Analysis, Synthesis, and Design of Chemical Processes

Fifth Edition

Richard Turton | Joseph A. Shaeiwitz
Debangsu Bhattacharyya | Wallace B. Whiting

PRENTICE HALL INTERNATIONAL SERIES IN THE PHYSICAL AND CHEMICAL ENGINEERING SCIENCES

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To the memory of Richard (Dick) C. Bailie (1928–2014)
Colleague, Friend, and Mentor

Contents

Preface

This book represents the culmination of many years of teaching experience in the senior design course at West Virginia University (WVU), Auburn University, and the University of Nevada, Reno. The program at WVU has evolved over the past 30 years and is still evolving, and the authors continue to integrate design throughout the undergraduate curriculum in chemical engineering.

We view design as the focal point of chemical engineering practice. Far more than the development of a set of specifications for a new chemical plant, design is the creative activity through which engineers continuously improve the operations of facilities to create products that enhance the quality of life. Whether developing the grassroots plant, proposing and guiding process modifications, or troubleshooting and implementing operational strategies for existing equipment, engineering design requires a broad spectrum of knowledge and intellectual skills to be able to analyze the big picture and the minute details and, most important, to know when to concentrate on each.

Our vehicle for helping students develop and hone their design skills is process design covering synthesis of the entire chemical process through topics relating to the preliminary sizing of equipment, flowsheet optimization, economic evaluation of projects, and the operation of chemical processes. The purpose of this text is to assist chemical engineering students in making the transition from solving well-posed problems in a specific subject to integrating all the knowledge that they have gained in their undergraduate education and applying this information to solving open-ended process problems.

In the fifth edition, we have replaced the majority of Section IV, Analysis of Process Performance. In previous editions, process performance was explained through a series of increasingly complex case studies. The approach adopted in the fifth edition is to provide a more logical pedagogy for the design of basic process equipment including pipes, pumps, and compressors (Chapter 19); heat exchangers (Chapter 20); separation equipment (Chapter 21); reactors (Chapter 22); and process vessels and steam ejectors (Chapters 23). Each chapter starts out with the design procedure and basic equations needed to design the equipment. At the end of each chapter, examples of performance (or rating) problems are given. The purpose of these chapters is to review the key concepts needed in the design and then show how to analyze systems in which the equipment already exists. It may be tempting to solve the performance of existing equipment using the process simulator, but using steady-state simulators to model these changes in equipment performance can be difficult. Dynamic simulators are the preferred method for simulating performance changes but are rarely used in the undergraduate curriculum. Therefore, we regard the material on equipment performance included in Section IV to be an essential part of the undergraduate design experience and encourage educators to adopt some if not all of this material in the design course or courses in each specific area that are often taught in the junior year. The content for Chapters 19–23 is taken from the book *Chemical Process Equipment Design* by Turton and Shaeiwitz (ISBN-13: 978-0-13-380447-8).

In addition to the changes in Chapters 19–23, a section on advanced optimization has been added to the chapter on advanced concepts in steady-state simulation (Chapter 16).

The arrangement of chapters into the six sections of the book is similar to that adopted in the fourth edition. These sections are as follows:

- Section I—Conceptualization and Analysis of Chemical Processes
- Section II—Engineering Economic Analysis of Chemical Processes
- Section III—Synthesis and Optimization of Chemical Processes
- Section IV—Chemical Equipment Design and Performance
- Section V—The Impact of Chemical Engineering Design on Society
- Section VI—Interpersonal and Communication Skills

In Section I, the student is introduced first to the principal diagrams that are used to describe a chemical process. Next, the evolution and generation of different process configurations are covered. Key concepts used in evaluating batch processes are included in Chapter 3, and the concepts of product design are given in Chapter 4. Finally, the analysis of existing processes is covered. In Section II, the information needed to assess the economic feasibility of a process is covered. This includes the estimation of fixed capital investment and manufacturing costs, the concepts of the time value of money and financial calculations, and finally the combination of these costs into profitability measures for the process. Section III covers the synthesis of a chemical process. The minimum information required to simulate a process is given, as are the basics of using a process simulator. The choice of the appropriate thermodynamic model to use in a simulation is covered, and the choice of separation operations is covered. Process optimization (including an introduction to optimization of batch processes) and heat integration techniques are covered in this section. In addition, advanced concepts using steady-state process simulators (Chapter 16), the use of dynamic simulators (Chapter 17), and process regulation (Chapter 18) are included in Section III. In Section IV, the analysis of the design of process equipment and the performance of existing process equipment is covered. The presentation of this material has changed substantially from all previous editions and was discussed previously. In Section V, the impact of chemical engineering design on society is covered. The role of the professional engineer in society is addressed. Separate chapters addressing ethics and professionalism, health, safety, and the environment, and green engineering are included. Finally, in Section VI, the interpersonal skills required by the engineer to function as part of a team and to communicate both orally and in written form are covered. An entire chapter is devoted to addressing some of the common mistakes that students make in written reports.

Finally, three appendices are included. Appendix A gives a series of cost charts for equipment. This information is embedded in the CAPCOST program for evaluating fixed capital investments and process economics. Appendix B gives the preliminary design information for 15 chemical processes: dimethyl ether, ethylbenzene, styrene, drying oil, maleic anhydride, ethylene oxide, formalin, batch manufacture of amino acids, acrylic acid, acetone, heptenes production, shift reaction, acid-gas removal by a physical solvent, the removal of H_2S from a gas stream using the Claus process, and finally coal gasification. This information is used in many of the end-of-chapter problems in the book. These processes can also be used as the starting point for more detailed analyses—for example, optimization studies. Other projects, given in Appendix C, are also included. The reader (faculty and students) is also referred to our Web site at https://richardturton.faculty.wvu.edu/projects, where a variety of design projects for sophomore-through senior-level chemical engineering courses is provided. In addition, a revised CAPCOST program is also available at https://richardturton.faculty.wvu.edu/publications/analysis-synthesis-and-design-of-chemical-processes-5th-edition as well as the HENSAD program and the virtual plant tour. It should be noted that revisions to the CAPCOST program will appear periodically on the Web site.

The structure of the senior-year design course obviously varies with each instructor. However, the following coverage of materials is offered as suggestions. For a one-semester design course, we recommend including the following core:

- Section I—Chapters 1 through 6
- Section III—Chapters 11, 12, and 13
- Section V—Chapters 25 and 26

For programs in which engineering economics is not covered in a separate course, Section II (Chapters 7–10) should also be included. If students have previously covered engineering economics, Chapters 14 and 15 covering optimization and pinch technology could be substituted. Similarly, for programs that have separate courses on process safety and/or where engineering ethics is treated elsewhere, Chapters 14 and 15 could be substituted.

For the second term of a two-term sequence, we recommend Chapters 19 through 23 (and Chapters 14 and 15 if not included in the first design course) plus a design project. Chapters 19 through 23 could also be the basis for an equipment design course that might precede a process design course. Alternatively, advanced simulation techniques in Chapters 16 and 17 could be covered. If time permits, we also recommend Chapter 18 (Regulation and Control of Chemical Processes with Applications Using Commercial Software) and Chapter 24 (Process Troubleshooting and Debottlenecking), because these tend to solidify as well as extend the concepts of Chapters 19 through 23, that is, what an entry-level process engineer will encounter in the first few years of employment at a chemical process facility. For an environmental emphasis, Chapter 27 could be substituted for Chapters 18 and 24; however, it is recommended that supplementary material be included.

We have found that the most effective way both to enhance and to examine student progress is through oral presentations in addition to the submission of written reports. During these oral presentations, individual students or a student group defends its results to a faculty panel, much as a graduate student defends a thesis or dissertation.

Because design is at its essence a creative, dynamic, challenging, and iterative activity, we welcome feedback on and encourage experimentation with this design textbook. We hope that students and faculty will find the excitement in teaching and learning engineering design that has sustained us over the years.

Finally, we would like to thank those people who have been instrumental to the successful completion of this book. Many thanks are given to all undergraduate chemical engineering students at West Virginia University over the years, particularly the period 1992–2018, and the undergraduate chemical engineering students at Auburn University from 2013–2018. We also acknowledge the many colleagues who have provided, both formally and informally, feedback about this text. In particular, our thanks go to Dr. Susan Montgomery (University of Michigan) and Dr. John Hwalek (University of Maine) for their extensive review of Chapters 19–23 and Dr. Fernando Lima (West Virginia University) for his review of the optimization material in Chapter 16. Finally, RT would like to thank his wife, Becky; JAS would like to thank his wife, Terry; and DB would like to thank his parents, Sambhunath and Gayatri, wife Pampa, and son Swagat for their continued support, love, and patience during the preparation of this fifth edition.

R.T.
J.A.S.
D.B
W.B.W.

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