Energy, Combustion and the Environment

Volume 2

Clean Combustion Technologies

Part B

Edited by

Maria da Graça Carvalho

Woodrow A. Fiveland

F. C. Lockwood

Christos Papadopoulos

Gordon and Breach Science Publishers

Clean Combustion Technologies

Selected Papers from the Proceedings of the Second International Conference Lisbon, Portugal, July 19–22, 1993

Part B

Edited by

Maria da Graça Carvalho
Instituto Superior Técnico
Lisbon, Portugal

F. C. Lockwood
Imperial College of Science, Technology and Medicine
London, UK

Woodrow A. Fiveland
Babcock & Wilcox
Alliance, Ohio, USA

Christos Papadopoulos
CINAR SA
Athens, Greece

Gordon and Breach Science Publishers
Australia • Canada • China • France • Germany
• India • Japan • Luxembourg • Malaysia • The Netherlands
• Russia • Singapore • Switzerland

Amsteldijk 166
1st Floor
1079 LH Amsterdam
The Netherlands

Some of the articles appearing in this book were originally published in *Combustion Science and Technology*, volume 108, numbers 4–6.

British Library Cataloguing in Publication Data

Clean combustion technologies : proceedings of the Second International Conference
Part B - (Energy, combustion and the environment ; v. 2
– ISSN 1073-7804)
1. Combustion engineering - Environmental aspects - Congresses
I. Carvalho, Maria da Graça
628.5'32

ISBN 90-5699-608-8 (part A)
90-5699-621-5 (part B)
90-5699-622-3 (two-part set)

Clean Combustion Technologies

Energy, Combustion and the Environment

A series edited by Scott Samuelsen
Professor of Mechanical, Aerospace, and Environmental Engineering
Director, UCI Combustion Laboratory
University of California, Irvine

The subject of this series is the production of energy and the relationship of this production to environmental impact. The scope focuses on: (1) fossil fuels, since these are projected to serve as the principal energy sources for more than 100 years; (2) three levels of environmental air quality impact, including urban air quality, tropospheric global warming and acid rain, and stratospheric ozone degradation; and (3) both stationary and aeroengine sources of energy production.

Volume 1
Combustion Technologies for a Clean Environment
Edited by Maria da Graça Carvalho, Woodrow A. Fiveland, F. C. Lockwood, and Christos Papadopoulos

Volume 2
Clean Combustion Technologies — Parts A and B
Edited by Maria da Graça Carvalho, Woodrow A. Fiveland, F. C. Lockwood, and Christos Papadopoulos

INTRODUCTION TO THE SERIES

The world is in transition toward acknowledging, and accepting, that a basic conflict exists between the provision of energy to support the world's economies and standard of living, and the protection of the air resource that sustains the world's life. The *Energy, Combustion and the Environment* book series is designed to place this conflict into perspective, and to provide readers—students, consulting engineers, regulators, legislative staff, and environmental action groups—with the information and tools required to understand the challenges and conduct analyses to address these challenges.

PREFACE

The conference sequence on Combustion Technologies for a Clean Environment, popularly known as the "Clean Air" conferences, was initiated by its organizers because they felt that, despite the many events dealing with environmental issues, this particular topic had rather surprisingly been largely missed. The popularity and overall success of the first conference bore testament to the validity of their perception. The second conference proved even more successful; contained in this volume are 75 of the reviewed, refereed papers presented at the second Clean Air conference. Topics covered range from chemical kinetics fundamentals to applied research in power stations. New subject areas include: pollutant dispersion, hybrid fueled combustors, new power generation cycles and concepts, and catalytic combustion.

The mix of academic and industry contributions that drew praise during the first Clean Air conference has been retained and, we hope, enhanced. Contributions from invited lecturers, who again comprise geographically dispersed and internationally reputed experts, are included. At this second conference, because it is a European-initiated conference series, two of the invited speakers lectured on themes relevant to the European Union.

It is probably useful at a scientific conference to have some comment from government sources since one thing is certain; pollution abatement measures, like aircraft safety, generally cost money; and in a world that is now almost completely based on market economy concepts, disasters are—in the absence of legislation—inevitable. Most of the atmospheric pollution we experience is due to combustion processes, as much from motor vehicles as from industry. Worldwide, this is accelerating rather than diminishing and the same is true even in some developed countries. To an extent, it may be argued that pollution abatement technology has failed to keep pace with market and, therefore, combustion growth. But the failure is also attributable to inability of government to effect more stringent regulations in a world where public material expectations seem invariably to exceed green aspirations, since the latter undoubtedly imply a degree of economic restraint.

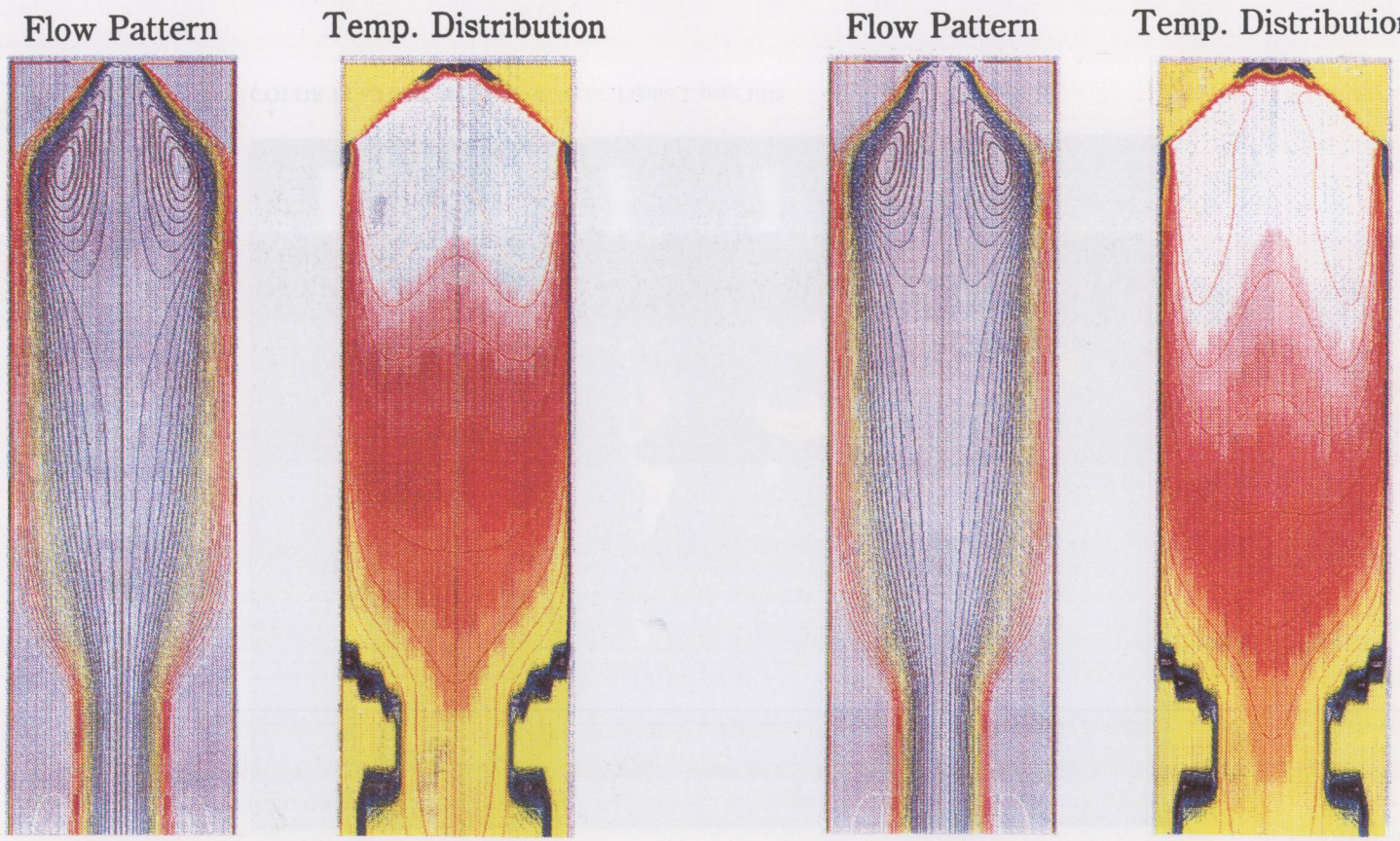
It is the hope of the organizers that the Clean Air conferences can continue to provide a forum for combustion technologies that will assist in suppressing the current dichotomy of economic prosperity and environmental protection.

ADVISORY COMMITTEE

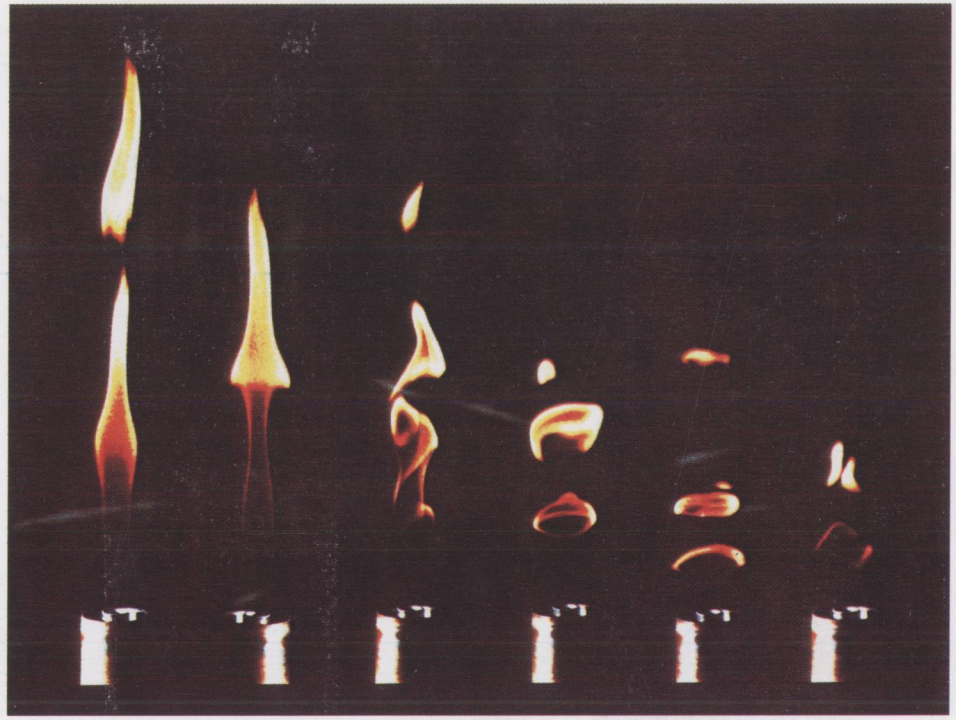
- **F. Antérion,** Saint-Gobain Recherche, Aubervilliers, France
- **L. Baxter,** Sandia National Laboratories, Livermore, California, USA
- **R. B. Collin,** Royal Institute of Technology, Stockholm, Sweden
- **C. Dopazo,** University of Zaragoza, Spain
- **I. Gulyurtlu,** INETI, Lisbon, Portugal
- **D. Hadjicostantis,** Titan Cement Co., Athens, Greece
- **K. Hein,** IVD, University of Stuttgart, Germany
- **J. D. Hickerson,** U.S. Department of Energy, Pittsburgh, Pennsylvania, USA
- **P. Hughes,** Canada Centre for Mineral and Energy Technology, Ottawa, Canada
- **J. Kezerle,** Gas Research Institute, Chicago, Illinois, USA
- **H. Kobayashi,** Praxair, Tarrytown, New York, USA
- **D. Lalas,** Lamda Technical Ltd., Athens, Greece
- **T. Miura,** Tohoku University, Sendai, Japan
- **M. Nina,** Instituto Superior Técnico, Lisbon, Portugal
- **A. J. Oliver,** National Power Plc Technology and Environmental Centre, Leatherhead, UK
- **C. Paulson,** CSIRO Division of Coal and Energy Technology, North Ryde, Australia
- **D. W. Pershing,** The University of Utah, Salt Lake City, Utah, USA
- **P. A. Pilavachi,** DG XII, C.E.C.
- **P. Roberts,** International Flame Research Foundation, Ijmuiden, The Netherlands
- **J. L. Roth,** IRSID, Maizierres-les-Metz, France
- **M. Sala,** Ansaldo Componenti, Milano, Italy
- **N. Shah,** Sundstrand Power Systems, San Diego, California, USA
- **M. Souza-Santos,** IGT—Institute of Gas Technology, Chicago, Illinois, USA
- **T. Suzuki,** Kobe Steel Co., Kobe, Japan
- **K. Takeda,** Kawasaki Steel Corp., Chiba, Japan
- **T. F. Wall,** The University of Newcastle, Newcastle, Australia
- **W. C. Welbourne,** NEI-International Combustion Ltd., Derby, UK
- **J. L. Wendt,** University of Arizona, Tucson, Arizona, USA
- **T. Yamada,** Idemitsu Kosan Co. Limited, Kimitsu Chiba, Japan

SPONSORING ORGANIZATIONS

- ADIST – Associação para o Desenvolvimento do Instituto Superior Técnico
- Babcock & Wilcox
- Banco Comercial Português
- Banco Nacional Ultramarino
- Câmara Municipal de Lisboa
- Direcção-Geral da Quai Idade do Ambiente
- Department of Defense (USA)
- FLAD–Fundação Luso-Americana para o Desenvolvimento
- Fundação Calouste Gulbenkian
- GALP
- GDP Gás de Portugal, SA
- ICEP–Investimentos, Comércio e Turismo de Portugal
- IST–Instituto Superior Técnico
- ITEC–Instituto Tecnológico para a Europa Comunitária
- JNICT–Junta Nacional de Investigação Cientifica e Tecnológica
- Palácio de Queluz
- SECIL–Companhia Geral de Cal e Cimento, SA
- SHELL
- THERMIE



COLOR PLATE I. *See* T. Suzuki *et al.*, Figure 10. page 705.



COLOR PLATE II. *See* D. Proctor *et al.*, Figure 2. page 1048.

CONTENTS