

Preface

Fuel cell is an electrochemical energy conversion device for environmentally friendly and sustainable energy production, and fuelled by hydrogen or hydrocarbon operating at a specific temperature ranging from 50 to 1,000 °C depending on the cell type. It is generally fabricated into a plate-type structure where the flow field consists of parallel plain flow channels separated by solid ribs, such as proton exchange membrane fuel cell (PEMFC) and planar solid oxide fuel cell (P-SOFC). The cell performance typically involves complicated multiphysical behaviours, such as transport phenomena and electrochemical performance. To understand the characteristics and mechanism of the fuel cell, mathematical modelling is an efficient approach, compared with repetitive and costly experimental techniques.

To date, about 12 books have been published in the literature on fuel cell modelling. The authors primarily reviewed the fundamental principles of fuel cells, and/or introduced the existing approaches for fuel cell modelling based on a full set of conservation equations. In general, however, detailed three-dimensional (3D) modelling of fuel cells is computationally expensive, especially for stacks, due to the highly coupled and nonlinear nature of the mathematical formulation as well as a large number of functional domains in the cell. Although some books have been published in the literature to develop mathematical models for fuel cells, none of them focused on reducing the 3D full models to efficient and accurate counterparts. There are simplified fuel cell models from 3D to 2D, but the assumptions on dimensionality tend to lower the fidelity of model prediction.

This is the first monograph of its kind, which is dedicated to developing reduced models of planar fuel cells and stacks. The present model reduction is primarily based on the method of spatial smoothing and asymptotic reduction, such that the fuel cell models can be solved fast and efficiently without sacrificing leading-order physics in numerical solutions. In particular, when reducing a 3D fuel cell model to a spatially smoothed counterpart, correlation and variation factors are developed to account for the effects of solid ribs on the pathways of heat, mass and charge transports. Reduced PEMFC and P-SOFC models are developed and verified with their 3D counterparts that were developed and validated with some experimental data reported in the literature. As a result, both the average and variability

of dependent variables along the cell width in the 3D geometry are captured by a quasi-3D reduced model solved with respect to the directions along the flow and through the cell thickness. The computational cost for cell and stack modelling is reduced by two orders of magnitude or more with desired numerical accuracy. Moreover, based on the efficient reduced models, integrated stochastic and deterministic sensitivity analysis is carried out to investigate not only individual but also simultaneous effects of a group of design factors (including geometrical, material, and operational parameters) on the cell and stack performance, which provides important information for fuel cell design. For such sensitivity analysis, Monte Carlo simulation of the reduced model is conducted with a sample size in the order of 10^3 at both single-cell and stack levels without prohibitive computation requirement, which is illustrated with the P-SOFC. In addition, apart from the PEMFC and P-SOFC, the present work can be extended to other kinds of plate-type fuel cells.

This book can primarily meet the needs of scientists and R&D engineers in the broad fields of fuel cell modelling and design, especially the PEMFC and P-SOFC. It is not only useful for them as a research reference but also allow further studies to extend the present work to suit their practical applications. The primary readers also include postgraduates doing research in the area of fuel cells, in particular, whose work involves numerical simulation, model reduction, scaling and asymptotic analysis, as well as sensitivity analysis. Possible secondary readers are the third- and fourth-year undergraduate students taking courses of advanced mechanical and electrochemical engineering. As a good reference source for course lectures, the book sections introducing the fundamental of fuel cell modelling are especially helpful for the students to learn more about fluid dynamics, electrochemistry, and transport phenomena pertaining to mass, momentum, and heat transfer. In addition, apart from fuel cells, the present approach of model reduction can also be extended to other energy systems where multiphysical phenomena are studied.

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Spatial Smoothing and Asymptotic Reduction

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