

Energy Conservation in Water and Wastewater Facilities

Water Environment Federation® (WEF®)

MANUAL OF PRACTICE No. 32

Contents

Preface	xxiii
List of Figures	xxvii
List of Tables	xxix
Chapter 1 Energy Efficiency	1
1.0 INTRODUCTION	1
2.0 ROLE OF MANAGEMENT	4
2.1 Monitoring	4
2.2 Resources	4
3.0 ENERGY AND POWER	6
4.0 CLIMATE CHANGE	7
4.1 Water Environment Federation Resolution on Climate Change	7
4.2 Greenhouse Gas Overview	8
4.3 Sources of Greenhouse Gas Emissions	8
4.4 Computing Greenhouse Gas Emissions	9
5.0 IDENTIFYING ENERGY CONSERVATION MEASURES	10
6.0 RANKING AND IMPLEMENTATION OF ENERGY CONSERVATION MEASURES	14
7.0 CASE STUDIES	15
7.1 California Energy Commission	15
7.2 Gloversville-Johnstown Joint Wastewater Treatment Facility	16
8.0 REFERENCES	16
9.0 SUGGESTED READINGS	17

Chapter 2 Utility Billing Procedures and Incentives 19

1.0 INTRODUCTION 20

2.0 COST-SAVING OPPORTUNITIES 21

 2.1 Obtain the Most Favorable Tariff 21

 2.2 Install High-Efficiency Transformers 21

 2.3 Shave Peak Demand and Transfer Loads 21

 2.4 Improve the Power Factor 21

 2.5 Install High-Efficiency Motors 21

3.0 ELECTRICITY 22

 3.1 Billing Charges 22

 3.1.1 *Customer* 22

 3.1.2 *Energy* 22

 3.1.3 *Demand* 23

 3.1.4 *Power Factor Adjustment* 25

 3.2 Miscellaneous Charges and Surcharges 26

 3.2.1 *Fuel-Cost Adjustment* 26

 3.2.2 *Regulatory Fees* 26

 3.2.3 *State and Local Taxes* 26

 3.2.4 *Transmission Voltage* 26

 3.2.5 *Standby Service* 27

 3.2.6 *Nonfirm Power Supply* 27

 3.3 Other Rate Structures 27

 3.3.1 *Flat Demand Rate* 27

 3.3.2 *Flat Energy Rate* 27

 3.4 Incentives to “Load Shift” and “Peak Shave” 28

 3.5 Electric Service Options 28

 3.6 Alternative Energy Sources 29

 3.7 Cogeneration Facilities 29

4.0 SAMPLE ELECTRIC BILLS 30

5.0 NATURAL GAS BILLING 32

 5.1 Rate Structures 32

 5.1.1 *Unbundled Utility Service* 32

5.1.2	<i>Transportation</i>	33
5.1.3	<i>Pipeline Direct</i>	33
5.2	Rates	33
5.2.1	<i>Gas Transportation Agreement</i>	34
5.3	Seasonal Pricing Incentive	34
5.4	Computing Thermal Consumption	35
6.0	UTILITY RATE AND SERVICE OPTIONS	36
Chapter 3	Electric Motors and Transformers	37
1.0	THE NEED FOR EFFICIENT MOTOR DESIGN	38
1.1	Motors as Part of a System	39
1.2	Components of Common Motors	39
2.0	MEASUREMENT OF ELECTRICAL CHARACTERISTICS	41
2.1	Voltage	41
2.2	Amperage	42
2.3	Power Factor	43
2.4	Resistance and Insulation	44
2.5	<i>Power</i>	45
2.6	<i>Slip</i>	46
3.0	OPERATING POWER	47
3.1	Service Factor	47
4.0	TYPES OF ELECTRIC MOTORS	48
4.1	Three-Phase Motors	48
4.1.1	<i>Squirrel Cage</i>	49
4.1.2	<i>Wound Rotor</i>	50
4.1.3	<i>Synchronous Motors</i>	50
4.2	Single-Phase Induction Motors	50
4.3	Direct Current Motors	51
5.0	CONVENTIONS FOR SPECIFYING MOTOR PERFORMANCE	52
5.1	Definition of Efficiency	52
5.2	<i>Test Procedures</i>	52
6.0	MATCHING MOTORS TO LOAD	52

Contents

7.0 STANDARDS FOR ENERGY-EFFICIENT MOTORS	53
7.1 Energy Policy Act of 1992	54
7.2 Department of Energy—Energy Efficiency and Renewable Energy Program	54
7.3 U.S. Environmental Protection Agency	54
7.4 Independent Energy Companies	55
7.5 International Motor Standards	55
7.6 National Electrical Manufacturers Association	55
7.6.1 <i>National Electrical Manufacturers Association Premium Motors Program</i> .	55
7.7 Institute of Electrical and Electronic Engineers	59
7.7.1 <i>Test Standards for Energy-Efficient Motors</i>	59
7.8 Consortium for Energy Efficiency	59
7.9 MotorMaster+	59
7.10 Motor Management	60
7.11 Motor Records	60
7.12 Motor Failure	60
7.12.1 <i>Motor Repairs</i>	62
7.12.2 <i>Selection of a Motor Repair Facility</i>	62
7.13 Transformers	63
8.0 REFERENCES	64
9.0 ADDITIONAL RESOURCES	65
Chapter 4 Pumps	67
1.0 PUMPING PRINCIPLES	68
1.1 Pump Characteristic Curves	69
1.2 Best Efficiency Point	69
1.3 System Head Curve	69
1.4 Operating Point	74
1.5 Relationship of Best Efficiency Point and Operating Point	74
2.0 ENERGY PRINCIPLES	75
2.1 Pump Efficiency	76
2.2 Energy Consumption	77

2.3 Multiple Operating Points	78
2.4 Measuring Pump System Efficiency	80
2.5 Demand Charge	80
3.0 REDUCING ENERGY USE AND COST	81
4.0 DISCHARGE	81
5.0 HEAD	82
5.1 Measuring Pump Head	82
5.2 System Head	83
5.3 Friction	85
5.4 Determining Head Loss	85
5.5 Low Flows	88
5.6 Pipe Restrictions	88
6.0 PRICE OF ENERGY	90
7.0 PUMP EFFICIENCY	91
8.0 DRIVE EFFICIENCY	91
9.0 MOTOR EFFICIENCY	93
10.0 LIFE CYCLE COSTING	94
11.0 OPERATION AND MAINTENANCE PRACTICES	94
12.0 FLOW METER CALIBRATION VERIFICATION	96
13.0 REFERENCES	98
14.0 SUGGESTED READINGS	98
Chapter 5 Variable Controls	101
1.0 INTRODUCTION	102
2.0 TYPES OF VARIABLE CONTROLS	103
2.1 Indirect Control	103
2.2 Control of the Driver	104
2.2.1 Motors	104
2.2.2 Engines.....	104
2.3 Motor Control	104
2.3.1 Adjustable-Speed Drives or Variable-Speed Drives.....	104
2.3.2 Variable-Frequency Drives	105

Contents

2.3.2.1	<i>Low-Voltage Drives</i>	106
2.3.2.2	<i>Medium-Voltage Drives</i>	106
2.3.2.3	<i>Scalar Versus Vector Control</i>	107
2.3.2.3.1	Scalar	107
2.3.2.3.2	Vector	107
2.3.2.3.3	Motor Compatibility	109
2.3.3	<i>Other Technologies</i>	110
2.3.4	<i>Harmonics</i>	112
2.3.4.1	Description	112
2.3.4.2	<i>Other Sources of Harmonics in Plants</i>	112
2.3.4.3	<i>Effect on Efficiency</i>	114
2.3.4.4	<i>Harmonics Mitigation Methods</i>	115
2.3.5	<i>Motor-Bearing Damage</i>	118
2.3.6	<i>Common-Mode Noise</i>	118
2.3.7	<i>Speed Control Considerations for Pumps, Blowers, and Compressors</i>	120
3.0	BLOWERS AND COMPRESSORS	121
4.0	OPTIMIZATION OF PUMP OPERATION	121
4.1	Affinity Laws	121
4.2	Drive Energy Savings Measurements	123
5.0	REFERENCES	123
Chapter 6 Energy Use In Water Treatment Plants		125
1.0	GENERAL OVERVIEW	126
2.0	RAW WATER INTAKES	132
3.0	RAW WATER PUMPING AND CONVEYANCE	132
4.0	PRETREATMENT: COAGULATION, FLOCCULATION, AND SEDIMENTATION	132
4.1	Flash Mix	132
4.2	Flocculation	134
4.3	Sedimentation	134
4.4	High-Rate Clarification	135
4.5	Dissolved Air Floatation	136

5.0 TASTE AND ODOR CONTROL	137
5.1 Air Stripping	137
5.2 Ozone	139
6.0 FILTRATION	146
6.1 Gravity Filtration	146
6.2 Membrane Filtration	147
6.2.1 Low-Pressure Membrane Filtration (Microfiltration/Ultrafiltration)	147
6.2.2 Low-Pressure Reverse Osmosis and Nanofiltration (Brackish Water Desalination)	150
7.0 DISINFECTION	150
7.1 Chlorine Gas	150
7.2 Bulk Sodium Hypochlorite	151
7.3 On-Site Hypochlorite Generation	151
7.4 Ultraviolet Systems	151
8.0 HIGH-SERVICE PUMPING	154
9.0 WATER PLANT RESIDUALS MANAGEMENT	155
9.1 Gravity Thickeners	156
9.2 Belt Filter Press	156
9.3 Centrifuges	157
9.4 Membrane Concentrate Disposal	157
10.0 REFERENCES	158

Chapter 7 Energy Use in Wastewater Treatment Processes 161

1.0 PRELIMINARY AND PRIMARY TREATMENT	163
1.1 Screening	163
1.2 Influent Wastewater Pumping	164
1.2.1 Opportunities for Energy Reduction	164
1.3 Grit Removal	166
2.0 PRIMARY TREATMENT	167
2.1 Conventional	167
2.2 Chemically Enhanced	168
2.3 Primary Sludge Pumping	168

Contents

3.0 SECONDARY TREATMENT	169
3.1 Activated Sludge Processes	169
3.2 Dissolved Oxygen Operating Levels	170
3.3 Secondary Clarification	172
3.4 Membrane Bioreactor Process	172
3.5 Anoxic-Zone Mixing	174
3.6 Fixed-Film Processes	174
3.7 Online Instrumentation	175
4.0 DISINFECTION	177
4.1 Chlorination/Dechlorination	177
4.2 Ultraviolet Disinfection	178
5.0 ADVANCED WASTEWATER TREATMENT	180
5.1 Granular Media Filtration	180
5.2 Activated Carbon Adsorption	181
5.3 Chemical Treatment	181
5.4 Nutrient Removal Processes	181
5.5 Side-Stream Nitrogen Removal Processes	185
5.6 Post-Aeration	188
6.0 MISCELLANEOUS ENERGY USES	188
7.0 REFERENCES	189
8.0 SUGGESTED READINGS	190

Chapter 8 Aeration Systems

1.0 DETERMINING OXYGEN REQUIREMENTS	192
1.1 Impact of Process Configuration, Nitrification, Denitrification, and Phosphorus Removal	195
2.0 TYPES OF AERATION EQUIPMENT	197
2.1 Surface	197
2.1.1 <i>Low-Speed Aerators</i>	197
2.1.2 <i>High-Speed Aerators</i>	198
2.1.3 <i>Aspirating Aerators</i>	198
2.1.4 <i>Brush Aerators</i>	198
2.1.5 <i>Disk Aerators</i>	199

2.2 Submerged	199
2.2.1 Diffusers.....	199
2.2.1.1 Coarse Bubble	199
2.2.1.2 Fine Pore	199
2.2.2 Sparger Turbines	200
2.2.3 Submerged Aerator Mixers	201
2.2.4 Static Tubes	201
2.2.5 Jet Aerators	201
2.2.6 U-Tube Aerators.....	201
3.0 DESIGN CONSIDERATIONS	202
3.1 Oxygen Transfer Efficiency	203
3.1.1 Mixing	205
3.1.2 Diffuser Flux Rate	205
3.1.3 Alpha	206
3.1.4 Beta.....	207
3.1.5 System Costs	207
4.0 OPERATIONAL CONSIDERATIONS	208
4.1 Waste Loading Distribution	208
4.2 Step-Feed/Complete-Mix Modes	209
4.3 Mixed Liquor Dissolved Oxygen	209
4.4 Process Monitoring and Control	214
4.5 Dissolved Oxygen Management in Membrane Bioreactor Systems	215
4.6 Fouling of Porous Diffusers	216
4.7 Diffuser Cleaning	217
4.7.1 Air-Side Fouling	217
4.7.2 Liquid-Side Fouling	217
5.0 DIFFUSED-AERATION CASE HISTORIES	219
5.1 Batesville, Arkansas	219
5.2 Beloit, Wisconsin	220
5.3 Palmyra, Wisconsin	220
6.0 MECHANICAL AERATION CONTROL	220
6.1 Submergence Adjustment	221

Contents

6.2 Speed Adjustment	221
6.3 On-Time Adjustment	222
6.4 Mechanical Aerator Maintenance and Troubleshooting	223
7.0 REFERENCES	223
8.0 SUGGESTED READINGS	225
Chapter 9 Blowers	227
1.0 APPLICATION CONSIDERATIONS	228
1.1 Effects of Compressibility	228
1.2 Common Blower Types	230
1.3 Blower Power Requirements	230
1.4 Blower and System Curves	232
1.5 Effect of Inlet Conditions	237
1.6 Other Considerations	238
2.0 POSITIVE-DISPLACEMENT BLOWERS	241
2.1 Operating Principles	241
2.2 Control Techniques	243
2.3 Application Considerations	244
2.4 Operating Limits	244
3.0 MULTI-STAGE CENTRIFUGAL BLOWERS	245
3.1 Operating Principles	245
3.2 Control Techniques	246
3.3 Application Considerations	248
3.4 Operating Limits	249
4.0 SINGLE-STAGE CENTRIFUGAL BLOWERS	249
4.1 Operating Principles	249
4.2 Control Techniques	250
4.3 Application Considerations	252
4.4 Operating Limits	255
5.0 BLOWER SYSTEM RETROFIT OPPORTUNITIES	255
5.1 Automatic Controls	255
5.2 Additional Energy Conservation Measures	256

6.0 REFERENCES	258
Chapter 10 Solids Processes	259
1.0 INTRODUCTION	260
1.1 Recycle Streams	260
1.1.1 <i>Energy-Saving Opportunities in the Treatment of Recycle Flows</i>	261
1.2 Process Removals	262
1.3 Thickening Optimization	263
2.0 ANAEROBIC DIGESTION PROCESSES	263
2.1 Temperature	265
2.1.1 <i>Class A—Anaerobic Digestion</i>	266
2.2 Staged Anaerobic Digestion	267
2.3 Two-Phase Digestion	267
2.4 Torpey Process	268
2.5 Co-Digestion Processes	268
2.6 Pretreatment of Sludge	270
2.7 Gas Composition	272
2.8 Energy Consumption in Conventional Digesters	272
2.8.1 <i>Digester Heating Requirements</i>	272
2.8.2 <i>Energy Requirements for Sludge Heaters and Recirculation Pumping</i> ...	275
2.8.3 <i>Mixing Energy</i>	276
2.9 Energy Recovery	277
3.0 AEROBIC DIGESTION	279
3.1 Energy-Saving Opportunities	280
3.2 Autothermal Aerobic Digestion	282
4.0 INCINERATION	283
4.1 Feasibility of Incineration	284
4.2 Air Emissions	285
4.3 Process Stability	285
4.3.1 <i>Multiple-Hearth Furnace</i>	286
4.3.2 <i>Fluidized-Bed Furnace</i>	287
4.4 Heat Requirements	288

Contents

4.4.1	<i>Heat Losses Associated with Water</i>	289
4.4.2	<i>Wastewater Solids Energy</i>	290
4.4.3	<i>Autogenous Combustion</i>	290
4.4.4	<i>Electrical Energy Use</i>	291
4.4.5	<i>Energy Recovery</i>	292
5.0	DRYERS	292
5.1	Purpose	293
5.1.1	<i>Energy Use</i>	294
6.0	REFERENCES	296
Chapter 11	Energy Management	299
1.0	ENERGY MANAGEMENT PLAN OVERVIEW	301
1.1	Energy Management Plan	301
1.2	Energy Awareness—Understanding Energy Use	303
1.3	Available Energy Computer Modeling	304
1.4	Tracking Utility Consumption and Costs	304
1.5	Communicate Value of Energy Awareness	304
2.0	ENERGY-EFFICIENT DESIGN	305
2.1	Energy Consumption Minimization	305
2.1.1	<i>Understanding Your Energy Bill</i>	306
2.2	Design Approach to Acknowledge the Value of Energy Efficiency	306
2.3	Energy Efficiency Education	307
2.3.1	<i>Life Cycle Cost Analysis</i>	308
2.4	Gather Data	308
2.4.1	<i>Treatment Process Sub-Metering</i>	310
2.4.2	<i>Develop a Baseline Consumption for Your Facility</i>	310
2.4.3	<i>Develop a Benchmark Consumption for Your Facility</i>	311
2.4.4	<i>Data Trending</i>	311
2.5	Analyze Data	311
2.5.1	<i>Pump Systems</i>	312
2.5.2	<i>Aeration Process</i>	312
2.5.3	<i>Solids Handling Process</i>	313

2.6	Developing an Energy Management Plan	313
2.6.1	<i>Implementation Plan</i>	313
2.6.2	<i>Modify Operations</i>	313
2.6.2.1	<i>Peak Electric Demand Reduction</i>	313
2.6.2.2	<i>Flow Equalization</i>	317
2.6.2.2.1	<i>Wastewater</i>	317
2.6.2.2.2	<i>Water</i>	318
2.6.2.3	<i>Priority Load Shedding</i>	318
2.7	Demand-Side Management	320
2.8	Communicate the Value of the Energy Management Plan	321
3.0	BENEFICIAL USE OF RENEWABLES	322
3.1	Biogas	322
3.2	Wind	322
3.3	Solar	323
3.4	Biomass	323
3.5	Hydro Turbines	323
3.6	Fuel Cells	324
4.0	ON-SITE ENGINE OR POWER UTILIZATION	324
4.1	Engine-Driven Pump	325
4.2	Power-Generating System—Traditional Transfer Scheme	326
4.3	Power-Generating System—Synchronized Transfer Scheme	326
4.4	Power-Generating System—Parallel with Utility	326
5.0	ON-SITE GENERATION OPTIONS	327
5.1	Using Emergency Backup Generators for Peak Shaving	327
5.2	Distributed Generation	328
5.3	Installing Cogeneration Units	329
5.4	Using Biogas, Sludge, and Other Byproducts of the Wastewater Treatment Process as Fuels	329
5.5	Feasibility Evaluation	330
5.5.1	<i>Ranking of Project Objectives</i>	330
5.5.2	<i>Facility Factors</i>	330
5.5.3	<i>Design Factors</i>	331

Contents

5.5.4	<i>Economic Factors</i>	332
5.5.5	<i>Operational Factors</i>	333
5.5.6	<i>Environmental Factors</i>	333
6.0	FINANCING APPROACHES	335
6.1	Project Financing	336
6.2	Revenue Bonds	336
6.3	Conventional Bank Financing	337
6.4	Lease Financing	337
6.4.1	<i>Direct Financing Lease</i>	337
6.4.2	<i>Leveraged Lease</i>	338
6.4.3	<i>Operating Lease</i>	338
6.4.4	<i>Conditional Sale Lease</i>	339
6.4.5	<i>Certificates of Participation</i>	339
6.4.6	<i>Tax-Exempt Leases</i>	339
6.4.7	<i>Sale-Leaseback</i>	339
6.4.8	<i>Lease Financing Considerations</i>	339
6.4.9	<i>Energy Services Contracting</i>	340
6.4.10	<i>Utility Services Contracting</i>	341
6.4.11	<i>Grants/Rebates</i>	342
6.5	Privatization	342
6.6	Joint Ownership and/or Development	342
6.7	Shared Savings	343
7.0	PROFILE OF ENERGY REQUIREMENTS	344
8.0	REFERENCES	344
9.0	SUGGESTED READINGS	345
Appendix A	Agencies and Organizations	347
Appendix B	Equations for Converting from English Units to Metric Units	349

Appendix C	Estimates of Electricity Used in Wastewater Treatment	351
Appendix D	Electricity Basics	355
1.0	ALTERNATING CURRENT VOLTAGE	356
2.0	VOLTAGE DROP	356
Index	359