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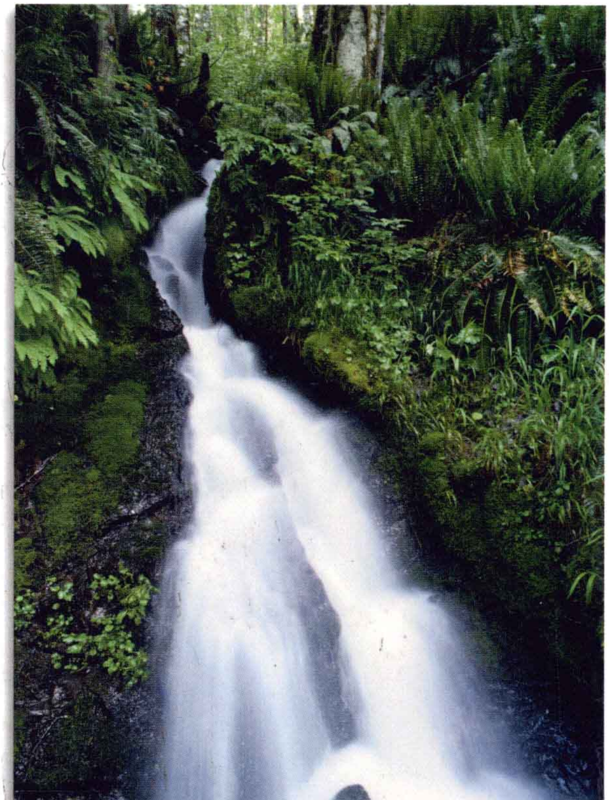
Environmental Biotechnology:

Principles and Applications



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ENVIRONMENTAL BIOTECHNOLOGY: PRINCIPLES AND APPLICATIONS

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Environmental Biotechnology: Principles and Applications is the essential tool for understanding and designing microbiological processes used for environmental protection and improvement. The book lays a foundation in microbiology and engineering principles and provides comprehensive coverage of all the major environmental applications, from traditional ones like activated sludge and anaerobic digestion to emerging applications like detoxification of hazardous chemical and biofiltration of drinking water. An abundance of worked examples that show in a step-by-step way how the tools are used in analysis and design enrich the discussion. *Environmental Biotechnology* is the authoritative source for learning how processes in environmental biotechnology work and how to create reliable processes to meet contemporary and emerging needs. Students, practitioners, and researchers will find this book invaluable.

Key features of this first edition include:

- Consistent backup of the fundamental principles of microbiological processes by their practical applications.
- Discussion of the traditional applications (e.g., activated sludge and anaerobic digestion) and the emerging applications (e.g., bioremediation and drinking water treatment).
- Numerous examples illustrating how the design and analysis tools are applied correctly.
- Each chapter consists of many problems, ranging in scope, that can be assigned as homework, used as supplemental examples in class, or used as study tools.
- Abundant use of figures to illustrate concepts.

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To Marylee and Martha for their patience and understanding

PREFACE

Environmental biotechnology utilizes microorganisms to improve environmental quality. These improvements include preventing the discharge of pollutants to the environment, cleaning up contaminated environments, and generating valuable resources for human society. Environmental biotechnology is essential to society and truly unique as a technical discipline.

Environmental biotechnology is historic and eminently modern. Microbiological treatment technologies developed at the beginning of the 20th century, such as activated sludge and anaerobic digestion, remain mainstays today. At the same time, new technologies constantly are introduced to address very contemporary problems, such as detoxification of hazardous chemicals. Important tools used to characterize and control processes in environmental technology also span decades. For example, traditional measures of biomass, such as volatile suspended solids, have not lost their relevance, even though tools from molecular biology allow us to explore the diversity of the microbial communities.

Processes in environmental biotechnology work according to well established principles of microbiology and engineering, but application of those principles normally requires some degree of empiricism. Although not a substitute for principles, empiricism must be embraced, because materials treated with environmental biotechnology are inherently complex and varying in time and space.

The principles of engineering lead to quantitative tools, while the principles of microbiology often are more observational. Quantification is essential if processes are to be reliable and cost-effective. However, the complexity of the microbial communities involved in environmental biotechnology often is beyond quantitative description; unquantifiable observations are of the utmost value.

In *Environmental Biotechnology: Principles and Applications,* we connect these different facets of environmental biotechnology. Our strategy is to develop the basic concepts and quantitative tools in the first five chapters, which comprise the principles part of the book. We consistently call upon those principles as we describe the applications in Chapters 6 through 15. Our theme is that *all microbiological processes behave in ways that are understandable, predictable, and unified.* At the same time, each application has its own special features that must be understood. The special features do not overturn or sidestep the common principles. Instead, they complement the principles and are most profitably understood in the light of principles.

Environmental Biotechnology: Principles and Applications is targeted for graduate-level courses in curricula that exploit microbiological processes for environmental-quality control. The book also should be appropriate as a text for upper-level undergraduate courses and as a comprehensive resource for those engaged in professional practice and research involving environmental biotechnology.

The material in *Environmental Biotechnology: Principles and Applications* can be used in one or several courses. For students not already having a solid background in microbiology, Chapter 1 provides a foundation in taxonomy, metabolism, genetics, and microbial ecology. Chapter 1 addresses the microbiology concepts that are most essential for understanding the principles and applications that follow. Chapter 1 can serve as the text for a first course in environmental microbiology, or it can be used as a resource for students who need to refresh their knowledge in preparation for a more process-oriented course, research, or practice.

The "core" of the principles section is contained in Chapters 2, 3, 4 and 5. Chapter 2 develops quantitative tools for describing the stoichiometry and energetics of microbial reactions: what and how much the microorganisms consume and produce. Stoichiometry is the most fundamental of the quantitative tools. Chapters 3 and 4 systematically develop quantitative tools for kinetics: how fast are the materials consumed and produced. Reliability and cost-effectiveness depend on applying kinetics properly. Chapter 5 describes how principles of mass balance are used to apply stoichiometry and kinetics to the range of reactors used in practice.

Chapters 6 through 15 comprise the applications section. Each chapter includes information on the stoichiometry and kinetics of the key microorganisms, as well as features that are not easily captured by the stoichiometric or kinetic parameters. Each chapter explains how processes are configured to achieve treatment objectives and what are the quantitative criteria for a good design. The objective is to link principles to practice as directly as possible.

In one sense, the applications chapters are arranged more or less in order from most traditional to most modern. For example, Chapters 6, 7, and 8 address the aerobic treatment of wastewaters containing biodegradable organic matter, such as the BOD in sewage, while Chapters 14 and 15 address biodegradation of hazardous chemicals. Aerobic treatment of sewage can be traced back to the early 20th century, which makes it quite traditional. Detoxification of hazardous chemicals became a major treatment goal in the 1980s. On the other hand, Chapters 6 to 8 describe newly emerging technologies for attaining the traditional goal. Thus, while a goal may be traditional, the science and technology used to attain it may be very modern.

We prepared a chapter on "Complex Systems" that does not appear in the book in an effort to keep the book to a reasonable length. The website chapter extends principles of Chapters 1 to 5 by systematically treating nonsteady-state systems (suspended and biofilm) and systems having complex multispecies interactions. McGraw-Hill agreed to put this chapter on a web site so that it would be available to those who are interested. Having an official web site for the book provides another advantage: We will now have a convenient location to post corrections to the inevitable errors that remain in the book. Perhaps there will be other book-related items that we may wish to post as times go by; we encourage the reader to occasionally check the web page.

One important feature of *Environmental Biotechnology: Principles and Applications* is that it contains many example problems. These problems illustrate the step-by-step procedures for utilizing the tools in order to understand how microbial systems work or to design a treatment process. In most cases, learning by example is the most effective approach, and we give it strong emphasis.

Each chapter contains many problems that can be assigned as "homework," used as supplemental examples in class, or used as study tools. The problems range in scope. Some are simple, requiring only a single calculation or a short expository response. At the other extreme are extensive problems requiring many steps and pages. Most problems are of intermediate scope. Thus, the instructor or student can gradually advance from simple, one-concept problems to comprehensive problems that integrate many concepts. Computer spreadsheets are very helpful in some cases, particularly when complex or iterative solutions are needed.

In an effort to promote uniformity in notation, we have elected to adapt the "Recommended Notation for Use in the Description of Biological Wastewater Treatment Processes," agreed upon internationally and as published in *Water Research* **16**, 1501–1505 (1982). We hope this will encourage others to do the same, as it will facilitate much better communication among us.

This text is too brief to do justice to general principles, applications of environmental biotechnology, and the numerous specific mechanical details that one must consider in the overall design of biological systems. We have chosen to focus on the principles and applications. For the specific design details, we suggest other references, such as the two-volume *Design of Municipal Wastewater Treatment Plants,* published jointly by the Water Environment Federation (Manual of Practice No. 8) and the American Society of Civil Engineers (Manual and Report on Engineering Practice No. 76).

We take this opportunity to thank our many wonderful students and colleagues, who have taught us new ideas, inspired us to look farther and deeper, and corrected our frequent errors. The numbers are too many to list by name, but you know who you are. We especially thank all of the students in our environmental biotechnology classes over the past few years. These students were subjected to our chapter first drafts and provided us with much welcomed feedback and many corrections. Thank you for everything.

A few individuals made special contributions that led directly to the book now in print. Viraj deSilva and Matthew Pettis provided the model simulations in the website chapter on "Complex Systems." Drs. Gene F. Parkin and Jeanne M. VanBriesen provided extensive suggestions and corrections. Pablo Pastén and Chrysi Laspidou provided solutions to many of the problems in the Solutions Manual. Janet Soule and Rose Bartosch deciphered BER's handwriting to create the original electronic files for all or parts of Chapters 1, 3, 4, 6, 8, 9, 10, 11, 12, and 15. Dr. Saburo Matsui and the Research Center for Environmental Quality Control (Kyoto University) provided a sabbatical venue for BER so that he could finish all the details of the text and send it to McGraw-Hill on time.

Finally, we thank Marylee and Martha for loving us, even when we became too preoccupied with the "book project."

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Physical constants

Avogadro constant		6.022×10^{23} mole^{-1}
Gas constant	R	8.314×10^{7} ergs/K mol
		8.314 J/K mol
		1.99 cal/K mol
		82.054 cm^3 atm/K mol
Faraday constant	F	96,485 C/equiv
		96,485 J/V equiv
		23.06 kcal/V equiv
Speed of light in a vacuum	c	2.99792×10^{8} m/s
Gravitational constant	g	9.81 m/s^2
		32.2 ft/s^2

Conversion factors

1 in	= 2.54 cm
1 lb	= 453.59 g
1 gal (U.S.)	= 3.78 l
1 ft^3	= 28.32 l
1 mg/l	= 8.34 lb/million gal (U.S.) water
1 cal	= 4.184 J
	= 0.003968 Btu
	= 0.0413 1 atm
1 J	= 1.000 VC
1 erg	= 10^{-7} J
1 atm	= 1.01325×10^{5} Pa
	= 14.7 lb/in^2

Fractions and multiples

atto	a	10^{-18}	milli	m	10^{-3}	kilo	k	10^{3}
femto	f	10^{-15}	centi	c	10^{-2}	mega	M	10^{6}
pico	p	10^{-12}	deci	d	10^{-1}	giga	G	10^{9}
nano	n	10^{-9}	deka	da	10	terra	T	10^{12}
micro	μ	10^{-6}	hecto	h	10^{2}			

CONTENTS

Chapter 3

MICROBIAL KINETICS 165

Chapter 4

BIOFILM KINETICS 207

Chapter 5

REACTORS 261

Chapter 6

THE ACTIVATED SLUDGE PROCESS 307

Chapter 7

LAGOONS 394

Chapter 8

AEROBIC BIOFILM PROCESSES 434

Chapter 9

NITRIFICATION 470

BRIEF CONTENTS