry, oxygen manufacturers, manufacturers of components for oxygen and other industrial gases service, manufacturers of materials intended for oxygen and other industrial gases service, and users of oxygen and oxygen-enriched atmospheres in aerospace, medical, industrial gases, chemical processing, steel and metals refining, as well as other diverse users of oxygen.

Theodore A. Steinberg
School of Mechanical, Medical, and Process Engineering
Faculty of Engineering
Queensland University of Technology
Brisbane, Queensland, Australia

Gwenael J. Chiffoleau
WHA International
Las Cruces, New Mexico, USA