# Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres

FIFTH VOLUME



Stoltzfus/McIlroy

EDITORS

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

Joel M. Stoltzfus and Kenneth McIlroy, editors

ASTM Publication Code Number (PCN) 04-011110-31



ISBN: 0-8031-1461-3

ASTM Publication Code Number (PCN): 04-011110-31

ISSN: 0899-6652

Copyright ©1991 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia, 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.

### **Photocopy Rights**

Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by the AMERICAN SOCIETY FOR TESTING AND MATERIALS for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of \$2.50 per copy, plus \$0.50 per page is paid directly to CCC, 27 Congress St., Salem, MA 01970; (508) 744-3350. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Service is 0-8031-1461-3/91 \$2.50 + .50.

### **Peer Review Policy**

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM 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 these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

## **Foreword**

This publication, Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifth Volume, contains papers presented at the symposium of the same name held in Cocoa Beach, FL., on 14–16 May, 1991. The symposium was sponsored by ASTM Committee G-4 on Compatibility and Sensitivity of Materials in Oxygen-Enriched Atmospheres. Joel Stoltzfus, NASA Johnson Space Center, White Sands Test Facility, and Kenneth McIlroy, Union Carbide Industrial Gases, Inc., Linde Division served as co-chairmen of the symposium and are also editors of the resulting publication.

# Acknowledgement

The quality of papers in this publication reflects not only the obvious efforts of the authors but also the unheralded work of the reviewers. Coleman Bryan, Barry Werley, Dr. Robert Lowrie, Kenneth McIlroy, Len Schoenman, Keith Miller, Dwight Janoff, and Joel Stoltzfus acted as review coordinators, enlisting appropriate reviewers and ensuring that reviews were completed properly and submitted on time. The editors also wish to acknowledge Monica Siperko and Rita Hippensteel for their efficient and diligent assistance in preparing this document.

Joel Stoltzfus Kenneth McIlroy

# **Contents**

Overview—J. M. STOLTZFUS AND K. MCILROY	1
KEYNOTE ADDRESS	
Combustion Fundamentals of Low Volatility Materials in Oxygen-Enriched Atmospheres—I. GLASSMAN	7
Development and Evaluation of Test Methods	
Flame Penetration Test for Protective Clothing in Oxygen—J. SANDERS AND J. L. CURRIE	29
Test Developments for Polymers in Oxygen-Enriched Environments— R. M. TAPPHORN, R. SHELLEY, AND F. BENZ	43
Ignition of Nonmetallic Materials by Impact of High Pressure Oxygen III: New Method Development—D. JANOFF, M. D. PEDLEY, AND L. J. BAMFORD	60
Automation of Autogenous Ignition Equipment—R. LOWRIE, H. GARCIA, AND R. L. HENNINGSON	75
Analysis of Oxygen Mechanical Impact Test Apparatuses and Methods— L. DEQUAY AND P. E. SCHEUERMANN	87
Recommended Changes in ASTM Test Methods D2512-82 and G86-84 for Oxygen-Compatibility Mechanical Impact Tests on Metals—J. D. MCCOLSKEY, R. P. REED, N. J. SIMON, AND J. W. BRANSFORD	126
IGNITION AND COMBUSTION OF NONMETALS	
Laser Resistant Endotracheal Tubes—Protection Against Oxygen-Enriched Airway Fires During Surgery?—A. L. DE RICHMOND	157
Endotracheal Tube Fires: A Flame Spread Phenomenon—G. W. SIDEBOTHAM, G. L. WOLF, J. STERN, AND R. AFTEL	168

Effects of Oxygen Concentration, Diluents, and Pressure on Ignition and Flame- Spread Rates of Nonmetals: A Review Paper—D. B. HIRSCH, R. L. BUNKER, AND D. JANOFF	179
IGNITION AND COMBUSTION OF METALS	
Reaction Sensitivities of Al-Li Alloys and Alloy 2219 in Mechanical-Impact Tests— N. J. SIMON, J. D. MCCOLSKEY, R. P. REED, AND C. M. GRACIA-SALCEDO	193
Aluminum-Lithium Alloys: Mechanical Property and Composition Effects on Liquid Oxygen Compatibility—w. T. TACK, D. K. MCNAMARA, J. M. STOLTZFUS, AND S. SIRCAR	216
Macro- and Microreactions in Mechanical-Impact Tests of Aluminum Alloys— R. P. REED, C. N. MCCOWAN, J. D. MCCOLSKEY, AND N. J. SIMON	240
The Relative Ignitability and Flammability of Lead-Tin Binary Alloys in Oxygen— S. SIRCAR, J. M. STOLTZFUS, AND M. V. GUNAJI	260
Promoted Ignition-Combustion Behavior of Selected Hastelloys in Oxygen Gas Mixtures—R. ZAWIERUCHA, K. MCILROY, AND R. B. MAZZARELLA	270
Promoted Ignition-Combustion Behavior of Precipitation Hardened Engineering Alloys—K. MCILROY AND R. ZAWIERUCHA	288
Iron Combustion in Microgravity—T. A. STEINBERG AND F. J. BENZ	298
The Analysis of Metals Combustion Using a Real-Time Gravimetric Technique— S. SIRCAR, H. GABEL, J. STOLTZFUS, AND F. BENZ	313
Burn Propagation Behavior of Wire Mesh Made from Several Alloys— J. STOLTZFUS, R. LOWRIE, AND M. V. GUNAJI	326
Oxygen Compatibility of High-Surface-Area Materials—B. R. DUNBOBBIN, J. G. HANSEL, AND B. L. WERLEY	338
Flame Propagation Rate of Unalloyed Beryllium and Silicon Nitride in Oxygen— L. SCHOENMAN AND J. E. FRANKLIN	354
ANALYSIS OF IGNITION MECHANISMS	
Temperature Increases in Aluminum Alloys During Mechanical-Impact Tests for Oxygen Compatibility—N. J. SIMON AND R. P. REED	367
Influence of Specimen-Absorbed Energy in LOX Mechanical-Impact Tests— R. P. REED, N. J. SIMON, J. R. BERGER, AND J. D. MCCOLSKEY	381

Thermodynamic and Fluid Mechanic Analyses of Rapid Pressurization in a Dead-End Tube—I. H. LESLIE	399
Use of Computer Analysis to Predict and Reduce Liquid Hammer Forces in High Pressure, High Flow Liquid Oxygen Systems—L. DEQUAY AND P. E. SCHEUERMANN	414
MATERIAL SELECTION	
An Assessment of the Metals Flammability Hazard in the Kennedy Space Center Oxygen Systems—C. J. BRYAN, J. M. STOLTZFUS, AND M. V. GUNAJI	453
Assessing LOX Compatibility for Aluminum-Lithium Alloys—B. K. NGUYEN AND B. T. PHAM	463
Oxygen Compatibility of Materials and Equipment for the Vulcain European Rocket Engine—J. M. DE MONICAULT, P. GARCEAU, AND G. VAGNARD	475
Test Methods and Interpretation of Results for Selecting Non-Metallic Materials for Oxygen Service—G. VAGNARD, G. DELODE, AND H. BARTHÉLÉMY	489
Ignition of Materials in Oxygen Atmospheres: Comparison of Different Testing Methods for Ranking Materials—H. BARTHÉLÉMY, G. DELODE, AND G. VAGNARD	· <b>506</b>
MISCELLANEOUS	
Is "LOX Clean" Enough?—C. J. BRYAN, W. R. CARMAN, T. A. SCHEHL, AND L. D. UNDERHILL	519
Special Construction Features of Centrifugal Compressors for Oxygen Service— K. BODDENBERG AND J. WALDMANN	528
Education and Training of Nonmedical Users of Portable Emergency Oxygen Inhalators at the Occupational Setting—L. M. STARR	546
Test Experience with a High-Pressure Oxygen Turbopump and Heat Exchanger— L. SCHOENMAN, R. L. SABIERS, AND M. C. MCILWAIN	556
Author ladex	574