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Adaptive and Intelligent Control of Microbial Fuel Cells

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Preface

Renewable and clean energy is a fundamental need of the human society today. At the same time, a third of the world population lacks adequate and cost-effective sanitation. Microbial Fuel Cells (MFCs) attempt to address both these needs by directly converting organic content to electricity from bacteria. It is now well known that electricity can be made using biodegradable material without even adding any special chemicals, simply by using bacteria already present in the wastewater with an anode compartment. The bacteria of a specifically designed fuel cell free of oxygen, attach to the anode. Because of lack of oxygen, they must transfer the electrons to the cathode rather than to oxygen. Then the electrons, oxygen, and protons combine to provide clean water. The electrodes, when at different potentials, create a fuel cell with influent food or "fuel" that is continuously used up by the bacteria.

This book provides basic information about fuel cells, and specifically MFCs, and the materials and the construction of such cells, all from the perspective of a control engineer in ensuring a regulated output from the cell. The book provides basic information about different modeling strategies applicable in MFCs, including outlines of statistical models, and more details with respect to engineering models. Mathematical models for single compartment MFCs with single microbial population and also dual microbial populations are described. Additionally, mathematical modeling for dual chamber MFCs is also presented. All these models are developed in a way that identifies the uncertain parameters and is appropriate for controller formulation such that the equivalent model is a control-oriented parametrized model appropriate for further control and estimation action.

The developed MFC model for single population is then individually analyzed for two types of inputs: (a) dilution rate and (b) influent concentration, with respect to the equilibrium points and the stability of those equilibrium points. A robust controller design for norm bounded uncertainty is studied for this single population MFC using Linearity Matrix Inequality (LMI) criterion.

Adaptive control methodologies are dealt with in detail in literature in the last half a century. However, in the context of MFCs, the authors felt the need to provide the basic formulations of the specific types of adaptive control methodologies with appropriate example that is relevant to the specific dynamical equations of the MFCs studied in this book. We also formulate, in detail, the dynamical equations representing single compartment MFCs containing single and dual populations, while systematically presenting the adaptive control methodologies most appropriate to the specific types of MFCs. An intelligent control method like the exact linearization method is presented for the more complicated MFC setup with dual chambers consisting of separate dynamical equations representing the anode and cathode chambers, but with a single population.

We have described a laboratory-level setup of five similar MFC setups with two-compartment configuration with cow dung slurry as the substrate. Using system identification techniques, the transfer function models of the cathode and anode compartments are developed, which is then controlled using two different MRAC techniques in the final chapter.

In summary, this book presents a systematic description of adaptive and intelligent control of different types of MFCs that span nonlinear control techniques like backstepping control, linear and robust control methods using linear matrix inequality, and estimation and adaptive update of uncertain parameters using adaptive control techniques. It is hoped that this book will facilitate a researcher to delve into the fundamentals of MFCs and position the researcher to develop and engineer the advanced control methods so as to able to make a well-presented handout for the formulation of new knowledge in this upcoming field of renewable energy.

The authors acknowledge the support received from Dr. Meenu Chabbra, Assistant Professor, Indian Institute of Technology Jodhpur and Dr. Sourav Das, Assistant Professor, Institute of Infrastructure Technology Research and Management, Ahmedabad, in developing the laboratory-level MFC setups which enabled validation of the control methodologies developed in this book.

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Acronyms

1-D	One-Dimensional
2-D	Two-Dimensional
3-D	Three-Dimensional
CEM	Cation Exchange Membrane
DC	Dual Chamber
FC	Fuel Cell
LMI	Linear Matrix Inequality
MFC	Microbial Fuel Cell
MIT	Massachusetts Institute of Technology
MPC	Model Predictive Control
MRAC	Model Reference Adaptive Control
ODE	Ordinary Differential Equation
PD	Proportional & Derivative
PDE	Partial Differential Equation
PEM	Proton Exchange Membrane
PI	Proportional & Integral
PID	Proportional Integral & Derivative
SC	Single Chamber
SISO	Single Input Single Output
SPSC	Single Population Single Chamber

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