

BASIC PRINCIPLES AND CALCULATIONS IN CHEMICAL ENGINEERING

EIGHTH EDITION

David M. Himmelblau
James B. Riggs



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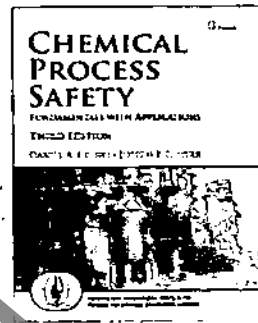
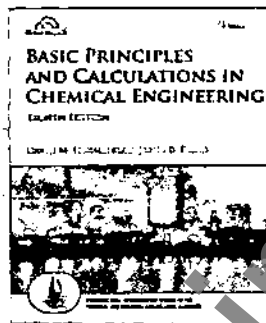
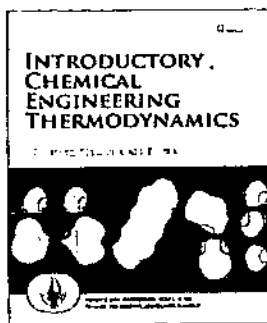
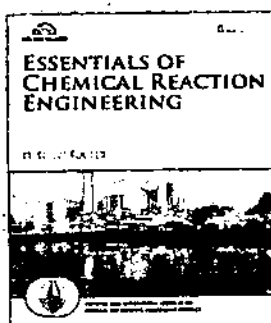
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*This book is dedicated to the memory of
David M. Himmelblau (1923–2011) and his contribution to
the field of chemical engineering.*

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David M. Himmelblau - James B. Riggs

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PREFACE

This book is intended to serve as an introduction to the principles and techniques used in the field of chemical engineering as well as biological, petroleum, and environmental engineering. Although the range of subjects deemed to be in the province of chemical engineering has broadened over the last twenty years, the basic principles of this field of study remain the same. This book presents the foundation of specific skills and information that are required for the successful undergraduate and postgraduate study of chemical engineering as well as the professional practice of chemical engineering. Moreover, your remaining chemical engineering classes will rely heavily on the skills that you will develop in this course: your ability to solve abstract problems as well as the application of material and energy balances. One can view the study of the field of chemical engineering as a tree with material and energy balances being the trunk and the subjects of thermodynamics, fluid flow, heat transfer, mass transfer, reactor kinetics, process control, and process design being the branches off the trunk. From this perspective, it is easy to see the importance of mastering the material that follows.

The primary objective of this book is to teach you how to systematically formulate and solve material and energy balance problems. More important, you should learn to systematically formulate and solve all types of problems using the methods presented in this text. In addition, this text serves to introduce you to the breadth of processes that chemical engineers work with, from the types of processes found in the refining and chemical industries to those found in bioengineering, nanoengineering, and the microelectronics industries. While the analysis used in this book will be based largely on a macroscopic scale (i.e., representing a complex system as a uniform system), your later engineering courses will teach you how to formulate microscopic material and energy balances that can be used to more completely describe

these systems. In fact, you will learn in these classes that to formulate a microscopic balance you only have to apply the balances presented in this textbook to a very small volume inside the process of interest.

This text is organized as follows:

- Part I Introduction: background information (Chapters 1–2)
- Part II Material Balances: how to formulate and solve material balances (Chapters 3–6)
- Part III Gases, Vapors, and Liquids: how to describe gases and liquids (Chapter 7–8)
- Part IV Energy: how to formulate and solve energy balances (Chapters 9–11)

Expecting to “absorb” the information and skills in this text by reading and listening to lectures is a bit naïve. It is well established that one learns by doing, that is, applying what you have been exposed to. In this regard, our text offers a number of resources to assist you in this endeavor. Probably the most important resources for your study of this material are the Self-Assessment Tests at the end of each section in the book. In particular, the Self-Assessment questions and problems are particularly valuable because by answering them and comparing your answers to the answers posted in Appendix A, you can determine what it is that you do not fully understand, which is quite an important piece of information. A number of valuable resources are provided to you on the CD that accompanies this book, which includes the physical property software, which provides timesaving access to physical properties for over 700 compounds and elements; Polymath for solving sets of equations, which comes with a 15-day free trial; and the Supplemental Problems Workbook with over 100 solved problems and process equipment descriptions. For more specific information on the resources available with this textbook and the accompanying CD, refer to the “Read Me” section that follows.

It is our sincere hope that this textbook and materials not only inspire you to continue to pursue your goal to become a chemical engineer, but also make your journey toward that goal easier.

Jim Riggs
Austin, Texas

READ ME

Welcome to *Basic Principles and Calculations in Chemical Engineering*. Several tools exist in the book in addition to the basic text to aid you in learning its subject matter. We hope you will take full advantage of these resources.

Learning Aids

1. Numerous examples worked out in detail to illustrate the basic principles
2. A consistent strategy for problem solving that can be applied to any problem
3. Figures, sketches, and diagrams to provide a detailed description and reinforcement of what you read
4. A list of the specific objectives to be reached at the beginning of each chapter
5. Self-Assessment Tests at the end of each section, with answers so that you can evaluate your progress in learning
6. A large number of problems at the end of each chapter with answers for about a third of them provided in Appendix E
7. Thought and discussion problems that involve more reflection and consideration than the problem sets cited in item 6
8. Appendixes containing data pertinent to the examples and problems
9. Supplementary references for each chapter
10. A glossary following each section

11. A CD that includes some valuable accessories:
 - a. Polymath—an equation-solving program that requires minimal experience to use. Polymath is provided with a 15-day free trial. Details on the use of Polymath are provided. A special web site gives significant discounts on educational versions of Polymath for various time periods: 4 months, 12 months, and unlimited use: www.polymath-software.com/himmelblau
 - b. Software that contains a physical properties database of over 700 compounds.
 - c. A Supplementary Problems Workbook with over 100 completely solved problems and another 100 problems with answers.
 - d. The workbook contains indexed descriptions of process equipment and animations that illustrate the functions of the equipment. You can instantly access these pages if you want to look something up by clicking on the page number.
 - e. Problem-solving suggestions including checklists to diagnose and overcome problem-solving difficulties that you experience.
 - f. Additional chapters and appendixes
 12. A set of steam tables (properties of water) in both SI and American Engineering units in the pocket in the back of the book
- Scan through the book now to locate these features.

Good Learning Practices (Learning How to Learn)

You cannot put the same shoe on every foot.

Publilius Syrus

Those who study learning characteristics and educational psychologists say that almost all people learn by practicing and reflecting, and not by watching and listening to someone else telling them what they are supposed to learn. "Lecturing is not teaching and listening is not learning." You learn by doing.

Learning involves more than memorizing

Do not equate memorizing with learning. Recording, copying, and outlining notes or the text to memorize problem solutions will be of little help in really understanding how to solve material and energy balance problems. Practice will help you to be able to apply your knowledge to problems that you have not seen before.

Adopt good learning practices

You will find that skipping the text and jumping to equations or examples to solve problems may work sometimes but in the long run will lead to frustration. Such a strategy is called “formula-centered” and is a very poor way to approach a problem-solving subject. By adopting it, you will not be able to generalize, each problem will be a new challenge, and the interconnections among essentially similar problems will be missed.

Various appropriate learning styles (information processing) do exist; hence you should reflect on what you do to learn and adopt techniques best suited to you. Some students learn through thinking things out in solitary study. Others prefer to talk things through with peers or tutors. Some focus best on practical examples; others prefer abstract ideas. Sketches and graphs used in explanation usually appeal to most people. Do you get bored by going over the same ground? You might want to take a battery of tests to assess your learning style. Students often find such inventories interesting and helpful. Look in the CD that accompanies this book to read about learning styles.

Whatever your learning style, what follows are some suggestions to enhance learning that we feel are appropriate to pass on to you.

Suggestions to Enhance Learning

1. Each chapter in this book will require three or more hours to read, assimilate, and practice your skills in solving pertinent problems. Make allowance in your schedule so that you will have read the pertinent material **before** coming to class. Instead of sitting in class and not fully understanding what your professor is discussing, you will be able to raise your understanding to a much higher level. It is not always possible, but it is one of the most efficient ways to spend your study time.
2. If you are enrolled in a class, work with one or more classmates, if permitted, to exchange ideas and discuss the material. But do not rely on someone to do your work for you.
3. Learn every day. Keep up with the scheduled assignments—don’t get behind, because one topic builds on a previous one.
4. Seek answers to unanswered questions right away.
5. Employ active reading; that is, every five or ten minutes stop for one or two minutes and summarize what you have learned. Look for connecting ideas. Write a summary on paper if it helps.

Suggestions for How to Use This Book Effectively

How can you make the best use of this book? Read the objectives before and after studying each section. Read the text, and when you get to an example, first cover up the solution and try to solve the stated problem. Some people, those who learn by reading concrete examples, might look at the examples first and then read the text. After reading a section, solve the self-assessment problems at the end of the section. The answers are in Appendix A. After completing a chapter, solve a few of the problems listed at the end of the chapter. R. P. Feynman, the Nobel laureate in physics, made the point: "You do not know anything until you have practiced." Whether you solve the problems using hand calculators or computer programs is up to you, but use a systematic approach to formulating the information leading to a proper solution. Use the supplement on the CD in the back of the book (print it out if you need to) as a source of examples of additional solved problems with which to practice solving problems.

This book functions as a savings account—what you put in, you get out, with interest.

ACKNOWLEDGMENTS

We are indebted to many former teachers, colleagues, and students who directly or indirectly helped in preparing this book, and in particular the present edition of it. We want to thank Professor C. L. Yaws for his kindness in making available the physical properties software database that is the basis of the physical properties package in the CD that accompanies our book, and also thanks to Professors M. B. Cutlip and M. Shacham who graciously made the Polymath software available. Far too many instructors using the text have contributed their corrections and suggestions to list them by name. Any further comments and suggestions for improvement of this textbook would be appreciated.

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ABOUT THE AUTHORS

David M. Himmelblau was the Paul D. and Betty Robertson Meek and American Petrofina Foundation Centennial Professor Emeritus in Chemical Engineering at the University of Texas, where he taught for 42 years. He received his B.S. from MIT in 1947 and his Ph.D. from the University of Washington in 1957. He was the author of 11 books and over 200 articles on the topics of process analysis, fault detection, and optimization, and served as President of the CACHE Corporation (Computer Aids for Chemical Engineering Education) as well a Director of the AIChE. His book, *Basic Principles and Calculations in Chemical Engineering*, has been recognized by the American Institute of Chemical Engineers as one of the most important books in chemical engineering.

James B. Riggs earned his B.S. in 1969 and his M.S. in 1972, both from the University of Texas at Austin. In 1977, he earned his Ph.D. from the University of California at Berkeley. Dr. Riggs was a university professor for 30 years, the first five years being spent at West Virginia University and the remainder at Texas Tech University. He was appointed Professor Emeritus of Chemical Engineering at Texas Tech University after he retired in 2008. In addition, he has a total of over five years of industrial experience in a variety of capacities. His research interests centered on advanced process control and online process optimization. During his academic career he served as an industrial consultant and founded the Texas Tech Process Control and Optimization Consortium, which he directed for 15 years. Dr. Riggs is the author of two other popular undergraduate chemical engineering textbooks: *An Introduction to Numerical Methods for Chemical Engineers*, Second Edition, and *Chemical and Bio-Process Control*, Third Edition. He currently resides near Austin in the Texas Hill Country.