
Contents

Part I Introduction and Basic Theory

1 Biotechnology for Air Pollution Control – an Overview

ZAROOK SHAREEFDEEN, BRIAN HERNER, AJAY SINGH	3
1.1 Introduction.....	3
1.2 Methods of Odor and VOC Control.....	3
1.3 Biological Reactors	4
1.3.1 Bioreactor Media	4
1.3.2 Microbiology	5
1.3.3 Types of Bioreactors.....	7
1.4 Modeling and Design of Bioreactors.....	8
1.4.1 Modeling of Bioreactors.....	8
1.4.2 Design of Bioreactors	9
1.5 Types of Contaminants	10
1.6 Case Studies	11
1.7 Conclusion.....	12
References	12

2 Environmental Laws and Regulations Related to Odor and Waste Gas Contaminants

RODNEY L. ALDRICH.....	17
2.1 Introduction.....	17
2.2 Control of VOCs.....	18
2.3 Control of Odor-Causing Chemicals.....	20
2.4 Brief Overview of Odor Restrictions Around the World	21
2.4.1 The United States of America	21
2.4.2 Japan	24
2.4.3 China.....	24
2.4.4 The United Kingdom.....	24
2.4.5 Canada.....	25
2.5 Conclusions.....	26
References	28

3 Methods of Odor and VOC Control

SERGIO REVAH, JUAN M. MORGAN-SAGASTUME	29
3.1 VOCs and Odor Definition	29
3.2 Methods for VOCs and Odor Control	30
3.3 Physical-chemical Methods.....	35
3.3.1 Dilution	35
3.3.2 Condensation.....	35
3.3.3 Membranes.....	36
3.3.4 UV Oxidation.....	36
3.3.5 Plasma	37
3.3.6 Adsorption	38
3.3.7 Combustion (Flares, Thermal and Catalytic Incinerators)	38
3.3.8 Masking	40
3.3.9 Caustic Scrubbing.....	40
3.3.10 Regenerative Gas Scrubbing	41
3.3.11 Chemical Precipitation	42
3.3.12 Chlorine Oxidation	42
3.3.13 Ozone Oxidation	42
3.3.14 Potassium Permanganate Oxidation	42
3.3.15 Catalytic Oxidation with Fe^{3+} (LO-CAT Process)	43
3.3.16 Hydrogen Peroxide Oxidation.....	43
3.3.17 Oxidation with FeO	43
3.4 Biological Methods.....	43
3.4.1 Terminology	45
3.4.2 Mechanisms.....	47
3.4.3 The Biological Phase	48
3.5 Types of Bioreactors	53
3.5.1 Biofilter	54
3.5.2 Biotrickling Filters	55
3.5.3 Rotating Biological Contactors.....	56
3.5.4 Bioscrubbers.....	56
3.5.5 Membrane Bioreactors	57
3.5.6 Suspended Cell Bioreactor	58
3.6 Conclusions.....	59
References	60

4 Selection of Bioreactor Media for Odor Control

RAKESH GOVIND, SANDEEP NARAYAN	65
4.1 Introduction.....	65
4.2 Diffusive Versus Convective Media	66
4.3 Naturally Bioactive Media	68
4.4 Synthetic Media	71
4.5 Randomly Packed Versus Structured Biomedial.....	83
4.6 Biofilter Versus Biotrickling Filter.....	85

4.7	Experimental Studies on Diffusive Biofilter Media.....	86
4.7.1	Experimental Setup.....	86
4.7.2	Analytical Procedure.....	87
4.7.3	Results and Discussion	88
4.8	Experimental Studies on Convective Biofilter Media	90
4.9	Studies on Encapsulated Biomass and Membrane Biofilters	92
4.10	Conclusions.....	94
	Appendix	95
	References	99

5 Microbiology of Bioreactors for Waste Gas Treatment

	AJAY SINGH, OWEN WARD	101
5.1	Introduction.....	101
5.2	Microbial Communities Involved in Waste Gas Treatment	102
5.3	The Nature of Microbial Biofilms	104
5.4	Biodegradation of Air Pollutants	106
5.4.1	Biokinetics	106
5.4.2	Biodegradation of Organic Compounds	107
5.4.3	Biodegradation of Inorganic Compounds.....	108
5.5	Factors Affecting Microbial Degradation of Air Contaminants ..	110
5.5.1	Bioavailability	110
5.5.2	Nutritional	111
5.5.3	Environmental	113
5.6	Genetic Approaches for Improved Microorganisms.....	114
5.7	Monitoring of Microbial Processes.....	115
5.8	Conclusions.....	116
	References	116

Part II Biological Reactor Technologies

6 Biofilter Technology

	INDRANI DATTA, D. GRANT ALLEN.....	125
6.1	Introduction.....	125
6.2	Overall Process Description	125
6.3	Biofiltration Terminology	126
6.3.1	Empty Bed Residence Time	127
6.3.2	Surface (or Volumetric) and Mass Loading Rate	127
6.4	Mechanism of Operation	128
6.4.1	Transfer and Partitioning of Contaminants to the Biofilm	128
6.4.2	Biodegradation	129
6.5	Characterizing Biofilter Performance	129
6.5.1	Removal Efficiency.....	129
6.5.2	Elimination Capacity	130
6.5.3	Maximum Elimination Capacity	130

6.6	Factors Affecting Biofilter Performance	131
6.6.1	Packing Media.....	131
6.6.2	Moisture Content.....	131
6.6.3	Temperature	132
6.6.4	Oxygen Content.....	132
6.6.5	pH.....	133
6.6.6	Nutrients	133
6.6.7	Pressure Drop	133
6.6.8	Medium Depth	134
6.6.9	Waste Gas Pretreatment.....	135
6.6.10	Maintenance	135
6.7	Microbiology of Biofilters	135
6.8	Advantages and Disadvantages.....	136
6.9	Applications of Biofilters	137
6.10	Conclusions.....	139
	References	140
7	Biotrickling Filter Technology	
	MARC A. DESHUSSES, DAVID GABRIEL	147
7.1	Introduction.....	147
7.2	Biotrickling Filter Design and Operation	150
7.3	Conversion of Chemical Scrubbers to Biotrickling Filters	152
7.3.1	First Approach to the Conversion	153
7.3.2	General Procedure to Convert Full-Scale Chemical Scrubbers	155
7.3.3	H ₂ S Treatment of Converted Chemical Scrubbers at OCSD.....	161
7.4	Conclusions.....	166
	References	166
8	Bioscrubber Technology	
	AJAY SINGH, ZAROOK SHAREEFDEEN, OWEN P. WARD	169
8.1	Introduction.....	169
8.2	Bioscrubbers	170
8.3	Bioscrubber Design	173
8.3.1	Mechanism for Odorous Gas Treatment by Bioscrubbers	173
8.3.2	The Absorber	174
8.3.3	The Bioreactor	177
8.3.4	Variations in Bioscrubber Designs.....	178
8.4	Bioprocess Control in Bioscrubbers	180
8.4.1	Microbiology	180
8.4.2	Nutrients	182
8.4.3	Oxygen	182
8.4.4	pH and Temperature	183
8.4.5	Sludge Accumulation and Disposal.....	183

8.5	Application of Bioscrubbers.....	184
8.5.1	Waste Gases from Wastewater Treatment Plant.....	184
8.5.2	Aerobic and Anaerobic Gas Treatment	187
8.5.3	Treatment of Flue Gases.....	187
8.5.4	Treatment of Waste Gas from Fish Feed Factory	188
8.5.5	Treatment of Waste Gas Containing VOCs	188
8.6	Conclusion and Future Directions	189
	References	190

9 Membrane Bioreactor Technology

	MARK W. FITCH	195
9.1	Introduction.....	195
9.2	Membrane Bioreactor Design.....	195
9.2.1	Mechanism	197
9.2.2	Membranes.....	198
9.2.3	Materials	199
9.3	Reactor Configuration.....	201
9.4	Operating Results.....	201
9.4.1	Loading and Elimination Capacity	201
9.4.2	Transient Loads and Aging.....	205
9.4.3	Biofilm Thickness	206
9.4.4	Heat.....	206
9.5	Models of Membrane Biofiltration	206
9.5.1	Mass Transfer.....	206
9.5.2	Biodegradation	208
9.5.3	Model Results.....	209
9.6	Conclusions.....	209
	References	209

10 Modeling of Biofilters and Biotrickling Filters for Odor and VOC Control Applications

	MARC A. DESHUSSES, ZAROOK SHAREEFDEEN	213
10.1	Introduction to Modeling	213
10.1.1	General Model Concepts	214
10.1.2	Importance of Modeling in Design and Operation	215
10.2	A Review of Biofilter Models	215
10.2.1	Steady-State Models	215
10.2.2	Transient Models	217
10.2.3	Critical Parameters	218
10.3	Uses of Biofilter Models in Full-Scale Designs	219
10.3.1	Wastewater Treatment Applications.....	219
10.3.2	Rendering Applications	221
10.4	A Review of Biotrickling Filter Models	222
10.5	Conclusions and Future Work	228
	References	229

Part III Biological Reactors – Applications

11 Biofilter Design and Operation

for Odor Control – The New Zealand Experience

ROGER CUDMORE, PETER GOSTOMSKI	235
11.1 Introduction.....	235
11.2 Stream Characterization.....	236
11.2.1 Composition	236
11.2.2 Process Knowledge	237
11.2.3 Temperature and Relative Humidity	238
11.2.4 Particulates.....	238
11.2.5 Odor Chemistry	239
11.3 Pretreatment/Conditioning of Airstream	239
11.3.1 Particulates.....	240
11.3.2 Temperature	240
11.3.3 Relative Humidity.....	241
11.3.4 Bed Design	242
11.3.5 Air Distribution.....	242
11.3.6 Bed Media	243
11.3.7 Specification of Soil and Bark	243
11.4 Operation and Monitoring.....	246
11.4.1 General Operation and Maintenance	246
11.4.2 Pressure Drop	247
11.4.3 Moisture.....	247
11.4.4 Temperature	248
11.4.5 pH.....	248
11.4.6 Emission Monitoring.....	248
11.4.7 Biofilter Maintenance	248
11.4.8 Common Failures	249
11.5 Conclusions.....	250
References	250

12 Biological Treatment of Waste Gases Containing Inorganic Compounds

MADJID MOHSENI	253
12.1 Introduction.....	253
12.2 Common Inorganic Air Pollutants	253
12.2.1 Ammonia	254
12.2.2 Amines	254
12.2.3 Nitrogen Oxides (NO _x)	254
12.2.4 Sulfur Oxides (SO _x).....	255
12.3 Treatment Technologies for Inorganic Air Pollutants	255
12.4 Biological Technologies for Inorganic Air Pollutants.....	259
12.4.1 Biodegradation of Ammonia	259
12.4.2 Biodegradation of NO _x	261
12.5 Biofiltration.....	262
12.5.1 Biofiltration of Ammonia	262

12.5.2	Biofiltration of Mixtures of Ammonia and Hydrogen Sulfide.....	265
12.5.3	Biofiltration of Nitrogen Oxides	265
12.6	Biotrickling Filtration	267
12.7	Bioscrubbing	269
12.8	Photobiodegradation	269
12.9	Other Biological Processes.....	270
12.9.1	Membrane Bioreactors	271
12.9.2	Fluidized/Spouted Bed Bioreactors	271
12.9.3	Phytoremediation	272
12.10	Conclusions and Further Research Needs	272
	References	274

13 Biological Treatment

of Waste Gases Containing Volatile Organic Compounds

	PIERRE LE CLOIREC, YVES ANDRÈS, CLAIRE GÉRENTE, PASCALINE PRÉ.....	281
13.1	Introduction.....	281
13.2	Biodegradation of Volatile Organic Compounds	282
13.2.1	Microbial Growth	282
13.2.2	Microorganisms and Pollutants	284
13.3	Applications of Biological Processes.....	286
13.3.1	General Operating Conditions	286
13.3.2	Biofilters.....	287
13.3.3	Biotrickling Filters	292
13.3.4	Bioscrubbers.....	292
13.4	By-Products Generated During Biological Treatments of VOCs ..	296
13.4.1	Overview of Wastes and By-Products Generated.....	296
13.4.2	Energy Recovery.....	297
13.5	Conclusions.....	300
	References	300

Part IV Biological Reactors – Case Studies

14 Odor Removal in Industrial Facilities

	VLADIMIR POPOV, VITALIY ZHUKOV	305
14.1	Introduction.....	305
14.2	Substrate Composition and Concentration	306
14.3	Biomass Control	307
14.4	Compliance	308
14.5	Modern Trends in Biofilter Development	309
14.6	Case Studies	315
14.6.1	Odorous VOC: Formaldehyde Removal	315
14.6.2	High-Performance/Enhanced Removal of Sulfur Compounds	317

14.7	Conclusions.....	324
	References	325
15	Odor Removal	
	in Municipal Wastewater Treatment Plants – Case Studies	
	TODD S. WEBSTER	327
15.1	Introduction.....	327
15.2	An Odor Control Biofilter Located Within a Sewer Manhole Cover	327
15.2.1	Design	328
15.2.2	Operation	329
15.2.3	Performance	329
15.3	Multiple Biofilter Application Treating Odors from a Headworks Operation	329
15.3.1	Design	331
15.3.2	Operation and Performance	332
15.4	Multiple Biofilter Application (High Flow) at a Wastewater Pumping Station	332
15.4.1	Design and Operation	332
15.4.2	Performance	332
15.5	A Single Biofilter Application (Low Flow) at a Wastewater Pumping Station	334
15.5.1	Design and Operation	335
15.5.2	Performance	336
15.6	Single Biofilter at a Wastewater Pumping Station Operated Under Varying Air Temperatures	338
15.6.1	Design and Operation	338
15.6.2	Performance	339
15.7	Biofiltration of Odors at a Biosolids Handling Facility.....	341
15.7.1	Design and Operation	342
15.7.2	Performance	344
15.8	An Intermittent Water Addition Biotrickling Filter Reactor	345
15.8.1	Design	345
15.8.2	Operation	346
15.8.3	Performance	348
15.9	Long-Term Operation of a Biotrickling Filter Reactor	350
15.9.1	Design	350
15.9.2	Operation and Performance	351
15.10	Conclusions.....	353
	References	353
16	Biotrickling and Bioscrubber Applications to Control Odor and Air Pollutants: Developments, Implementation Issues and Case Studies	
	BART KRAAKMAN	355
16.1	Introduction.....	355
16.2	Definitions, Advantages and Limitations.....	356
16.2.1	Definitions.....	356

16.2.2	Advantages of Biotrickling Filters and Bioscrubbers versus Biofilters	356
16.2.3	Disadvantage	357
16.3	Recent Developments.....	357
16.4	Robustness.....	362
16.5	Missing Gaps for Future Developments	363
16.6	Case Studies	364
16.6.1	Odor Removal from Waste Gas Emissions at an Anaerobic Wastewater Treatment Plant with a Purspring Bioreactor	364
16.6.2	H ₂ S Removal from Stripped Groundwater with a Purspring Bioreactor	368
16.6.3	V-Spring Bioreactor System Treating CS ₂ Emissions at a Fungicide Manufacturing Plant	371
16.7	Conclusions.....	373
	References	375

Part V Future of Biotechnology

17 Future Prospects of Biotechnology for Odor Control

	FETHIYE OZIS, ARASH BINA, JOSEPH S. DEVINNY	383
17.1	The Growing Need for Odor Control	383
17.2	Biotechnology is an Important Alternative.....	384
17.3	Possible Obstacles	386
17.4	Current Successes.....	387
17.4.1	Wastewater Treatment Plant Odor Control.....	388
17.4.2	Swine Industry	390
17.5	Technology Developments.....	391
17.5.1	Rational Design.....	391
17.5.2	Reliability	391
17.5.3	Inert Packing	393
17.5.4	Biomass Control	394
17.5.5	Inoculation	395
17.5.6	Standards	396
17.5.7	Sensing and Automation.....	396
17.5.8	Increasing Size	397
17.5.9	Wastewater Will Lead the Way	397
17.5.10	Application to New Effluents	398
17.5.11	Development of Green Manufacturing-Biosystem Combinations.....	398
17.6	Conclusions.....	399
	References	399

Subject Index

Biotechnology for Odor and Air Pollution Control

Shareefdeen, Z.; Singh, A. (Eds.)

2005, XVIII, 409 p. 70 illus., Hardcover

ISBN: 978-3-540-23312-1