

# Bioprocesses for Environmental Control

Pakamas Chetpattananondh

# Table of Contents

Chapter 1 Basic Microbiology.....	1
1.1 Microorganism Characterization.....	1
1.1.1 Virus.....	4
1.1.2 Fungi.....	5
1.1.3 Algae.....	6
1.1.4 Protozoa.....	7
1.1.5 Archaea.....	8
1.1.6 Bacteria.....	9
1.2 Condition Effecting Cell Growth.....	11
1.2.1 Nutritional Requirements of Cell Growth.....	11
1.2.1.1 The Major Elements.....	12
1.2.1.2 Trace Elements.....	13
1.2.1.3 Carbon and Energy Sources.....	13
1.2.1.4 Growth Factors.....	14
1.2.1.5 Culture Media.....	15
1.2.2 The Effect of Oxygen.....	16
1.2.3 The Effect of pH.....	17
1.2.4 The Effect of Temperature.....	18
1.2.5 The Effect of Moisture.....	19
1.2.6 The Effect of Light.....	20
1.2.7 The Effect of By-product of Cell Growth.....	20
1.3 Bacterial Growth: Bacterial Populations.....	21
1.3.1 Growth in Batch Culture.....	21
1.3.2 Continuous Culture.....	25
1.3.3 Effect of substrate concentration on specific growth rate.....	26
1.3.4 Methods for Measurement of Cell Growth.....	27
1.3.5 Methods to Control Cell Growth.....	28
1.3.6 Metabolism.....	31
1.4 Microbiology Laboratory.....	34
1.4.1 Streak Plate.....	34
1.4.2 Spread Plate.....	35
1.4.3 Pour Plate.....	36
Study Questions.....	37

References .....	38
Chapter 2 Bioreactor Design .....	39
2.1 Bioreactor Types.....	39
2.1.1 Suspended-Growth Reactors .....	39
2.1.2 Biofilm Reactors .....	44
2.1.3 Reactor Arrangements.....	47
2.1.4 Bubble Column Reactor.....	48
2.1.5 Airlift Reactor.....	49
2.2 Stoichiometry .....	50
2.3 Mass Balance .....	54
2.4 Bioreactor Design .....	56
2.4.1 A Batch Reactor.....	56
2.4.2 A Continuous-Flow Stirred-Tank Reactor with Effluent Recycle.....	59
2.4.3 A Plug-Flow Reactor.....	60
2.5 Linking Stoichiometric Equations to Mass-Balance Equations.....	62
2.6 Engineering Design of Reactors .....	65
Study Questions .....	67
References .....	68
Chapter 3 Wastewater Treatment .....	69
3.1 Water Quality Parameters.....	69
3.1.1 Total Solids.....	69
3.1.1.1 Total Suspended Solids .....	69
3.1.1.2 Total Dissolved Solids .....	69
3.1.2 Turbidity.....	70
3.1.3 Temperature.....	71
3.1.4 Color.....	71
3.1.5 Odor .....	72
3.1.6 Hardness.....	72
3.1.7 Alkalinity .....	72
3.1.8 Dissolved Oxygen .....	73
3.1.9 Biochemical Oxygen Demand.....	73
3.1.10 Chemical Oxygen Demand.....	74
3.1.11 Total Organic Carbon .....	75
3.1.12 Nitrogen.....	75
3.2 Activated Sludge Processes .....	78

3.2.1 Process Description .....	78
3.2.2 Process Microbiology.....	81
3.2.3 Process Options .....	82
3.2.3.1 Conventional Activated Sludge .....	82
3.2.3.2 Step-Feed Activated Sludge.....	83
3.2.3.3 Contact Stabilization Activated Sludge .....	83
3.2.3.4 Completely Mixed Activated Sludge .....	85
3.2.3.5 Extended Aeration Activated Sludge .....	86
3.2.3.6 High-Purity Oxygen Activated Sludge.....	87
3.2.3.7 Selector Activated Sludge .....	88
3.2.3.8 Sequencing Batch Reactor Activated Sludge.....	88
3.2.4 Comparison of Process Options .....	89
3.2.5 Process Design .....	91
3.2.5.1 Selection of Reactor Type.....	92
3.2.5.2 Loading Criteria .....	92
3.2.5.3 Sludge Production .....	95
3.2.5.4 Oxygen Requirements and Transfer .....	95
3.2.5.5 Nutrient Requirements .....	96
3.2.5.6 Control of Filamentous Organisms .....	97
3.2.5.7 Return Activated Sludge Control .....	100
3.2.5.8 Sludge Wasting.....	102
3.2.6 Biofilm Processes .....	109
3.2.7 Nature of Biofilms .....	109
3.2.8 Trickling Filters.....	110
3.2.8.1 Process Description.....	110
3.2.8.2 Process Microbiology .....	112
3.2.8.3 Filter Classification.....	113
3.2.8.4 Process Design.....	114
3.2.9 Rotating Biological Contactors.....	126
3.2.9.1 Process Description.....	126
3.2.9.2 Process Design Considerations .....	127
3.2.9.3 Physical Facilities for RBC Process.....	130
3.2.9.4 Operating Problems.....	131
3.2.9.5 Process Design.....	131
3.3 Nitrification/Denitrification Processes .....	134

3.3.1 Process Description .....	134
3.3.2 Classification of Nitrification/Denitrification Processes.....	135
3.3.2.1 Combined Nitrification/Denitrification (Single-Sludge) System .....	136
3.3.2.2 Separate-Stage Denitrification (Separate-Sludge System) .....	141
Study Questions .....	148
References .....	150
Chapter 4 Contaminated Land.....	151
4.1 Contaminants.....	151
4.1.1 Inorganic Contaminants.....	151
4.1.2 Organic Contaminants .....	152
4.2 Sources of Contaminants .....	153
4.3 Acceptable Levels of Contamination .....	156
4.4 Behavior of Contaminants in Soil.....	161
4.5 Decontamination Methods.....	164
4.5.1 Containment Strategies.....	164
4.5.1.1 In-ground Barriers .....	165
4.5.1.2 Cover Systems.....	166
4.5.2 Removal Strategies .....	168
4.5.3 Treatment Strategies.....	168
4.5.3.1 Physical Processes.....	169
4.5.3.2 Chemical Processes.....	176
4.5.3.3 Solidification Processes .....	182
4.5.3.4 Thermal Processes.....	185
4.5.3.5 Biological Processes .....	192
4.6 Biodegradation and Bioremediation .....	205
4.6.1 Sorption to Surfaces.....	206
4.6.2 Formation of a Nonaqueous Phase .....	208
4.6.3 Biopile Design.....	211
4.6.3.1 Process Design Considerations.....	211
4.6.3.2 Respiration Test.....	213
Study Questions .....	220
References .....	221
Chapter 5 Control of Air Pollution.....	225
5.1 Classification of Pollutants.....	225
5.1.1 Particulates Pollutants.....	225

5.1.1.1 Physical Characteristics .....	226
5.1.1.2 Chemical Characteristics.....	229
5.1.1.3 Biological Characteristics.....	229
5.1.1.4 Effects of Particulates .....	229
5.1.1.5 Sources of Particulates .....	230
5.1.1.6 Detection and Analysis.....	230
5.1.2 Gaseous Pollutants.....	233
5.1.2.1 Carbon Monoxide .....	233
5.1.2.2 Hydrocarbons .....	233
5.1.2.3 Oxides of Sulfur.....	235
5.1.2.4 Oxide of Nitrogen.....	236
5.1.2.5 Photochemical Oxidants.....	237
5.1.3 Volatile Organic Compounds.....	239
5.2 Ambient-Air-Quality and Emissions Standards .....	242
5.3 Control of Air Pollutants.....	243
5.3.1 Control of Particulate Contaminants.....	243
5.3.1.1 Gravity Settling Chambers.....	244
5.3.1.2 Centrifugal Collectors .....	246
5.3.1.3 Wet Collectors.....	248
5.3.1.4 Fabric Filters (Baghouse Filters).....	251
5.3.1.5 Electrostatic Precipitatos (ESP).....	252
5.3.2 Control of Gases and Volatile Organic Compounds .....	254
5.3.2.1 Adsorption Processes.....	254
5.3.2.2 Absorption Processes.....	255
5.3.2.3 Combustion (Incineration) Processes .....	255
5.3.2.4 Biofiltration Processes .....	256
5.3.2.5 Biodesulfurization Processes .....	274
Study Questions.....	286
References.....	287
Index.....	292