

Contents

Preface..... xiii

Author..... xv

Acronyms and Abbreviations xvii

Section I The Basics

1. Introduction.....3

1.1 Setting the Stage.....3

1.2 Sustainable Water/Wastewater Infrastructure.....5

1.2.1 Maintaining Sustainable Infrastructure.....5

1.2.2 Cash Cows or Cash Dogs?.....7

1.3 Water/Wastewater Infrastructure Gap.....8

1.4 Energy Efficiency: Water/Wastewater Treatment Operations9

References and Recommended Reading9

2. Characteristics of the Wastewater and Drinking Water Industries 11

2.1 Introduction12

2.1.1 Wastewater and Drinking Water Terminology12

2.2 Characteristics of the Wastewater Industry22

2.2.1 Wastewater Treatment Process: The Model.....22

2.3 Characteristics of the Drinking Water Industry.....23

2.4 Capital Stock and Impact on Operations and Maintenance.....24

2.4.1 Useful Life of Assets.....24

2.4.2 Operating and Maintaining Capital Stock.....26

2.5 Wastewater Capital Stock.....27

2.6 Drinking Water Capital Stock28

2.7 Costs of Providing Service.....29

References and Recommended Reading30

3. Water, Wastewater, and Energy 31

3.1 Introduction31

3.2 Energy Basics.....31

3.2.1 Potential Energy.....32

3.2.2 Kinetic Energy.....33

3.3 Renewable and Nonrenewable Energy.....34

3.3.1 Mix of Energy Production Changes.....35

3.4 Units for Comparing Energy35

References and Recommended Reading36

4. Planning for a Sustainable Energy Future 37

4.1 Wastewater and Drinking Water Treatment Energy Usage37

4.1.1 Current and Future Challenges.....37

4.2	Fast Facts	38
4.3	Benchmark It!.....	39
4.3.1	What Benchmarking Is	40
4.3.2	Potential Results of Benchmarking	41
4.3.3	Targets	41
4.3.4	Process of Benchmarking	41
4.3.5	Benchmarking Steps.....	41
4.3.6	Collection of Baseline Data and Tracking Energy Use.....	42
4.4	Baseline Audit	46
4.4.1	Field Investigation.....	47
4.4.2	Create Equipment Inventory and Distribution of Demand and Energy.....	47
	References and Recommended Reading	50

Section II Energy-Efficient Equipment, Technology, and Operating Strategies

5.	Energy-Efficient Equipment	53
5.1	Introduction	53
5.2	Motors	53
5.2.1	AC Motors	53
5.2.2	Electric Motor Load and Efficiency	57
5.2.3	Determining Motor Loads.....	59
5.2.4	Determining Motor Efficiency	63
5.3	Variable-Frequency Drives	65
5.4	HVAC Enhancements	67
5.5	Energy-Smart Lighting.....	68
	References and Recommended Reading	72
6.	Energy-Efficient Operating Strategies	73
6.1	Introduction	73
6.2	Electrical Load Management.....	73
6.2.1	Rate Schedules.....	73
6.2.2	Energy Demand Management.....	74
6.2.3	Electrical Load Management Success Stories	75
6.3	Biosolids Management	78
6.3.1	Biosolids: Background Information	79
6.3.2	Sources of Biosolids	79
6.3.3	Biosolids Characteristics.....	80
6.4	Operations and Maintenance: Energy- and Cost-Saving Procedures.....	81
6.4.1	Chandler Municipal Utilities, Arizona.....	82
6.4.2	Airport Water Reclamation Facility, Prescott, Arizona.....	83
6.4.3	Somerton Municipal Water, Arizona	84
6.4.4	Hawaii County Department of Water Supply	85
6.4.5	Eastern Municipal Water District, California.....	87
6.4.6	Port Drive Water Treatment Plant, Lake Havasu, Arizona.....	88
6.4.7	Truckee Meadows Water Authority, Reno, Nevada.....	89

- 6.4.8 Tucson Water, Arizona 91
- 6.4.9 Prescott–Chino Water Production Facility, Prescott, Arizona 93
- 6.4.10 Somerton Municipal Wastewater Treatment Plant, Arizona..... 94
- 6.5 Inflow and Infiltration Control 95
 - 6.5.1 Combined Sewer Systems..... 95
 - 6.5.2 Basement Sump Pump Redirection 97
- References and Recommended Reading 101

Section III Energy-Efficient Technology

- 7. Combined Heat and Power (CHP)..... 105
 - 7.1 Introduction 105
 - 7.2 CHP Key Definitions 106
 - 7.3 Calculating Total CHP System Efficiency 107
 - 7.4 Calculating Effective Electric Efficiency 108
 - 7.5 Selecting CHP Efficiency Metrics 109
 - 7.6 Wastewater Treatment Facilities with CHP 109
 - 7.7 Overview of CHP Technologies..... 111
 - References and Recommended Reading 111
- 8. Gas Turbines..... 113
 - 8.1 Introduction 113
 - 8.2 Applications..... 114
 - 8.3 Gas Turbine Technology 115
 - 8.3.1 Modes of Operation..... 116
 - 8.3.2 Design Characteristics 116
 - 8.3.3 Performance Characteristics 117
 - 8.3.4 Emissions 121
 - References and Recommended Reading 122
- 9. Microturbines..... 123
 - 9.1 Introduction 123
 - 9.2 Microturbine Applications 123
 - 9.3 Microturbine Technology 124
 - 9.3.1 Basic Components..... 125
 - 9.3.2 CHP Operation..... 127
 - 9.4 Design Characteristics..... 128
 - 9.5 Microturbine Performance Characteristics 128
 - 9.5.1 Effects of Ambient Conditions on Performance..... 129
 - 9.5.2 Heat Recovery..... 129
 - 9.5.3 Performance and Efficiency Enhancements 129
 - 9.5.4 Maintenance 131
 - 9.5.5 Fuels..... 132
 - 9.5.6 Availability..... 132
 - 9.5.7 Disadvantages 132
 - 9.6 Emissions 132
 - References and Recommended Reading 133

10. Reciprocating Engines	135
10.1 Introduction	135
10.2 Applications	136
10.2.1 Combined Heat and Power	137
10.3 Reciprocating Engine Technology	138
10.4 Design Characteristics	139
10.5 Performance Characteristics	140
10.5.1 Electrical Efficiency	140
10.5.2 Load Performance	140
10.5.3 Heat Recovery	140
10.5.4 Performance and Efficiency Enhancements	142
10.5.5 Maintenance	143
10.5.6 Fuels	143
10.6 Emissions	145
10.6.1 Nitrogen Oxides (NO _x)	146
10.6.2 Carbon Monoxide	146
10.6.3 Unburned Hydrocarbons	146
10.6.4 Carbon Dioxide	147
References and Recommended Reading	147
11. Steam Turbines	149
11.1 Introduction	149
11.2 Applications	150
11.2.1 Industrial and CHP Applications	150
11.2.2 Combined-Cycle Power Plants	151
11.3 Steam Turbine: Basic Process and Components	151
11.3.1 Boilers	153
11.3.2 Types of Steam Turbines	153
11.3.3 Design Characteristics	154
11.4 Performance Characteristics	155
11.4.1 Electrical Efficiency	155
11.4.2 Operating Characteristics	155
11.4.3 Process Steam and Performance Trade-Offs	156
11.4.4 CHP System Efficiency	156
11.4.5 Performance and Efficiency Enhancements	156
11.4.6 Steam Reheat	157
11.4.7 Combustion Air Preheating	157
11.4.8 Maintenance	157
11.4.9 Fuels	158
11.4.10 Availability	158
11.5 Emissions	158
References and Recommended Reading	158
12. Fuel Cells	161
12.1 Introduction	161
12.2 Fuel Cells: The Basics	162
12.2.1 Open Cells vs. Closed Cells	162
12.3 Hydrogen Fuel Cells: A Realistic View	164

Contents

12.3.1 Hydrogen Storage 165

12.3.2 How a Hydrogen Fuel Cell Works 165

12.4 CHP Applications 166

References and Recommended Reading 167

Section IV Biomass Power and Heat Generation

13. CHP and Wastewater Biogas 171

13.1 Grasshopper Generation 171

13.2 Biomass 173

13.2.1 Feedstock Types..... 173

13.2.2 Composition of Biomass 174

13.3 Biomass for Power and Heat Generation.....175

13.4 Biogas (Methane, CH₄)..... 176

13.4.1 The 411 on Methane 177

13.5 Wastewater Treatment Plant Biogas 178

13.5.1 Anaerobic Digestion 179

13.6 Cogeneration Using Landfill Biogas 182

13.7 Biodiesel 183

References and Recommended Reading 186

Section V Sustainability Using Renewable Energy

14. Macro- and Microhydropower..... 193

14.1 Introduction 193

14.2 Hydropower..... 193

14.2.1 Impoundment..... 195

14.2.2 Diversion 196

14.2.3 Pumped Storage..... 196

14.3 Hydropower Basic Concepts 196

14.3.1 Stevin's Law 197

14.3.2 Density and Specific Gravity..... 198

14.3.3 Force and Pressure..... 200

14.3.4 Hydrostatic Pressure 201

14.3.5 Head..... 202

14.3.6 Flow and Discharge Rates: Water in Motion 204

14.3.7 Area and Velocity 205

14.3.8 Pressure and Velocity..... 206

14.3.9 Conservation of Energy 206

14.3.10 Energy Head 206

14.3.11 Energy Available..... 206

14.3.12 Major Head Loss 206

14.3.13 Minor Head Loss..... 209

14.4 Reservoir Stored Energy 209

14.5 Hydroturbines 211

14.5.1 Impulse Turbine..... 211

14.5.2 Reaction Turbine 211

14.6 Advanced Hydropower Technology 211

14.7	Hydropower Generation: Dissolved Oxygen Concerns.....	212
14.8	Bottom Line on Macrohydropower.....	213
14.9	Microhydropower Concepts.....	214
14.9.1	Microhydropower Key Terms.....	214
14.9.2	Potential Microhydropower Sites.....	216
14.9.3	Head at Potential Microhydropower Site.....	217
14.9.4	Flow at Potential Microhydropower Site.....	218
14.9.5	Economics.....	220
14.10	Permits and Water Rights.....	220
	References and Recommended Reading.....	220
15.	Solar Power.....	223
15.1	Introduction.....	223
15.2	Concentrating Solar Power.....	225
15.2.1	Linear Concentrators.....	225
15.2.2	Dish/Engine Systems.....	226
15.2.3	Power Tower System.....	227
15.2.4	Thermal Energy Storage.....	228
15.3	Photovoltaics (PV).....	231
15.4	Solar Power Applications.....	232
15.4.1	Solar Hot Water.....	233
15.4.2	Solar Process Heat.....	234
15.5	Structure Daylighting.....	236
15.5.1	Daylight Zone.....	236
15.5.2	Window Design Considerations.....	237
15.5.3	Effective Aperture (EA).....	238
15.5.4	Light Shelves.....	238
15.5.5	Toplighting Strategies.....	238
15.6	Water and Wastewater Treatment Plant Applications.....	239
	References and Recommended Reading.....	240
16.	Wind Power.....	245
16.1	Introduction.....	245
16.2	It's All about the Wind.....	246
16.3	Air in Motion.....	247
16.4	Wind Energy.....	250
16.5	Wind Power Basics.....	252
16.6	Wind Turbine Types.....	252
16.6.1	Horizontal-Axis Wind Turbines.....	253
16.7	Turbine Features.....	253
16.8	Wind Energy and Power Calculations.....	255
16.8.1	Air-Density Correction Factors.....	257
16.8.2	Elevation and Earth's Roughness.....	257
16.8.3	Wind Turbine Rotor Efficiency.....	258
16.8.4	Derivation of Betz's Law.....	258
16.8.5	Tip Speed Ratio (TSR).....	260
16.9	Small-Scale Wind Power.....	262
16.10	Wind Power Applications in Water/Wastewater Treatment.....	266
	References and Recommended Reading.....	267

17. Energy Conservation Measures for Wastewater Treatment:269

17.1 Introduction 269

17.2 Pumping System Energy Conservation Measures..... 270

17.2.1 Pumping System Design..... 271

17.2.2 Pump Motors..... 272

17.2.3 Power Factor 277

17.2.4 Variable-Frequency Drives 280

17.3 Design and Control of Aeration Systems 281

17.3.1 ECMs for Aeration Systems..... 282

17.3.2 Control of the Aeration Process..... 286

17.3.3 Innovative and Emerging Control Strategies
for Biological Nitrogen Removal 294

17.4 Blowers 296

17.4.1 High-Speed Gearless (Turbo) Blowers 299

17.4.2 Single-Stage Centrifugal Blowers with
Inlet Guide Vanes and Variable Diffuser Vanes..... 299

17.4.3 New Diffuser Technology 300

17.4.4 Preventing Diffuser Fouling 301

17.4.5 Innovative and Emerging Energy Conservation Measures 301

17.4.6 UV Disinfection 302

17.4.7 Membrane Bioreactors 306

17.4.8 Anoxic and Anaerobic Zone Mixing..... 307

References and Recommended Reading 311

Section VI Appendices

Appendix A. Magnetic Bearing Turbo Blowers at the Green Bay Metropolitan
Sewerage District De Pere Wastewater Treatment Facility..... 317

Appendix B. Turblex® Blowers and Air Flow Control Valves
on the Sheboygan Regional Wastewater Treatment Plant 325

Appendix C. Upgrade from Mechanical Aeration to Air-Bearing
Turbo Blowers and Fine-Bubble Diffusers at the Big Gulch
Wastewater Treatment Plant..... 333

Appendix D. Optical DO Sensor Technology and Aerator Rotor VFD Control
at the City of Bartlett, Tennessee, Wastewater Treatment Plant..... 343

Appendix E. Advanced Aeration Control for the
Oxnard, California, Wastewater Treatment Plant 349

Appendix F. DO Optimization Using Floating Pressure
Blower Control in a Most Open Valve Strategy at the
Narragansett Bay Commission Bucklin Point WTP, Rhode Island 359

Appendix G. Capacity and Fuel Efficiency Improvements
at Washington Suburban Sanitary Commission Western
Branch WWP, Prince Georges County, Maryland 369

Contents

Appendix H. Permit-Safe and Energy-Smart Greening of Wastewater Treatment Plant Operations at the San Jose/Santa Clara, California, Water Pollution Control Plant.....	379
Appendix I. Diffuser Upgrades and DO Controlled Blowers at the Waco, Texas, Metropolitan Area Regional Sewer System Wastewater Treatment Facility	389
Glossary	397
Index	431