



Preface

I am thankful to all the readers for the encouragement they have given to the first edition of the book.

Based on the interaction with various students and faculty in the last five years, the present edition is revised bringing in a few changes and additions. Two new chapters are included on **Heat Transfer**, one dealing with heat transfer in bioprocessing and the other on heat transfer equipment. This was felt necessary as the earlier edition did not deal with heat transfer. Also a third chapter on **Bioprocess Economics** was added at the end. A biochemical-engineering textbook is not complete without a mention of bioprocess economics which is so vital for any project on engineering operations.

The topic of Enzyme Kinetics in Chapter 9 was merged with Chapter 4 which exclusively deals with Enzymes. Similarly, Chapter 6 on Media Design for Fermentation was merged with Chapter 5 dealing with Fermentation. Kinetics of Homogeneous Reactions was shifted to Chapter 7 on **Microbial Growth and Biochemical Reactors**.

In addition to the above, based on the response from students, a number of **worked examples** are included in various chapters. It is hoped that students who go through the worked examples will definitely appreciate the applicability of various engineering principles and calculations in the design and operation of fermentation processes. As has been done in the first edition, all efforts have been made to judiciously blend the chemical-reaction engineering principles for successful design and operation of fermenters.

The book is ideally suited for the UG students of biotechnology pursuing a BTech or masters degree(MSc) in biotechnology. Even though all efforts have been made to present the engineering principles without an overdose of mathematical derivations, knowledge of mathematics at the 10+2 level would definitely be an added advantage. The book is also ideally suited for students of BTech (Chemical Engineering) and MSc(Food Technology) for their first course in Biochemical Engineering. The book adequately covers bioprocessing principles and biochemical engineering. Various chapters in the book can be subdivided as follows:

Bioprocessing	(Ch 1→4→5→6→7→16)
Biochemical Engineering	(Ch 8→9→10→11→12→13→14→15→19→20)
Downstream Processing	(Ch 17→18)
Process Engineering Principles	(Ch 1→5→8→10→11→12→13→14)
Enzyme Engineering	(Ch 4→5→8→15)

Chapter 1 introduces the reader to bioprocessing, viz., the historical developments in bioprocessing, overview of traditional and modern applications of biotechnology and various steps outlined in bioprocessing. The understanding of biochemical engineering is strengthened with a brief discussion on the fundamentals of microbiology and biochemistry in **Chapters 2 and 3**. **Chapter 4** on Enzymes outlines the enzyme classification, and how enzymes specifically catalyse certain bioprocesses. The concept of biocatalysts is introduced here. Some common immobilization methods and industrial applications of enzymes are also described. **Chapter 5** introduces Fermentation with its requirements, range of processes, and different types of fermentation, viz., aerobic, anaerobic, solid state and submerged. Design and construction aspects are also highlighted. A brief mention about different types of fermenters is made at the end of this chapter.

Media design, their requirements, and various sources of carbon, nitrogen and the energy required for the medium are also discussed. Sterilization, which is an important component in any biochemical/biotechnological process, is discussed in **Chapter 6**. Various methods of sterilization of media, viz., batch and continuous, and of calculation of batch sterilization time are also explained. **Chapter 7** deals with the kinetics of microbial growth and biochemical reactions. The general principles of biochemical kinetics, and the methods to evaluate the rate and order of reaction are stressed in this chapter.

The biochemical engineering principles are highlighted in **Chapters 8-15** and **Chapter 19**. **Chapter 8** starts with a description of ideal reactors, viz., batch reactor, plug flow reactor and continuous flow reactor. Design features of these reactors are also highlighted in this chapter. **Chapter 9** classifies the biochemical reaction systems into simple, parallel, series reactions and a combination of these. This classification is akin to that done by Deindoerfer (1960). Efforts were made to cite examples of biochemical reactions that fall into each of these categories. Non-isothermal reaction systems and the criterion for achieving thermal stability are also discussed. After having discussed the ideal reactions and ideal reactor systems, non-ideal reactors (i.e., reactors with non-ideal flow) are highlighted in **Chapter 10**. This chapter is very important because of the fact that most of the fermenters behave non-ideally.

The concept of non-ideality was explained with RTD (residence time distribution) studies. **Chapter 11** discusses the rheology and mixing in fermentation broths. **Chapter 12** discusses Heat Transfer in Bioprocessing through the methods of conduction, convection and radiation. **Chapter 13** deals with Heat Transfer Equipment like double-pipe, shell and tube heat exchangers. **Chapter 14** highlights the oxygen mass transfer phenomena, which is an important aspect in the aerobic fermentation processes.

In a way, **Chapter 14** is a treatment of homogeneous systems with the dissolution of oxygen in the fermentation broths, while heterogeneous systems involving immobilized bioreactor systems are highlighted in **Chapter 15**. The diffusional limitations and how the mass transfer affects the immobilized cell reactions are also highlighted. Thus, **Chapter 15** discusses the engineering applications of enzymes dealt in **Chapter 4**, and may be considered as an extension to the same. Bioreactors and fermentation processes are discussed in **Chapter 16**. This chapter blends the bioreactor operations with fermentation processes. Various bioseparation steps (downstream processing steps) for separation and purification of the metabolic products are discussed in **Chapter 17**. General principles of effluent treatment with the concept of Central Effluent Treatment Plants (CETP) are discussed in **Chapter 18**. In the biochemical engineering aspect, the design and analysis of bioreactors are discussed in **Chapter 19**. The scale-up criterion for bioreactors is also discussed in this chapter. The choice of different bioreactors is highlighted based on the physico-chemical properties of the fermentation broths. Finally, Bioprocess Economics is discussed in **Chapter 20**.

I am greatly indebted to the publishers, Tata McGraw Hill Education Pvt. Ltd., New Delhi, for their constant encouragement during the revision, and their efforts in bringing out the book in its present form by providing excellent editorial support. I am grateful to the various authors and publishers who have accorded permissions to utilise their materials in this book.

The numerous reviewers who took out time to review the book also deserve a special mention. Their names are mentioned below.

T R Sreekrishnan	<i>IIT Delhi, Delhi</i>
Ashish M Gujrathi	<i>BITS Pilani, Rajasthan</i>
Susmita Dutta	<i>NIT Durgapur, West Bengal</i>
Amalash Sirkar	<i>HIT Haldia, West Bengal</i>
Sameer Jadhav	<i>IIT Bombay, Mumbai, Maharashtra</i>
T Panda	<i>IIT Madras, Chennai, Tamil Nadu</i>
P Ravichandran	<i>St Joseph's College of Engineering, Chennai, Tamil Nadu</i>
A V N Swamy	<i>JNTU College of Engineering, Anantpur, Andhra Pradesh</i>

A heartfelt thanks to my young daughters, Asha Latha and Priyanka, who have cheerfully typed the additional chapters and worked examples from my illegibly handwritten manuscripts. I would also like to acknowledge the help I have received from the staff of JNTU, particularly Prof. M Lakshmi Narasu, Head, Centre for Biotechnology and Mr D Kiran Kumar for helping me at different times during the

course of preparation of this book. A special thanks to Mrs V Rohini for helping me in the writing of Chapter 2. My thanks are also due to a few of my relatives and friends who constantly encouraged me in this endeavour. Last but not the least, I wish to appreciate the role of my wife, Sai Leela, for her ungrudging endurance during the period of writing this book.

It has always been my endeavour to keep the contents of the book crisp and easily comprehensible. I feel that the contents in the book are by no means exhaustive, and am afraid that certain mistakes and omissions may have inadvertently crept in. Readers may kindly indicate them to me for future improvement. Any suggestions for improving this book are most welcome. Users of the book can contact me at dgrao1950@rediffmail.com.

Dated 3rd July, 2009

D G Rao