

Journal of ASTM International
Selected Technical Papers



STP 1522

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres

12th Volume

JAI Guest Editors

Hervé Barthélémy
Theodore Steinberg
Christian Binder
Sarah Smith

Journal of ASTM International
Selected Technical Papers STP1522
**Flammability and Sensitivity
of Materials in Oxygen-Enriched
Atmospheres: 12th Volume**

JAI Guest Editors:

Hervé Barthélémy
Theodore A. Steinberg
Christian Binder
Sarah Smith



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

Printed in the U.S.A.

ASTM Stock #: STP1522

Library of Congress Cataloging-in-Publication Data

ISBN: 978-0-8031-7508-2

ISSN: 0899-1308

Copyright © 2009 ASTM INTERNATIONAL, West Conshohocken, PA. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

Journal of ASTM International (JAI) Scope

The JAI is a multi-disciplinary forum to serve the international scientific and engineering community through the timely publication of the results of original research and critical review articles in the physical and life sciences and engineering technologies. These peer-reviewed papers cover diverse topics relevant to the science and research that establish the foundation for standards development within ASTM International.

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use, or the internal, personal, or educational classroom use of specific clients, is granted by ASTM International provided that the appropriate fee is paid to ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9634; online: <http://www.astm.org/copyright>.

The Society is not responsible, as a body, for the statements and opinions expressed in this publication. ASTM International does not endorse any products represented in this publication.

Peer Review Policy

Each paper published in this special issue was evaluated in accordance with the *JAI* review process.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editors, 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", J. ASTM Intl., volume and number, Paper doi, ASTM International, West Conshohocken, PA, Paper, year listed in the footnote to the paper. A citation is provided as a footnote on page one of each paper.

Foreword

THIS COMPILATION OF THE *JOURNAL OF ASTM INTERNATIONAL (JAI)*, STP1522, on *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: 12th Volume*, contains only the papers published in JAI that were presented at a symposium in Berlin, Germany, on October 7, 2009–October 9, 2009 and sponsored by ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres.

The JAI Guest Editors are Hervé Barthélémy, Air Liquide Corporate, Paris, France, Theodore Steinberg, Queensland University of Technology, Brisbane, Australia, Christian Binder, BAM Federal Institute for Materials Research and Testing, Berlin, Germany, and Sarah R. Smith, NASA White Sands Test Facility, Las Cruces, NM, USA.

Contents

Overview	vii
Keynote—Materials Selection for Oxidizer Service—Successes and Challenges	
J. W. Slusser	1
Promoted Ignition-Combustion Behavior of Cobalt and Nickel Alloys in Oxygen-Enriched Atmospheres	
J. F. Million, A. V. Samant, and R. Zawierucha	10
Defining the Flammability of Cylindrical Metal Rods Through Characterization of the Thermal Effects of the Ignition Promoter	
D. Lynn, T. Steinberg, K. Sparks, and J. M. Stoltzfus	21
A Proposed Qualitative Framework for Heterogeneous Burning of Metallic Materials: The “Melting Rate Triangle”	
N. R. Ward and T. A. Steinberg	38
Ignition of Contaminated Aluminum by Impact in Liquid Oxygen—Influence of Oxygen Purity	
E. Werlen, F. Crayssac, O. Longuet, and F. Willot	49
Verification of the ASTM G-124 Purge Equation	
K. E. Robbins, S. E. Davis, and S. D. Herald	68
Determination of Burn Criterion for Promoted Combustion Testing	
K. M. Sparks, J. M. Stoltzfus, T. A. Steinberg, and D. Lynn	80
Promoted Ignition Testing of Metallic Filters in High-Pressure Oxygen	
G. A. Odom, G. J. A. Chiffolleau, B. E. Newton, and J. R. Fielding	96
Oxygen Compatibility of Brass-Filled PTFE Compared to Commonly Used Fluorinated Polymers for Oxygen Systems	
S. D. Herald, P. M. Frisby, and S. E. Davis	109
Ignition Sensitivity of Nonmetallic Materials in Oxygen-Enriched Air (NITROX): A Never Ending Story in SCUBA Diving?	
C. Binder, T. Brock, O. Hesse, S. Lehné, and T. Tillack	124
The Importance of Quality Assurance and Batch Testing on Nonmetallic Materials Used for Oxygen Service	
C. Binder, K. Art, T. Brock, P. Hartwig, O. Hesse, and T. Tillack	133
Identification and Quantification of Combustion Products Released by Non-Metallic Materials Used for Medical Oxygen Equipment	
M. Carré, H. Barthélémy, J. Bruat, S. Lombard, O. Longuet, and J. P. Schaaff	144
Determination of Time Required for Materials Exposed to Oxygen to Return to Reduced Flammability	
S. Harper, D. Hirsch, and S. Smith	175
Effect of Oxygen Concentration on Autogenous Ignition Temperature and Pneumatic Impact Ignitability of Nonmetallic Materials	
S. Smith	195
Liquid Oxygen Rotating Friction Ignition Testing of Aluminum and Titanium with Mone[®] and Incone[®] for Rocket Engine Propulsion System Contamination Investigatio	
S. F. Peralta, K. R. Rosales, and J. M. Stoltzfus	204
Electrical Arc Ignition Testing for Common Handheld Electrical Devices in Oxygen-Enriched Atmosphere	
K. Sparks, T. Gallus, and S. Smith	219

High Pressure Quick Disconnect Particle Impact Tests K. R. Rosales and J. M. Stoltzfus	227
Advanced Crew Escape Suits (ACES) Particle Impact Test K. R. Rosales and J. M. Stoltzfus	246
Good Practices for Avoiding Fires in Steel Mill Oxygen Systems E. T. Forsyth, B. E. Newton, G. J. A. Chiffolleau, and B. Brophy	266
Oxygen Fire Hazards in Valve-Integrated Pressure Regulators for Medical Oxygen E. T. Forsyth, B. E. Newton, G. J. A. Chiffolleau, and B. Forsyth	285
Sealed Aluminum Cavity Reactions when Submerged in Pure O₂ Reboiler Sump W. P. Schmidt, M. Cawthra, P. A. Houghton, R. H. McDonald, Jr., R. J. Sherwood, and S. J. Wieder	303
Vacuum Superinsulated Liquid Oxygen Piping and Vessels A. Colson, E. Werlen, and H. Barthélémy	322
Adiabatic Compression Testing—Part I: Historical Development and Evaluation of Fluid Dynamic Processes Including Shock-Wave Considerations B. E. Newton and T. Steinberg	337
Adiabatic Compression Testing—Part II: Background and Approach to Estimating Severity of Test Methodology B. E. Newton, G. J. A. Chiffolleau, T. Steinberg, and C. Binder	362
Tribocharging of Particle Contaminants Evaluated as an Ignition Source in Oxygen- Enriched Environments A. Oza, S. Ghosh, and K. Chowdhury	389
An Approach to Understanding Flow Friction Ignition: A Computational Fluid Dynamics (CFD) Study on Temperature Development of High-Pressure Oxygen Flow Inside Micron-Scale Seal Cracks J. D. Hooser, M. Wei, B. E. Newton, and G. J. A. Chiffolleau	429
The Rate-Limiting Mechanism for the Heterogeneous Burning of Cylindrical Iron Rods N. R. Ward and T. A. Steinberg	450
Chlorine Trifluoride Exposure Testing and Oxidizer Reactivity Results J. VanOmmeren	468
Author Index	495
Subject Index	497

Overview

This is the twelfth Special Technical Publication (STP) originating from ASTM Committee G04 focusing on the Flammability and Sensitivity of Materials in Oxygen-Enriched Environments. As in the past STPs, the twelfth volume expands upon the objectives that have been carried forward since the first STP was published in 1983. These objectives include:

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

The twelfth Volume consists of a group of peer-reviewed publications from the *Journal of ASTM International* that were also presented at Committee G04's Twelfth International Symposium held in Berlin, Germany in October 2009. The volume contains 29 papers on topics related to ignition and combustion of non-metals, ignition and combustion of metals, oxygen compatibility of components and systems, analysis of ignition and combustion, failure analysis and safety, and includes aerospace and industry oxygen applications.

The keynote address at the Twelfth International Symposium was presented by Joseph Slusser, Senior Engineering Associate—Materials, Air Products and Chemicals, Inc, Allentown, PA USA. He has been involved with materials selection for oxygen and other strong oxidizers since joining Air Products and Chemicals, Inc in 1980 and has been a member of Committee G04 since 1997. Mr. Slusser has been active in Committee activities, is currently the Chairman of Committee G04, and also serves on the ASTM Committee on Standards. In addition, he has been involved with several CGA task groups related to oxygen compatibility issues and has published several papers on oxygen and nitrogen trifluoride compatibility topics.

Eight papers focus on ignition and combustion of metals. A study is presented by Praxair on the promoted Ignition of cobalt and nickel alloys in oxygen enriched atmosphere. They found that although nickel and cobalt alloys are generally considered as having superior combustion resistance in oxygen—enriched atmospheres, flammability testing is necessary prior to service as there may be considerable variation in their promoted ignition-combustion resistance. Queensland University of Technology presents two papers; one where they show that heat transfer is the rate-limiting mechanism for the heterogeneous burning of cylindrical iron rod and, in the other, introduce the concept of the “melting rate triangle” to aid in the discussion of burning metallic materials. The fourth paper in this section presents results on the ignition of contaminated aluminum by mechanical impact in liquid oxygen. There are two papers, one submitted by NASA White Sands Test Facility and one by Queensland University of Technology that, together, define and validate the burn criterion used in the recent rewrite of ASTM Committee G04’s G124 standard on burning metallic materials. The last two papers in this section are submitted by Wendell Hull & Associates; one a test method developed to quantify the ignitability of metallic materials and the other presenting the test result for metallic filters for use in high-pressure oxygen.

Six papers are related to the use of non-metallic materials in oxygen-enriched atmospheres. The first, submitted by NASA Marshall Space Flight Center, looks at the compatibility of brass-filled PTFE as compared to other fluorinated polymers. The second and third papers in this section, submitted by BAM, first investigate the ignition of nonmetallics in NITROX mixes as encountered in typical SCUBA diving applications followed by a discussion on the importance of quality assurance and batch testing in the qualification of nonmetallic materials for oxygen service. The fourth paper on nonmetallics, submitted by Air Liquide, provides information on the type and quantity of combustion products produced when nonmetallic materials burn in oxygen systems. The final two papers in this section are submitted by NASA White Sands Test Facility with the first evaluating the time it takes for non-metallics exposed to oxygen to no longer be considered “oxygen enriched”, and the second looking at the effect of oxygen concentration on the AIT and ignitability by pneumatic impact of nonmetallic materials.

Eight papers focus on issues related to oxygen compatibility of components and systems. Four papers are by NASA White Sands Test Facility; the first is a study on a frictional heating of contaminated metals in a liquid oxygen rocket engine propulsion system, the second evaluated the arc ignition characteristics of common handheld devices in oxygen-enriched atmospheres and, both the third and fourth looked at particle impact ignition in a high pressure quick disconnect and in the Advanced Crew Escape Suits. Two papers submitted by Oxygen Safety Consultants and Wendell Hull & Associates evaluate the fire hazards in steel mill oxygen systems and within valve-integrated pressure regulators. The seventh paper in this section

looks at reactions within a sealed aluminum cavity within a reboiler while the final paper discusses vacuum super insulated liquid oxygen piping and vessels.

The final section of the STP contains six papers related to specific applications (or other areas). Two papers presented here by Wendell Hull & Associates, look in detail at adiabatic compression testing with the first presenting a background on this important testing and the second providing a proposed framework within which the severity of the test can be related to real components in service. The next two papers are an attempt to help clarify the mechanism behind flow friction ignition. The first provides a discussion on the importance of tribocharging of particle contaminants while the other uses CFD analysis as an explanation of this ignition phenomena. Next a submission from NASA Marshall Space Flight Center verifies the purge equation used in the G124 metals standard. Finally, some work is presented on Chlorine Trifluoride reactivity and testing.

The twelfth *Volume on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres* provides a diverse source of new information to 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 aerospace, medical, industrial gases, chemical processing, steel and metals refining, as well as to military-commercial-recreational diving.

Hervé Barthélémy
Air Liquide International Fellow
Paris, France

Theodore A. Steinberg
School of Engineering Systems
Faculty of Built Environment and Engineering
Queensland University of Technology
Brisbane, Queensland, Australia

Christian Binder
BAM
Berlin, Germany

Sarah Smith
NASA, WSTF
Las Cruces, NM

