Developments in Heat Transfer

Transport Phenomena in Fuel Cells

WIT PRESS

Editors: B. Sundén and M. Faghri

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International Series on Developments in Heat Transfer

Objectives

The Developments in Heat Transfer book Series publishes state-of-the-art books and provides valuable contributions to the literature in the field of heat transfer. The overall aim of the Series is to bring to the attention of the international community recent advances in heat transfer by authors in academic research and the engineering industry.

Research and development in heat transfer is of significant importance to many branches of technology, not least in energy technology. Developments include new, efficient heat exchangers, novel heat transfer equipment as well as the introduction of systems of heat exchangers in industrial processes. Application areas include heat recovery in the chemical and process industries, and buildings and dwelling houses where heat transfer plays a major role. Heat exchange combined with heat storage is also a methodology for improving the energy efficiency in industry, while cooling in gas turbine systems and combustion engines is another important area of heat transfer research.

To progress developments within the field both basic and applied research is needed. Advances in numerical solution methods of partial differential equations, high-speed, efficient and cheap computers, advanced experimental methods using LDV (laser-doppler-velocimetry), PIV (particle-image-velocimetry) and image processing of thermal pictures of liquid crystals, have all led to dramatic advances during recent years in the solution and investigation of complex problems within the field.

The aims of the Series are achieved by contributions to the volumes from invited authors only. This is backed by an internationally recognised Editorial Board for the Series who represent much of the active research worldwide. Volumes planned for the series include the following topics: Compact Heat Exchangers, Engineering Heat Transfer Phenomena, Fins and Fin Systems, Condensation, Materials Processing, Gas Turbine Cooling, Electronics Cooling, Combustion-Related Heat Transfer, Heat Transfer in Gas-Solid Flows, Thermal Radiation, the Boundary Element Method in Heat Transfer, Phase Change Problems, Heat Transfer in Micro-Devices, Plate-and-Frame Heat Exchangers, Turbulent Convective Heat Transfer in Ducts, Enhancement of Heat Transfer and other selected topics.

Preface

Fuel cells are expected to play a significant role in the next generation of energy systems and road vehicles for transportation. However, substantial progress is required in reducing manufacturing costs and improving the performance. Solid Oxide fuel cells (SOFC), Proton Exchange Membrane fuel cells (PEMFC) and Direct Methanol fuel cells (DMFC) are of current interest.

Many of the associated heat and mass transport processes are not well understood and include multidimensional flow and heat transfer in multi phase flows, multicomponent transport of gaseous species in porous media and electrochemical reactions including heat generation. Depending on the fuel being used, modifications in the design of the next generation of fuel cells are needed. Therefore, additional transport processes even at micro scale level need to be investigated. Other important considerations are air management system for oxygen supply, water management and recovery or rejection of heat of exhaust products.

Currently an extensive amount of research and development activities are carried out for fuel cells worldwide. The dissemination of results is through various generic and specialized journals and conference proceedings. There is no comprehensive book available to address the analysis of transport phenomena in fuel cells.

This book aims to contribute to the understanding of the transport processes in SOFC, PEMFC and DMFC fuel cells. The nine chapters cover a wide range of topics and are invited contributions from some prominent scientists in the field.

The first chapter presents the thermodynamic and electrochemical fundamentals of SOFC. Efficiency, energy distribution, chemical equilibrium, losses of electrical potential, ohmic losses and losses due to mass transfer resistance are discussed. Modeling and numerical simulations of the coupled transport processes which determine the local and overall electromotive force in a SOFC are provided. Chapter 2 discusses various numerical techniques to model single-cells and stacks of planar SOFC. In chapter 3 a numerical model for analysis of a tubular SOFC including indirect internal reforming is presented. Fundamental results and strategies to reduce the maximum temperature and temperature gradient of the cell are discussed. Chapter 4 provides numerical analysis of heat, mass transfer (species flow), two-phase transport and effects on the performance in SOFC and PEMFC. In chapter 5 information on transport phenomena in the electrodes of PEMFC is provided. The physical characteristics of such electrodes are also discussed. The focus is on two-phase flow in porous media, with a discussion of driving forces and various flow regimes. Also, the mathematical models are summarized. Chapter 6 presents mathematical models and numerical simulations of PEMFC to evaluate effects of various designs and operating parameters on the fuel cell performance. The three-dimensional model can be used for optimisation of design and operation and serve as a building block for modeling and understanding of PEMFC stacks and systems. In chapter 7 scaling analysis, nondimensionalization and asymptotic techniques are used to identify the governing parameters in order to obtain a simplified model. Illustrations are provided for PEMFC and DMFC. In chapter 8 a mathematical model for a PEMFC stack is formulated. Distributions of pressure, fuel and oxidant mass flow rates in the stack are determined by a hydraulic network analysis. Finally chapter 9 provides an overview of the latest developments in the DMFC technology. Experimental and modeling works to elucidate critical transport phenomena, including two-phase mierofluidics, heat and mass transport are presented.

All of the chapters follow a unified outline and presentation to aid accessibility and the book provides invaluable information for both graduate research and R & D engineers at industry and consultancy.

We are grateful to the authors and reviewers for their excellent contributions. We also appreciate the cooperation and patience provided by the staff of WIT Press and for their encouragement and assistance in producing this volume. The editors would also like to thank the Wenner-Gren Center Foundation in Sweden for financial support.

B. Sundén and M. Faghri
2005

Contents