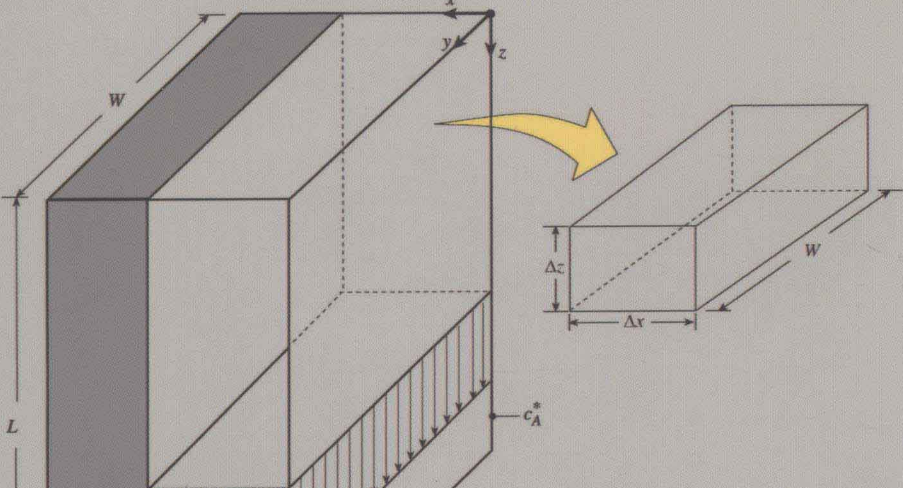
Second Edition

Modeling in Transport Phenomena

A Conceptual Approach



İsmail Tosun

Modeling in Transport Phenomena

A Conceptual Approach

Second Edition

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PREFACE TO THE SECOND EDITION

While the main skeleton of the first edition is preserved, Chapters 10 and 11 have been rewritten and expanded in this new edition. The number of example problems in Chapters 8–11 has been increased to help students to get a better grasp of the basic concepts. Many new problems have been added, showing step-by-step solution procedures. The concept of time scales and their role in attributing a physical significance to dimensionless numbers are introduced in Chapter 3.

Several of my colleagues and students helped me in the preparation of this new edition. I thank particularly Dr. Ufuk Bakır, Dr. Ahmet N. Eraslan, Dr. Yusuf Uludağ, and Meriç Dalgıç for their valuable comments and suggestions. I extend my thanks to Russell Fraser for reading the whole manuscript and improving its English.

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October 2006

The Solutions Manual is available for instructors who have adopted this book for their course. Please contact the author to receive a copy, or visit http://textbooks.elsevier.com/9780444530219

PREFACE TO THE FIRST EDITION

During their undergraduate education, students take various courses on fluid flow, heat transfer, mass transfer, chemical reaction engineering, and thermodynamics. Most of them, however, are unable to understand the links between the concepts covered in these courses and have difficulty in formulating equations, even of the simplest nature. This is a typical example of not seeing the forest for the trees.

The pathway from the real problem to the mathematical problem has two stages: perception and formulation. The difficulties encountered at both of these stages can be easily resolved if students recognize the forest first. Examination of the trees one by one comes at a later stage.

In science and engineering, the forest is represented by the **basic concepts**, i.e., conservation of chemical species, conservation of mass, conservation of momentum, and conservation of energy. For each one of these conserved quantities, the following inventory rate equation can be written to describe the transformation of the particular conserved quantity φ:

$$\begin{pmatrix} \text{Rate of} \\ \varphi \text{ in} \end{pmatrix} - \begin{pmatrix} \text{Rate of} \\ \varphi \text{ out} \end{pmatrix} + \begin{pmatrix} \text{Rate of } \varphi \\ \text{generation} \end{pmatrix} = \begin{pmatrix} \text{Rate of } \varphi \\ \text{accumulation} \end{pmatrix}$$

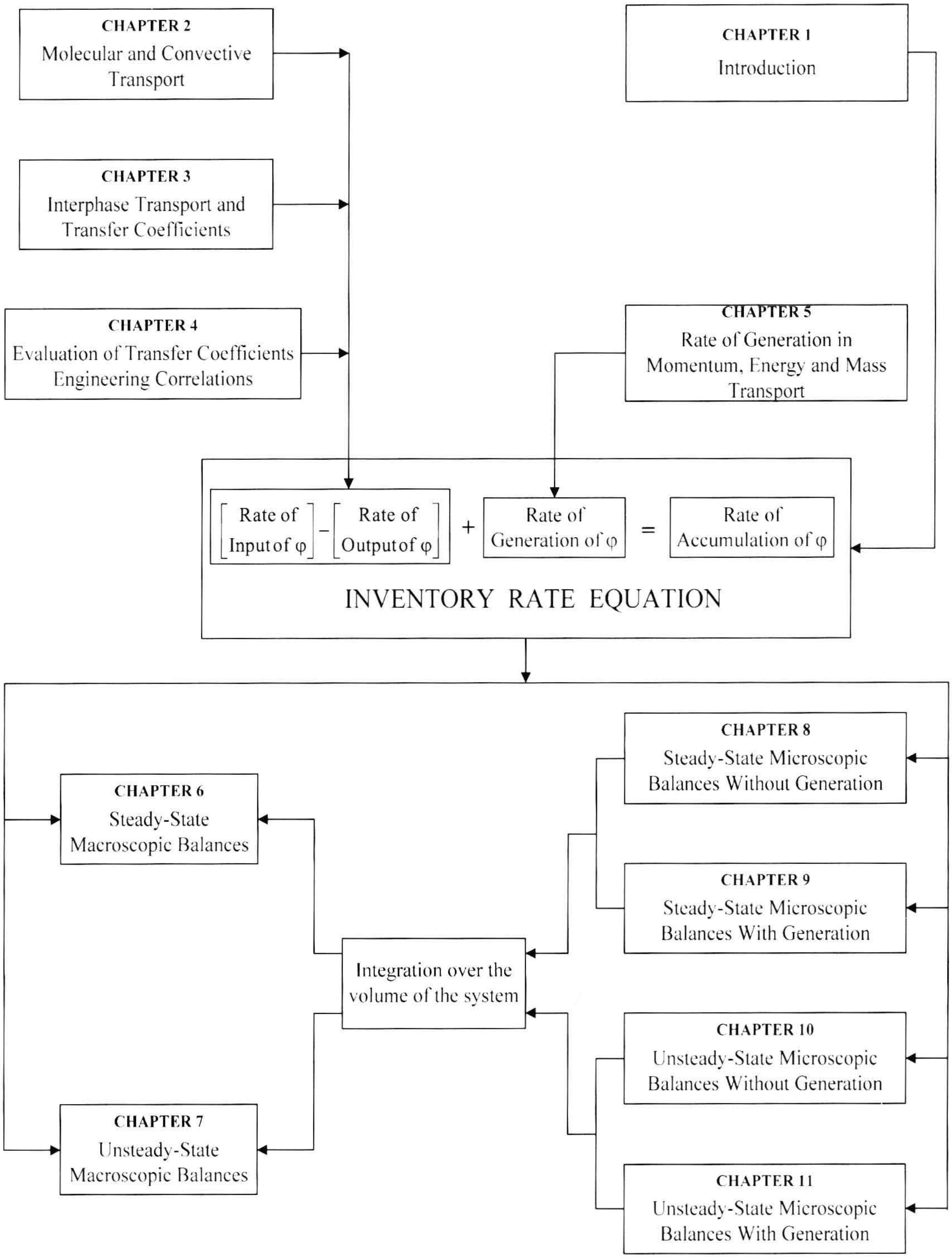
in which the term φ may stand for chemical species, mass, momentum, or energy.

My main purpose in writing this textbook is to show students how to translate the inventory rate equation into mathematical terms at both the macroscopic and microscopic levels. It is not my intention to exploit various numerical techniques to solve the governing equations in momentum, energy, and mass transport. The emphasis is on obtaining the equation representing a physical phenomenon and its interpretation.

I have been using the draft chapters of this text in my third year *Mathematical Modelling in Chemical Engineering* course for the last two years. It is intended as an undergraduate textbook to be used in an (Introduction to) Transport Phenomena course in the junior year. This book can also be used in unit operations courses in conjunction with standard textbooks. Although it is written for students majoring in chemical engineering, it can also be used as a reference or supplementary text in environmental, mechanical, petroleum, and civil engineering courses.

An overview of the manuscript is shown schematically in the figure below.

Chapter 1 covers the basic concepts and their characteristics. The terms appearing in the inventory rate equation are discussed qualitatively. Mathematical formulations of the "rate of input" and "rate of output" terms are explained in Chapters 2, 3, and 4. Chapter 2 indicates that the total flux of any quantity is the sum of its molecular and convective fluxes. Chapter 3 deals with the formulation of the inlet and outlet terms when the transfer of matter takes place through the boundaries of the system by making use of the transfer coefficients, i.e., friction factor, heat transfer coefficient, and mass transfer coefficient. The correlations available in the literature to evaluate these transfer coefficients are given in Chapter 4. Chapter 5 briefly talks about the rate of generation in transport of mass, momentum, and energy.


CHAPTER 2
Molecular and Convective Transport
CHAPTER 1
Introduction
CHAPTER 3
Interphase Transport and Transfer Coefficients
CHAPTER 4
Evaluation of Transfer Coefficients Engineering Correlations
CHAPTER 5
Rate of Generation in Momentum, Energy and Mass Transport
Rate of Input of φ − Rate of Output of φ + Rate of Generation of φ = Rate of Accumulation of φ
INVENTORY RATE EQUATION
CHAPTER 8
Steady-State Microscopic Balances Without Generation
CHAPTER 6
Steady-State Macroscopic Balances
CHAPTER 9
Steady-State Microscopic Balances With Generation
Integration over the volume of the system
CHAPTER 10
Unsteady-State Microscopic Balances Without Generation
CHAPTER 7
Unsteady-State Macroscopic Balances
CHAPTER 11
Unsteady-State Microscopic Balances With Generation

Traditionally, the development of the microscopic balances precedes that of the macroscopic balances. However, it is my experience that students grasp the ideas better if the reverse pattern is followed. Chapters 6 and 7 deal with the application of the inventory rate equations at the macroscopic level.

The last four chapters cover the inventory rate equations at the microscopic level. Once the velocity, temperature, or concentration distributions are determined, the resulting equations are integrated over the volume of the system to obtain the macroscopic equations covered in Chapters 6 and 7.

I had the privilege of having Professor Max S. Willis of the University of Akron as my PhD supervisor, who introduced me to the real nature of transport phenomena. All that I profess to know about transport phenomena is based on the discussions with him as a student, a colleague, a friend, and a mentor. His influence is clear throughout this book. Two of my colleagues, Güniz Gürüz and Zeynep Hiçşaşmaz Katnaş, kindly read the entire manuscript and made many helpful suggestions. My thanks are also extended to the members of the Chemical Engineering Department for their many discussions with me and especially to Timur Doğu, Türker Gürkan, Gürkan Karakaş, Önder Özbelge, Canan Özgen, Deniz Üner, Levent Yılmaz, and Hayrettin Yücel. I appreciate the help provided by my students, Gülden Camçı, Yeşim Güçbilmez, and Özge Oğuzer, for proofreading and checking the numerical calculations.

Finally, without the continuous understanding, encouragement and tolerance shown by my wife Ayşe and our children Çiğdem and Burcu, this book could not have been completed and I am particularly grateful to them.

Suggestions and criticisms from instructors and students using this book will be appreciated.

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Ankara, Turkey
March 2002

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