TECHNOLOGIES FOR UPGRADING EXISTING OR DESIGNING NEW DRINKING WATER TREATMENT FACILITIES

CRC Press
Taylor & Francis Group
an informa business
www.crcpress.com

ISBN 978-1-138-47532-8
9 781138 475328

TECHNOLOGIES FOR DRINKING WATER TREATMENT FACILITIES

CRC Press

TECHNOLOGIES FOR UPGRADING EXISTING OR DESIGNING NEW DRINKING WATER TREATMENT FACILITIES

Office of Drinking Water
Center for Environmental Research Information
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

此为试读，需要完整PDF请访问：www.ertongbook.com

Acknowledgments

This document is a compilation of the material presented in a series of workshops on "Emerging Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities." Some of these workshops were sponsored by local sections of the American Water Works Association (AWWA) and others by the Association of State Drinking Water Administrators (ASDWA). Other sponsors included the United States Environmental Protection Agency's (EPA) Offices of Drinking Water and Research and Development and Regions.

Overall management of the workshop series and preparation of this document was provided by Dr. James E. Smith, Jr., of EPA's Center for Environmental Research Information. He was assisted in providing technical direction by representatives of ASDWA, the local AWWA Sections, EPA Regional Personnel, John Trax and Ken Hay of EPA's Office of Drinking Water, and Walter Feige and other members of EPA's Drinking Water Research Division.

Unless otherwise noted, the technical material in this document was taken from handout materials and presentations provided by the following speakers in the workshops: Dr. Robert M. Clark, Director of EPA's Drinking Water Research Division, Cincinnati, Ohio; John F. Dyksen, Director, Department of Water Supply, Village of Ridgewood, New Jersey; Sigurd Hansen, HDR, Inc., Cameron Park, California; Dr. Gary S. Logsdon, Chief of EPA's Microbiological Treatment Branch, Cincinnati, Ohio; Dr. Rip G. Rice, Rice International Consulting Enterprises, Ashton, Maryland; and Dr. Edward Singley, James Montgomery Consulting Engineers, Gainesville, Florida. Appreciation is also expressed to those individuals around the country who participated in panels and presented case histories of their treatment experiences.

Organization and presentation of the material, technical writing, and editorial work was provided by Lynn Knight, John Reinhardt, and Susan Richmond of Eastern Research Group, Inc., Arlington, Massachusetts. Appreciation is expressed to those individuals in EPA's Offices of Drinking Water and Research and Development who assisted in reviewing drafts of this publication; especially Peter Cook, Ronnie Levin, Michael Schock, and Tom Sorg. The workshop presenters are acknowledged for their assistance in reviewing materials, especially John Dyksen who provided overall technical review.

In addition, EPA gratefully acknowledges the assistance of:

Kalyan Ramen, Environmental Engineer, Malcolm Pirnie, Inc.
Ross Hymen and Paul Anderson, Massachusetts Dept. of Environmental Quality Engineering.
Tom Boshar, Lally Associates
Dr. Carl Nebel, PCI Ozone Corporation
Fred Zinnbauer, Aquionics, Inc.
Gary Swanson, Robert Peccia Associates

Contents

Tables ix
Figures xii
Acknowledgments xiii

Chapter 1. Introduction 1

Chapter 2. Selecting and Evaluating Treatment Processes 3
2.1 Overview of Federal Drinking Water Regulations 3
2.2 Selecting Treatment Technologies 5
2.3 Overview of Available Treatment Alternatives 7
2.3.1 Filtration 7
2.3.2 Disinfection 9
2.3.3 Organic Contaminant Removal 11
2.3.4 Inorganic Contaminant Removal and Control 12
2.4 Final Process Selection and Design 14

Chapter 3. Prefiltration Treatment Elements 17
3.1 Modifying Chemical Feed 18
3.1.1 Chemical Type 18
3.1.2 Chemical Dosage Management 19
3.1.3 Chemical Application Methods and Considerations 21
3.2 Modifying or Adding Rapid Coagulant Mixing 22
3.3 Improving Flocculation 25
3.3.1 Improving Mixing 25
3.3.2 Improving Flocculator Inlet and Outlet Conditions 26
3.3.3 Improving Basin Circulation with Baffles 27
3.4 Improving Sedimentation 27
3.4.1 Horizontal Flow Sedimentation Basins 29
3.4.2 Upflow Solids Contact Clarifiers 30

Chapter 4. Filtration Technologies 33
4.1 Modifying Filtration Systems 33
4.1.1 General Effectiveness of Filtration Systems 34
4.1.2 Filtration System Improvements 34
4.1.3 System Design Checklist 37
4.2 Direct Filtration 37
4.2.1 Process Description 37
4.2.2 System Performance 38
4.3 Slow Sand Filtration 38
4.3.1 System Design Considerations 39
4.3.2 Operation and Maintenance 39
4.3.3 System Performance 41
4.3.4 System Costs 41
4.4 Package Plant Filtration 41
4.4.1 Selecting a Package Plant System 42
4.4.2 System Description and Design Considerations 42
4.4.3 Operation and Maintenance 43

4.4.4 System Performance 44
4.4.5 System Costs 44
4.5 Diatomaceous Earth Filtration 44
4.5.1 System Design 46
4.5.2 Operation and Maintenance 46
4.5.3 System Performance 47
4.5.4 System Costs 47
4.6 Other Filtration Systems 48
4.6.1 Membrane Filtration 48
4.6.2 Cartridge Filtration 51
4.7 Selecting the Appropriate Filtration Treatment System 52
4.7.1 Steps in an Evaluation 52
4.7.2 Need for Pilot Studies 53
4.7.3 Flocculation and Sedimentation Studies 53
4.7.4 Filtration Studies 53

Chapter 5. Disinfection and Disinfection By-Products 57
5.1 The Objectives of Disinfection 57
5.1.1 CT Values 58
5.2 Disinfection By-Products 59
5.2.1 The Chemistry of Oxidation 60
5.2.2 The Presence of Disinfection By-Products in Drinking Water 61
5.2.3 Strategies for Controlling Disinfection By-Products 61
5.3 Comparing Disinfectants 63
5.3.1 Chlorine 63
5.3.2 Chlorine Dioxide 63
5.3.3 Monochloramine 63
5.3.4 Ozone 64
5.3.5 Ultraviolet Radiation 65
5.3.6 Advanced Oxidation Processes 65
5.4 Primary Disinfection Technologies 65
5.4.1 Chlorine 66
5.4.2 Ozone 72
5.4.3 Chlorine Dioxide 81
5.4.4 Ultraviolet Radiation 87
5.5 Secondary Disinfectants 92
5.5.1 Chloramination 92

Chapter 6. Treatments of Organic Contaminants 97
6.1 Pretreatment for Natural Organic Contaminant Removal 97
6.1.1 Coagulant Pretreatment 99
6.1.2 Oxidation Pretreatment 100
6.2 Granular Activated Carbon 100
6.2.1 Process Design Considerations 101
6.2.2 Tests for Deriving Carbon Usage and Other Design Criteria 104
6.2.3 Least Cost Design Criteria 104
6.2.4 Facility Design Criteria 105
6.2.5 Operation and Maintenance 105
6.2.6 System Performance 106
6.2.7 System Costs 106
6.3 Packed Column Aeration 109
6.3.1 System Design Considerations 112
6.3.2 Pilot Testing PCA 112

6.3.3 VOC Emission Control 113
6.3.4 Operation and Maintenance 115
6.3.5 System Performance 115
6.3.6 System Costs 115
6.4 Powdered Activated Carbon Plus Conventional Treatment 118
6.4.1 PAC Application Techniques 118
6.4.2 System Design Considerations 119
6.4.3 System Performance 120
6.5 Diffused Aeration 120
6.5.1 System Design Considerations 121
6.5.2 System Performance 121
6.6 Multiple Tray Aeration 121
6.6.1 System Design 121
6.6.2 System Performance 121
6.7 Emerging Applications of Treatment Technologies for Organic Contaminants 121
6.7.1 Oxidation Including Ozone 122
6.7.2 Reverse Osmosis 124
6.7.3 Mechanical Aeration 124
6.7.4 Catenary Grid 124
6.7.5 Higee Aeration 124
6.7.6 Resins 125

Chapter 7. Treatments for Inorganic Contaminants 131
7.1 Techniques for Controlling Corrosion 131
7.1.1 The Problem of Corrosion 132
7.1.2 Diagnosing and Evaluating the Problem 133
7.1.3 Corrosion Controls 135
7.2 Treatment Technologies for Controlling Inorganic Contaminants, Including Radionuclides 139
7.2.1 Removing Radionuclides in Drinking Water 141
7.2.2 Conventional Treatment: Coagulation and Lime Softening 141
7.2.3 Reverse Osmosis 144
7.2.4 Ion Exchange 148
7.2.5 Activated Alumina 149

Chapter 8. Current and Emerging Research 153
8.1 Current Research on Disinfection By-Products 153
8.1.1 Identifying and Controlling Chlorination By-Products 153
8.1.2 Identifying Ozone By-Products 153
8.2 Treatment of Organic and Inorganic Contaminants 153
8.2.1 Granular Activated Carbon Systems 155
8.2.2 Ozone Oxidation Systems 157
8.2.3 Ultraviolet Treatment 157
8.2.4 Reverse Osmosis 157
8.2.5 Ultrafiltration 157
8.2.6 Packed Tower Aeration 157
8.2.7 Conventional Treatment 158
8.2.8 Ion Exchange 158
8.2.9 Technologies for Removing Radionuclides 158
8.2.10 Secondary Sources of Pollution 159
8.2.11 Small Systems Technologies 159
8.3 Mandatory Disinfection 159
8.3.1 Treatment/Distribution Microbiology 159

8.3.2 Bacterial Detection/Monitoring 160
8.4 Prohibition of Lead Materials 160
8.5 Systems and Cost Modeling Studies 160
8.6 Future Directions 161

Chapter 9. References 163

Appendix A Experience Modifying Existing Filtration Systems 169
A.1 Upgrading Existing Treatment Facilities 169
A.1.1 Horizontal Flow Basin Example 169
A.1.2 Upflow Solids Contact Clarifier Example 170
A.1.3 Sacramento, California 170
A.1.4 Erie County, New York 170
A.1.5 Corvallis, Oregon 171
A.1.6 Novato, California 172
A.2 Slow Sand Filter Systems 173
A.2.1 Idaho State 173
A.2.2 New York State 173
A.2.3 McIndoe Falls, Vermont 174
A.2.4 Village of 100 Mile House, British Columbia, Canada 175
A.3 Package Plants 175
A.3.1 Conventional Package Plants 175
A.3.2 Adsorption Clarifier Package Plants 176
A.4 Diatomaceous Earth Filters 180
A.4.1 Colorado State University Study 180
A.4.2 McIndoe Falls, Vermont 180
A.5 Selecting a Filtration System 180
A.5.1 Lake County, California 180

Appendix B Case Histories of Emerging Disinfection Technologies 185
B.1 Ozone Case Histories 185
B.1.1 Primary Disinfection with Ozone: North Andover, Massachusetts 185
B.1.2 Preozonation for THM Control: Kennewick, Washington 186
B.2 UV Radiation Case Histories 188
B.2.1 Ultraviolet Radiation for Primary Disinfection: Fort Benton, Montana 188
B.3 Chlorine Dioxide Case Histories 188
B.3.1 Predisinfection for THM Control: Evansville, Indiana 188
B.3.2 Primary and Secondary Disinfection with Chlorine Dioxide: Hamilton, Ohio 189
B.3.3 Preoxidation with Chlorine Dioxide, Postchlorination with Chlorine Dioxide and Chloramine: Galveston, Texas 191
B.4 Chloramine Case Histories 192
B.4.1 Prechlorination, Postchloramination: Bloomington, Indiana 192
B.4.2 Prechlorine Dioxide, Prechlorination, and Postchloramination: Philadelphia, Pennsylvania 192

Appendix C. Experience with Treatment Technologies for Organic Contaminants 195
C.1 Experience with Granular Activated Carbon 195
C.1.1 GAC for VOC Removal: Washington, New Jersey 195
C.1.2 GAC for Contaminant Control: Cincinnati, Ohio 195
C.1.3 EPA Health Advisory Example 196
C.2 Experience with PTA: Scottsdale, Arizona 196
C.3 Experience with PAC 197

Appendix D. Experience with Treatment Technologies for Inorganic Contaminants 203
D.1 Corrosion Control 203
D.1.1 Controlling Lead: Seattle, Washington 203
D.1.2 Controlling Lead with pH Adjustment: Boston, Massachusetts 203
D.2 Coagulation to Control Barium: Illinois 204
D.3 Reverse Osmosis: Sarasota, Florida 204
D.4 Ion Exchange: McFarland, California 205
D.5 Activated Alumina: Gila Bend, Arizona 206

Appendix E Summary of Corrosion Indices 209

此为试读，需要完整PDF请访问：www.ertongbook.com

Tables

2-1. Contaminants Required to be Regulated Under the SDWA Amendments of 1986 4
2-2. Final MCLGs and MCLs for VOCs 5
2-3. Monitoring for Unregulated VOCs 5
2-4. Proposed MCLGs and MCLs for SOCs and IOCs 6
2-5. Proposed SMCLs 6
2-6. Overview of Water Treatment Technologies 8
2-7. Typical Influent Characteristics and Capacities for Filtration Technologies 10
2-8. Removal Capacities of Seven Filter Options 10
2-9. Advantages and Disadvantages of Five Disinfectants 11
2-10. Disinfectant Production Considerations 11
2-11. Desired Points of Disinfectant Application 11
2-12. Disinfectant Application Considerations 12
2-13. Treatment Technology Removal Effectiveness Reported for Organic Contaminants (percent) 13
2-14. Operational Conditions for Organic Treatments 14
2-15. Corrosion Control Considerations 14
2-16. Most Probable Treatment Application for Inorganic Treatments 14
2-17. Removal Effectiveness for Nine Processes by Inorganic Contaminant 15
2-18. Advantages and Disadvantages of Inorganic Contaminant 16
3-1. Summary of Conventional Treatment Operating Issues 17
3-2. Chemical Costs for Conventional Treatment 18
3-3. Estimated Costs for Supplementing Surface Water Treatment by Adding Alum Feed Facilities 23
3-4. Estimated Costs for Supplementing Surface Water Treatment by Adding Polymer Feed Facilities 23
3-5. Estimated Costs for Supplementing Surface Water Treatment by Adding Sodium Hydroxide Feed Facilities 23
3-6. Estimated Costs for Supplementing Surface Water Treatment by Adding Sulfuric Acid Feed Facilities 24
3-7. Typical Rapid Mixer Contact Times and Velocity Gradients 24
3-8. Estimated Costs for Supplementing Surface Water Treatment by Adding Rapid Mix 25
3-9. Estimated Costs for Supplementing Surface Water Treatment by Adding Flocculation 28
3-10. Horizontal Flow Basins Loading Rates 30
3-11. Upflow Clarifier Loading Rates for Cold Water 31
3-12. Estimated Costs for Supplementing Surface Water Treatment by Adding Tube Settling Modules 32
4-1. Generalized Capability of Filtration Systems To Accommodate Raw Water Quality Conditions 35
4-2. Removal Efficiencies Of *Giardia Lamblia* By Water Treatment Processes 35
4-3. Removal Efficiencies Of Viruses By Water Treatment Processes 35
4-4. Estimated Costs For Supplementing Surface Water Treatment By Slow Sand Filtration 42
4-5. Summary Of Results Of Adsorption Clarification Package Plants 46
4-6. Estimated Costs for Supplementing Surface Water Treatment by Complete Treatment Package Plants 146
4-7. Estimated Costs for Supplementing Surface Water Treatment by Direct Filtration Using Diatomaceous Earth 48

4-8. Estimated Costs for Supplementing Surface Water Treatment by Package Membrane Filtration Plants 52
5-1. CT Values for Achieving 90 Percent Inactivation of *Giardia Lamblia* 58
5-2. CT Values for Achieving 99.9 Percent Inactivation of *Giardia Lambliaa* 59
5-3. CT Values for Achieving Inactivation of Viruses at pH 6 Through 9 59
5-4. Oxidation Potentials of Water Treatment Oxidants 60
5-5. Occurrence of Chlorinated Disinfection By-Products at 10 Water Utilities 61
5-6. Summary of Health Effects Associated with Chlorination By-Products 61
5-7. Disinfectants and Disinfectant By-Products Listed in the First Drinking Water Priority List 66
5-8. Capital Costs for Gas Chlorination 70
5-9. Capital Costs for Gas Chlorination 70
5-10. Capital Costs for Liquid Chlorinators 71
5-11. Operation and Maintenance Cost Summary for Sodium Hypochlorite Solution Feed 72
5-12. Costs of Ozonation Equipment for Small Water Supply Systems: Supplier A 80
5-13. Costs of Ozonation Equipment for Small Water Supply Systems: Supplier B 81
5-14. Operating and Maintenance Costs for Small Ozone Systems 82
5-15. Costs of Chlorine Dioxide Generating Equipment 90
5-16. Operation and Maintenance Cost Summary for Chlorine Dioxide Generating and Feed Systems 90
5-17. Construction Costs for Ultraviolet Light Disinfection 94
5-18. Operation and Maintenance Costs for Ultraviolet Light Disinfection 94
5-19. Chemical Costs for Generating Monochloramine for 2,500 GPD Water Treatment Plant 95
6-1. Performance Summary for Five Organic Technologies 98
6-2. Readily and Poorly Adsorbed Organics 101
6-3. Summary of Carbon Usage Rates 103
6-4. Cost for 95 Percent Removal of Several Organics and Radon Using GAC Adsorption 109
6-5. Henry's Law Constants for Nine Organic Chemicals 111
6-6. Typical Air Stripping Design Parameters for Removal of 13 Commonly Occurring Volatile Organic Chemicals 116
6-7. Examples of Removal Efficiencies for PTA Systems 119
6-8. Cost for 99 Percent Removal of Several VOCs and Radon Using Packed Tower Aeration 120
6-9. Typical Performance of Conventional Treatment Processes without and with PAC 121
6-10. Typical Performance of Diffused Aeration 123
6-11. Design Parameters for Peroxide-Ozone Treatment Plant and Assumptions for Cost Comparisons 126
6-12. Comparison of Annual Treatment Costs for Removal of PCE and TCE from Ground Water 126
6-13. Typical Performance of Ozonation Process 126
6-14. Typical Performance of Reverse Osmosis Process 127
7-1. Factors Affecting the Corrosivity of Drinking Water 132
7-2. Galvanic Series - Order of Electrochemical Activity of Common Metals Used in Water Distribution Systems 133
7-3. Typical Customer Complaints Due to Corrosion 134
7-4. Percentage of Test Sites with Lead in Drinking Water Greater than 20 µg/L at Low pH 134
7-5. Percentage of Test Sites with Lead in Drinking Water Greater than 20 µg/L at Medium pH 135

7-6. Percentage of Test Sites with Lead in Drinking Water Greater than 20 µg/L at High pH 135
7-7. Corrosion Properties of Frequently Used Materials in Water Distribution Systems 136
7-8. Pipe Wall Linings 140
7-9. Water Storage Tank Linings and Coatings 140
7-10. Removal Effectiveness for Eight Processes by Inorganic Contaminant 142
7-11. Most Effective Treatment Methods for Removal of Inorganic Contaminants 142
7-12. Advantages and Disadvantages of Inorganic Contaminant Removal Processes 143
7-13. Treatment Technologies for Removing Radionuclides 143
7-14. Radionuclide Process Treatment Costs 143
7-15. Costs for Removing Radon from Drinking Water by Packed Tower Aeration 144
7-16. Costs of Radon Treatment at the Plant Scale (200 GPD) for GAC Versus Aeration 144
7-17. Removal Efficiency Potential of Alum Versus Ferric Chloride 144
7-18. Removals Possible with Lime Softening 144
8-1. Common Chlorination By-Products 154
8-2. Treatment Technologies Evaluated by the Drinking Water Research Division 155
8-3. Chemicals for Which Carbon Usage Rates are Being Developed 156
A-1. Characteristics of Slow Sand Filter Installations in New York 174
A-2. Filter Ripening Data - Summary 174
A-3. Water Treatment Facilities Surveyed in Field Study 177
A-4. Treatment Process Characteristics 178
A-5. Plant Turbidity Values (NTU) 179
A-6. Operating Data – Greenfield, IA 179
A-7. Operating Data – Lewisburg, WV 180
A-8. Operating Data – Philomath, OR 180
A-9. Operating Data – Harrisburg, PA 181
A-10. Operating Data – Red Lodge, MT 181
A-11. Clear Lake Water Quality Analysis 181
A-12. Clear Lake Water Quality at DWR Sampling Station No. 1 at Lakeport 183
B-1. Design Criteria for Kennewick Water Treatment Plant Preozonation Facilities 187
B-2. Summary of THM Data at Bloomington, Indiana, with Free Chlorination, August 16, 1984 192
B-3. Summary of THM Data at Bloomington, Indiana, with Postchloramination, August 26, 1984 192
C-1. Profile of System used in EPA Health Advisory 200
C-2. Influent Characterization for System Used in EPA Health Advisory 200
D-1. Metropolitan District Commission Water Quality Data 203
D-2. Design Criteria of Reverse Osmosis Equipment 205
D-3. Pre- and Posttreatment Reverse Osmosis Processes 206
D-4. Chemical Analyses of Sarasota County Reverse Osmosis Systems 207
D-5. Reverse Osmosis Treatment System Costs 208
D-6. Ion Exchange Cost Components for McFarland, California ($1983) 208

Figures

3-1. Simplified diagram of streaming current detector. 20
3-2. In-line jet injection mixer. 26
3-3. Coagulant diffuser. 27
3-4. Divided flocculation basin.. 28
3-5. Typical tube settler installation in rectangular basin. 30
3-6. Radial solids contact clarifier with tube settlers. 31
4-1. Relationship between cyst removal and filtered water turbidity. 35
4-2. Cutaway view of typical rapid sand filter. 36
4-3. Flow diagram of typical direct filtration system. 38
4-4. Flow diagram of in-line direct filtration system. 38
4-5. Flow diagram of modified direct filtration system. 39
4-6. Typical unhoused slow sand filter installation. 40
4-7. Typical housed slow sand filter installation. 40
4-8. Flow diagram of a package plant. 43
4-9. Adsorption clarifier package plant. 44
4-10. Operating cycles of package plant. 45
4-11. Typical pressure diatomaceous earth filtration system. 47
4-12. Flow diagram of membrane filtration system. 49
4-13. Skid-mounted membrane filtration assembly. 51
4-14. Tube settling test module. 54
4-15. Pilot filter schematic. 55
5-1. Distribution of hypochlorous acid and hypochlorite ions in water at different pH values and temperatures of 0°C and 20°C. 67
5-2. Graphical representation of the breakpoint chlorination reaction. 68
5-3. Solution feed-gas chlorination system. 70
5-4. Low pressure air feed-gas treatment schematic for ozone generation. 75
5-5. High pressure air feed-gas treatment schematic for ozone generation. 76
5-6. Typical ozone generating configuration for a Corona discharge cell. 77
5-7. Two-compartment ozone contactor with porous diffusers. 79
5-8. Schematic diagram of an automatic feed, automatic flow-proportional chlorine dioxide system: Generation from chlorine and sodium chlorite. 87
5-9. Manual feed equipment arrangement for generating chlorine dioxide from sodium hypochlorite solution and mineral acid. 88
5-10. Schematic of CIFEC chlorine dioxide generating system. 89
5-11. Schematic of manual chlorine dioxide system. 89
5-12. Proportions of mono- and dichloramines in water with equimolar concentrations of chlorine and ammonia. 95
6-1. Effect of carbon cost on facility cost. 101
6-2. Steady-state adsorption/decay curve for radon. 103
6-3. Effect of contaminant on carbon life. 103
6-4. Effect of compound on carbon life. 104
6-5. Application of Freundlich Isotherm Relationship. 106
6-6. Adsorption isotherms for several organic compounds found in ground-water supplies. 106
6-7. Diagram of pilot column test system. 107

6-8. Diagram of dynamic mini-column adsorption system. 107
6-9. GAC treatment options. 108
6-10. Wavefront within GAC contactor. 108
6-11. GAC facility cost components. 110
6-12. Cost comparison of carbon regeneration/replacement options. 111
6-13. Packed tower aeration system. 113
6-14. Distributor types. 114
6-15. Effect of compound on packed-column design. 116
6-16. Packing height vs. removal efficiency for trichloroethylene. 116
6-17. Schematic of pilot aeration column. 117
6-18. Schematic of catalytic incineration process. 118
6-19. Vapor-phase carbon system for treatment of aeration exhaust air. 119
6-20. Schematic of the Roberts-Haberer process. 120
6-21. Schematic of PAC adsorption process. 122
6-22. Schematic of a plant-scale diffused aeration process. 122
6-23. Home diffused aeration system. 123
6-24. Schematic of a redwood slat tray aerator. 125
6-25. Schematic of mechanical aeration process. 127
6-26. Catenary grid system. 128
6-27. Schematic of Higee system. 129
7-1. Solubility of lead as a function of pH and carbonate. 137
7-2. Lime softening treatment system. 145
7-3. Schematic of a reverse osmosis system. 146
7-4. Two types of reverse osmosis membranes. 147
7-5. Ion exchange treatment system. 149
7-6. Activated alumina systems: Operating mode flow schematics 150
8-1. Pilot plant schematic for disinfection by-product control. 155
A-1. Flow diagram of the pilot filtration equipment. 171
A-2. *Giardia* cysts in the raw water. 176
A-3. Average raw and filtered water turbidity. 177
C-1. GAC treatment plant schematic Vannatta Street Station. 196
C-2. Cincinnati treatment train with addition of GAC. 197
C-3. Typical TOC reduction curve during pilot study. 198
C-4. Regeneration system schematic. 199
C-5. Schematic diagram of a Scottsdale packed column. 201

此为试读，需要完整PDF请访问：www.ertongbook.com