H. SCOTT FOGLER

ELEMENTS of CHEMICAL REACTION ENGINEERING

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ELEMENTS OF CHEMICAL REACTION ENGINEERING

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Preface

> The man who has ceased to learn ought not to be allowed to wander around loose in these dangerous days.
>
> M. M. Coady

This book is intended for use as both an undergraduate- and graduate-level text in chemical reaction engineering. The level of difficulty will depend on the choice of chapters to be covered and the type and degree of difficulty of problems assigned from those at the end of each chaper. Most problems requiring significant numerical computations can be solved with a personal computer which has at least BASIC as a programming language.

The thrust of this book is to present in a clear and concise manner the fundamentals of chemical reaction engineering. First, a structure is developed that allows the reader to solve reaction engineering problems through reasoning rather than through memorization and recall of numerous equations and the restrictions and conditions under which each equation applies. In perhaps no other area of engineering is mere formula plugging more hazardous; the number of physical situations in reaction engineering that can arise appears infinite, and the chances of a simple formula being sufficient for the adequate design of a real reactor are vanishingly small. However, the algorithms presented in the text for reactor design provide a framework with which one can develop confidence through reasoning rather than memorization.

Due to the rapid addition of new information and scientific principles, a true engineer must constantly expand his or her horizons beyond simple gathering of information and engineering principles. Thus the second goal of this book is to increase the student's lifelong learning skills by presenting hueristics and problems that encourage the student to practice certain intellectual skills. To accomplish this, we use (1) conventional problems that reinforce the student's understanding of the basic concepts and principles (included at the end of each chapter); (2) problems whose solution requires reading the literature, handbooks, or other textbooks on chemical engineering kinetics; and (3) problems that give students practice in problem definition and alternative pathways to solutions.

Another important skill fostered in this text is a critical analysis of journal articles. For the last ten years students in the graduate reactor engineering class at the University of Michigan have been required to carry out an in-depth critique of a journal article on chemical engineering kinetics. Although the students were told that choosing an article with erroneous data or reasoning was not necessary for a successful critique, it was stated that finding an error made the whole assignment much more fun. Consequently, a select number of problems at the end of chapters involve the critique of journal articles on reactor engineering which may or may not have major or minor inconsistencies. In some cases a small hint is given to guide the student in his or her analysis.

Many of the problems at the end of the various chapters were selected from those which have appeared in California Board of Registration for Civil and Professional Engineers–Chemical Engineering Examinations (PECEE) over past years. The permission for use of these problems, which, incidentally, may be obtained from the Documents Section, California Board of Registration for Civil and Professional Engineers–Chemical Engineering, 1004 6th Street, Sacramento, CA 95814, is gratefully acknowledged. (*Note:* These problems have been copyrighted by the California Board of Registration and many not be reproduced without their permission.) Additional problems are available on diskettes for use with the personal computer. Information about these interactive programs may be obtained from the author.

The strategy behind the presentation of material is the application, modification, or extrapolation of several basic ideas in chemical reaction engineering to solve a wide variety of problems. These ideas are referred to as the *Pillars of Chemical Reaction Engineering*, on which different applications rest. The pillars holding up the application of chemical reaction engineering are shown in Figure P-1.

The architecture and construction of the structure shown in Figure P-1 had many participants, most notably Professors Amundson, Aris, Smith, Levenspiel, and Denbigh. The contents of this book may be studied in virtually any order after the first four chapters, with few restrictions. A flow diagram showing possible paths is shown in Figure P-2.

In a three-hour undergraduate course at the University of Michigan approximately eight chapters are covered in the following order: Chapters 1, 2, 3, 4, Sections 5.1–5.3, 6.1–6.5, and Chapters 8, 10, 11, and parts of 13.

The reader will observe that although metric units are used primarily in this text (e.g., kmol/m^3, J/mol), a variety of other units are also employed (e.g., lb/ft^3).

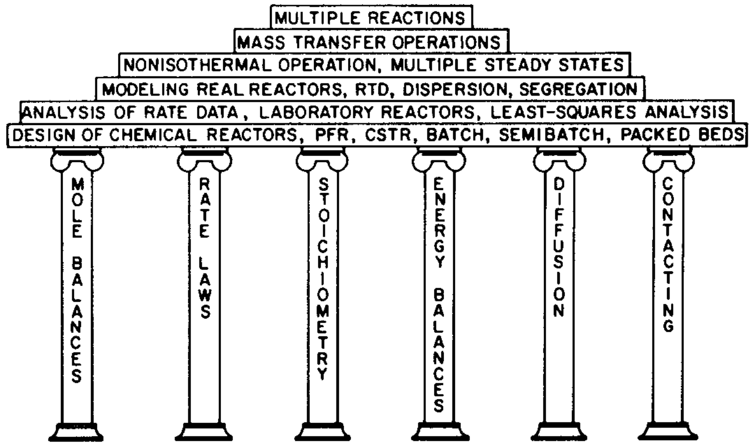

Figure P-1

This is intentional. It is our feeling that whereas most papers published in the future will use the metric system, today's engineers as well as those graduating over the next ten years will be caught in the transition between English, SI, and metric units. As a result, engineers will be faced with extracting information and reaction rate data from older literature which uses English units, as well as the current literature using metric, and should be equally at ease with both. However, all intensive laws tend often to have exceptions. Very interesting concepts take

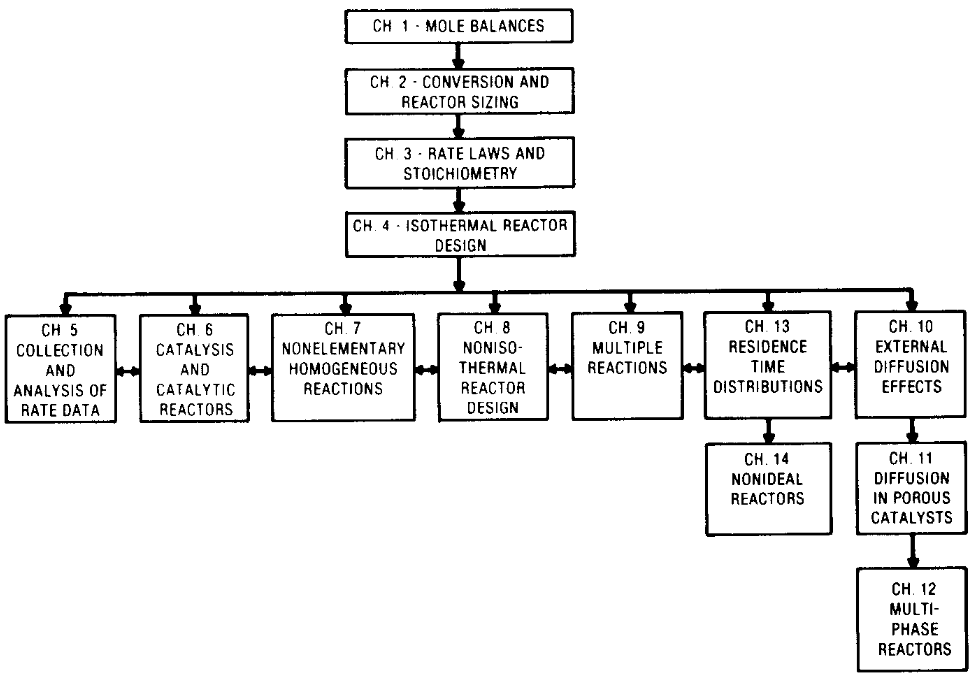

Figure P-2

orderly, responsible statements. Virtually all laws instinctively are normal thoughts. General observations become laws under experimentation.

The notes in the margins are meant to serve two purposes. One is to act as a guide or commentary as one reads through the material. Second, they identify key equations and relationships that are used to solve chemical reaction engineering problems.

Approximately three years after my first book, *The Elements of Chemical Kinetics and Reactor Calculations*, was published, I decided to revise and expand the programmed learning approach of the text. I asked Professor Lee Brown, whose research interests are kinetics and catalysis, to join me in rewriting the book, as he had used my programmed text in his course. I had always been impressed with the penetrating problems posed by Lee, which could not be solved by mere formula plugging. Dr. Brown later left the academic life for industry, and his limited time prevented him from participating to the extent that we originally expected. However, Dr. Brown collaborated in Chapters 13 and 14 (which are of joint authorship), provided material for Chapters 3, 6, and 8, and gave a critical reading of the entire book.

There are so many colleagues and students who contributed to this book that it would require another chapter to thank them all in an appropriate manner. Unfortunately, since Prentice-Hall has already requested a page reduction, this is not possible. However, certain people cannot go unacknowledged. The first is Neal Amundson, "The Chief," who I am sure is unaware of the various ways in which he has touched the author's career. Three of my colleagues at Michigan have, at different times and in different ways, been very important to the author personally and professionally. This book is dedicated to them: Guiseppe Parravano, Joe Martin, and Don Katz. I am also indebted to Max Peters and Octave Levenspiel, who first spawned my interest in chemical reaction engineering; Klaus Timmerhaus, who provided early guidance and a model to follow; Rane Curl, Uzi Mann, Erdogan Gulari, and Johannes Schwank, for their many insights and stimulating discussions; and certainly to Lee Brown for his friendship, penetrating questions, and artful presentation of material. Two other colleagues, Bob Kabel at Penn State and R. S. Shankar at I.I.T. Bombay, provided not only comments on the prepublication manuscript but also problems found at the ends of some chapters. To my colleagues in the department, thank you for your support and confidence, and for generating an atmosphere that spawns creativity and scholarship in teaching and research. J. S. Schultz was instrumental in helping to create such an atmosphere. A number of graduate and undergraduate students also contributed to the material in the book, primarily Abhaya Datye, T. Y. Hsieh, and Steve Le Blanc. Tim Nolan, Herb Alvord, Don DiMassi, Sunil Rege, and Greg McCabe helped proofread the final draft manuscript. Bruce Pynnonen was instrumental in helping to proofread the galley proof, and Tia Badalamente was invaluable in proofreading the page proofs. I would also like to thank Barbara Zeiders and her staff at Service to Publishers for their patient and outstanding job in taking the final manuscript through the final page proofs.

My wife Janet, family Peter, Robert, and Kristin, and parents, Ralph and Anne, contributed greatly to the support necessary to complete a task such as this. Many people contributed to typing portions of the original manuscript, including, in the early stages, Diana Delonnay and Jill Taber. However, this book would never have been completed were it not for Susan Montgomery, an alumna of my undergraduate chemical reaction course. Susan typed, retyped, edited, pasted, proofread, and commented on the entire book many times in addition to handling the many details associated with putting the manuscript in final form.

H.S.F.

Ann Arbor
February 1986

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