Chemical and Bioprocess Engineering

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Fundamental Concepts for First-Year Students

Springer

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This book is dedicated to our wives, Anita and Padma, and family, José Ignacio, María Jesús, Enrique and Amit and Nevin.

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Preface

To give anything less than your best, is to sacrifice the gift.

Steve Prefontaine

There are many excellent introductory books for future chemical and bioprocess engineers. So what motivates us to write this book?

Why and How?

No introductory chemical engineering book covers all the branches related to chemical engineering in the twenty-first century. In addition, existing books, independent of content, generally cover only chemical engineering or biochemical engineering, but not both chemical and bioprocess engineering. Bioprocess engineering is broader than biochemical engineering, covering other areas such as food engineering, environmental engineering, biochemical processing, and biological engineering.

Many books offer broad-based introductions to the subject but do not reveal the underpinnings of future knowledge. One key motivation in our case is the approach of Robert H. Frank (http://www.robert-h-frank.com/), wherein the building of understanding of the fundamentals via practice with relevant real-world examples takes precedence over the coverage of large amounts of material. Herein, we identify specific areas within which specific levels of competencies are to be attained. To facilitate and orient professors and students, we will classify each chapter following Bloom's taxonomy (BT). Each chapter will be identified in relation to the cognitive domains of BT: (1) knowledge, (2) comprehension, (3) application, (4) analysis and synthesis, (5) evaluation, and (6) creation.

Our approach involves a thorough grounding in the fundamentals so that the background may be used in future work. Here we present numerous solved and proposed exercises (more than 400). In each chapter, problems will be classified by level of difficulty (from 1 to 10^+, were 10^+ is the most difficult). Each chapter will have references and selected Web pages to vividly illustrate all the examples. Since this is intended to be an introductory book, some concepts will receive closer attention than others. Therefore, as mentioned, each chapter will be clearly marked according to BT. A note to students using this book: we are not pretending that you will be an expert in

everything, but you will be fully prepared as a problem solver and with probably the most important knowledge of a future chemical and bioprocess engineer, which is to say you will receive a rigorous preparation in material balances. As stated, you will not learn a large quantity of material, but you will be armed with the necessary tools for success. Just follow our recommendations firmly and consistently. As we repeatedly tell our students, you need to be dutiful.

Motivation is a key aspect and component in your first steps as an engineer. There is a need to engage students with interesting material, especially in a subject matter like units and dimensions, which are critically important but somewhat dry. Thus, many of the examples involve real-world situations to which students may be able to relate readily. In this book, you will be exposed to all of the chemical and bioprocess engineering areas, so you will understand your future role in society, and, most importantly, we will do our best to communicate to you the enchantment we feel with this marvelous profession.

What Is an Engineer?

First and foremost, an engineer is a problem solver, independent of his or her specialization. Therefore, in Chap. 5, we develop a method and strategy to give you the necessary tools to start on your long journey to becoming a strong and solid problem solver. Experience has shown us that with the correct methodology and the necessary background, you will be prepared to face intricate problems. As a strong problem solver in chemical and bioprocess engineering, you should acquire a good knowledge of basic sciences, mainly mathematics, chemistry, biochemistry, microbiology, economics, and physics.

Secondly, your main mission and role as an engineer will be to connect or channel the discoveries made by scientists at the laboratory scale to transform them into products made at the factory level and, finally, to scale them up as a profitable end product for society. This text will familiarize you with the whole range of areas that comprise this field. Its multidisciplinary characteristics will imply that most of the time you will have to work in teams, meaning that you should acquire the ability and the language to communicate with persons from different fields.

What Do We Expect from You and Why?

In the mid-1980s, psychologists discovered and elaborated what is called the theory of cumulative advantages. In simple terms, if you practice continuously and systematically, at the end you will achieve a high standard on this specific topic or field of study. (The concept has other applications, too.) The interesting and robust message behind this theory is that, more important than your IQ, it is your attitude and effort put forth in what you are pursuing that matter. We are convinced that if you follow our advice rigorously and work

with effort, effort, and more effort, at the end you will be entirely compensated. If you want to excel or, more importantly, to be satisfied with your achievements, you need to understand that it mostly depends on you and your attitude. We will do our best to be good guides, but always remember that we need your collaboration, and, of course, you need to cooperate with your professors and advisers at your college/university.

What You Will Learn?

You will need to master the basic skills of chemical and bioprocess engineers. Most notably, we are committed to having an impact on you. We are committed to showing you all aspects of this fascinating field. Ultimately, we expect to teach you to be a much better problem solver, to motivate and captivate you with the enormous diversity and brilliant future of this profession, and to enable you to acquire one of the most important gems of knowledge required for a chemical and bioprocess engineer: a strong and solid preparation in material balances and economy fundamentals to introduce you to the first stages in project evaluation. As Albert Einstein said, *"Imagination is more important than knowledge*."

In summary, attitude, questioning, effort, a sound method and strategy to solve problems (mainly Chap. 5), material balances (Chaps. 7 and 8), and basic economic principles (Chap. 12) will be the main topics and patterns to be learned. In addition, you will be given a clear overview of this profession.

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To Our Students, Colleagues and Tutors

The only thing worse than being blind is having sight but no vision.

Helen Keller

Where there is no vision, there is no hope.

George Washington Carver

Leadership is the capacity to translate vision into reality.

Warren G. Bennis

Engaging Freshmen Engineering Students

As was stressed in the preface, our main goal is to enchant freshman students with the broad field of chemical and bioprocess engineering. We have learned over the years that the most effective way of engaging freshman students is by motivating them. Normally, when we have been invited to share our experience with freshman engineering students, we say that the three most important characteristics are motivation, motivation, and motivation. Most will probably agree, but the key question is how? First, experience has shown us that accomplishments are normally accompanied by coherent foundational beliefs. One of the intentional, subtle, guiding beliefs of this book is that with a clear method and procedure, problems are normally easier to solve. We have long experience with freshmen who have internalized, simultaneously, this guiding belief and the proposed methodology with extraordinary success. We attribute this success primarily to the fact that, from the very beginning, students feel that problems can be solved, and they develop the necessary confidence to do so. In addition, students are introduced to a well-founded methodology and procedures to solve engineering problems. Further, we have attempted to structure the book so as to attract students to the broad field of chemical and bioprocess engineering. As an example, we have included chapters that, while not essential for the book, will help us engage freshmen and, in addition, help these young students have a better and a broader comprehension of process engineering. We specifically refer to Chaps. 4 and 10, "Learning from Nature" (biomimetics) and "Scale-Up."

Bloom's Taxonomy

We have classified each chapter in accordance with Bloom's taxonomy (from 1 to 5) to guide the user regarding the relevance of each topic for this freshman course. In addition, we would like to emphasize that our main goal is to empower students to formulate problems (Chap. 5) and teach them material balance (Chaps. 7 and 8). Although the book is composed of 12 chapters, some of them could be disregarded at the instructor's discretion. Nevertheless, the key object remains: to teach problem formulation and material balance as key aspects for freshman students, always keeping in mind the importance of

enchanting and delighting students with the exciting and broad field of chemical and bioprocess engineering.

Key Concepts

In what follows, we would like to share with you, colleagues and instructors, some ideas and concepts on how to better understand and seize the advantages of this book.

Problem Formulation

First, as was already mentioned, an engineer is a problem solver. As you will see throughout the book, our main objective is to empower students with a method and strategy for correctly formulating problems. The first steps in problem formulation are presented in Chap. 5, and these concepts are applied to chemical and bioprocess engineering problems throughout Chaps. 6, 7, 8, 11, and 12. It is very clear that during their future engineering careers, students will be trained in problem resolution. From our vantage point, problem formulation is a critical point because in our experience, normally small amounts of time and effort are dedicated to teaching students to correctly formulate problems compared to the prodigious amounts of time and energy devoted to teaching mathematical methods on how to solve equations. This only gets worse with high school students, who are normally very poorly trained in problem formulation.

Method of Problem Formulation

As a strategy, we have chosen first to present in each chapter examples and solved problems, from introductory to advanced levels. We then provide a long list of proposed problems (with answers). In these proposed problems, we indicate the degree of difficulty (from 1 to 10^+, with 10^+ being the hardest) according to our experience and our students' feedback. In some proposed problems that we consider most difficult (8 to 10^+ on our scale) we include hints to facilitate their resolution. Finally, in specific cases, we considered it relevant to include references and background details. In Chap. 5, we present a method on solving problems, and then, in Chap. 7, the method is expanded and detailed for the solution of material balance problems. Experience has shown us repeatedly that freshmen can be empowered to formulate and solve interesting and intricate material balance problems and, at the same time, enjoy chemical and bioprocess engineering.

Material Balance

Chapters 7 and 8 form the core of the book. As we say to our students, half-jokingly: "If you learn material balance, you are 50 % of a process engineer." Experience has shown that without much background knowledge, students can reach a high level of comprehension and feel empowered to formulate and solve material balance problems. Furthermore, material balance gives professors the opportunity to show, in a fruitful way, the breadth of chemical and bioprocess engineering.

Optimization and Alternative Decisions

An important question is whether freshmen, just out of high school, have the mathematical background to tackle optimization problems. Our answer is no, in most cases they do not. Nevertheless, with the help of spreadsheets we will be able to introduce freshmen to the fascinating world of process engineering. Two objectives are expected to be accomplished simultaneously. First, familiarize and delight freshmen with the applications of optimization in a career in chemical and bioprocess engineering and, second, provide them with the elementary tools (graphics and spreadsheets) to solve interesting and challenging optimization problems.

Using the Book

As you can appreciate, the book is a bit long for one semester. Although it is possible to cover all the topics in one semester, we suggest an alternative course of action. First, depending on the course objectives, you may decide to skip some chapters (possibly Chaps. 4, 9, and 10) or just cover some chapters in one session. Because of the relevance that we assign to this course for freshmen, our suggestion is to cover Chaps. 1, 2, 4, 5, 7, 8, and 10 in the first semester and leave Chaps. 3, 6, 9, 11, and 12 for the second semester. Why? Because in the first semester you can focus on problem solving and material balance (reactive and nonreactive systems) with elementary tools from high school and then in the following semester cover the engineering topics. By the second semester, students will have acquired some basic tools of mathematics, physics, and chemistry, and it will be easier at that point to approach and teach the engineering chapters. As you may have noticed, in conformance with our emphasis on motivating freshman engineering students, we have assigned Chaps. 4 (biomimetics) and 10 (scale-up) to the first semester.

In addition, an advantage of dividing the course into two semesters is the observation that normally chemical engineering students do not become familiar with process engineering courses until their third and fourth semesters. Normally, the first three semesters of college are devoted to giving them the necessary tools of mathematics, physics, chemistry, and biology. Dividing this critical course into two semesters will ease their initial preparation for process engineering courses.

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