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Energy Conservation Measures at WWTPs

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Evaluation of Energy Conservation Measures

for Wastewater Treatment Facilities

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Cover photo:
Bucklin Point WWTF, RI. Photo courtesy of Narragansett Bay Commission.

Cover insert photos (left to right):
High Speed Magnetic Bearing Turbo Blower at the De Pere WTF, WI. Photo courtesy of Green Bay Metropolitan Sewerage District.
Oxidation Ditch with Aeration Rotor at the City of Bartlett WWTP #1, TN. Photo courtesy of City of Bartlett Wastewater Division.
Variable Outlet Vane Diffuser. Photo courtesy of Turblex, Inc.

Preface

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of environmental laws, the Agency strives to formulate and implement actions leading to a balance between human activities and the ability of ecosystems to support and sustain life. To meet this mandate, the Office of Wastewater Management (OWM) provides information and technical support to help solve environmental problems today and to build the knowledge base necessary to protect public health and the environment well into the future. This document was prepared under contract to EPA, by The Cadmus Group. The document provides information on current state-of-development as of the publication date; however, it is expected that this document will be revised periodically to reflect advances in this rapidly evolving area. Except as noted, information, interviews, and data development were conducted by the contractor. While there are many proven, cost-effective energy conservation practices and numerous new technologies or modifications of existing technologies available for detailed study, the case studies in this document were selected on the basis of specific criteria. The criteria included the ability to provide as least one year of full-scale operating and performance data, capability of providing detailed capital, operations, and maintenance cost breakdowns, and the ability to provide the data within the time frame established for completing the document. It is anticipated that as the document is updated, additional case studies on new technologies could be included.

Disclaimer

This information represents new, innovative or emerging approaches, techniques, or technologies that may assist utility owners and operators reduce the capital or operating costs of wastewater treatment. Some of the information, especially related to emerging technologies, was provided by the manufacturer or vendor of the equipment or technology, and could not be verified or supported by a full-scale case study. In some cases, cost data were based on estimated savings without actual field data. When evaluating technologies, estimated costs, and stated performance, efforts should be made by the reader to collect current and more up-to-date information.

The mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by EPA or the federal government. Stated results, conclusions, usage, or practices contained herein may be different depending on specific site conditions and do not necessarily represent the views or policies of EPA.

This document has been reviewed in accordance with EPA's peer and administrative review policies and approved for publication

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While every effort was made to accommodate all of the Peer Review comments, the results and conclusions do not indicate consensus and may not represent the views of all the reviewers.

The authors sincerely appreciate the review and guidance provided by the technical expert panel members and peer reviewers.

Acronyms and Abbreviations

ACEEE	American Council for an Energy Efficient Economy
APPA	American Public Power Association
ASCE	American Society of Civil Engineers
ASE	Alliance to Save Energy
AWWA	American Water Works Association
BEP	Best Efficiency Point
bhp	Brake Horsepower
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
CCCSD	Central Contra Costa Sanitary District
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFO	Cost Flow Opportunity
CHP	Combined Heat and Power
DCS	Distributed Control System
DO	Dissolved Oxygen
DOE	Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
ECM	Energy Conservation Measure
EPACT	Energy Policy Act
EPC	Energy Performance Contracting
EPRI	Electric Power Research Institute
ESCO	Energy Services Company
GBMSD	Green Bay (Wisconsin) Metropolitan Sewerage District
gpm	Gallons per minute
hp	Horsepower
I&I	Inflow and infiltration
IOA	International Ozone Association
IUVA	International Ultraviolet Association
kW	Kilowatt
kWh	Kilowatt hour
LPHO	Low Pressure High Output
MBR	Membrane Bioreactor
mg	Million Gallons
mgd	Million Gallons per Day
MLE	Modified Ludzack-Ettinger process
MPN	Most Probable Number
NAESCO	National Association of Energy Service Companies
NEMA	National Electrical Manufacturers Association
NYSERDA	New York State Research and Development Authority
PG&E	Pacific Gas and Electric
PLC	Programmable Logic Controller
PSAT	Pump System Assessment Tool
psi	Pounds per Square Inch
psig	Pounds per Square Inch Gauge

rpm	Revolutions per Minute
SRT	Solids Residence Time
TDH	Total Dynamic Head
TSS	Total Suspended Solids
TVA	Tennessee Valley Authority
UV	Ultraviolet Light
UVT	UV transmittance
VFD	Variable Frequency Drive
W	Watt
WEF	Water Environment Federation
WEFTEC	Water Environment Federation Technical Exhibition and Conference
WERF	Water Environment Research Foundation
WMARSS	Waco Metropolitan Area Regional Sewer System
WPCP	Water Pollution Control Plant
WRF	Water Research Foundation
WSU	Washington State University
WWTP	Wastewater Treatment Plant

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1. Introduction

Chapter 1 covers:

1.1 Background

Providing reliable wastewater services and safe drinking water is a highly energy-intensive activity in the United States. A report prepared for the Electric Power Research Institute (EPRI) in 1996 estimated that by the end of that year, the energy demand for the water and wastewater industry would be approximately 75 billion kilowatt hours (kWh) per year, or about 3 percent of the electricity consumed in the U.S. (Burton 1996). The Consortium for Energy Efficiency (CEE) now estimates the annual energy usage at approximately 100 billion kWh per year (Burton 1996, extrapolated by CEE). At an average energy cost of $0.075 per kWh, the cost for providing safe drinking water and providing effective wastewater treatment is approximately $7.5 billion per year.

Energy is used throughout the wastewater treatment process; however, pumping and aeration operations are typically the largest energy users (see Figure 1-1 for a typical energy use profile for a medium sized wastewater treatment plant). Energy costs in the wastewater industry are rising due to many factors, including:

- Implementation of more stringent effluent requirements, including enhanced removal of nutrients and other emerging contaminants of concern that may, in some cases, lead to the use of more energy intensive technologies.

- Enhanced treatment of biosolids including drying/pelletizing.

- Aging wastewater collection systems that result in additional inflow and infiltration, leading to higher pumping and treatment costs.

- Increase in electricity rates.

As a consequence of these rising costs, many wastewater facilities have developed energy management strategies and implemented energy conservation measures (ECMs). Using the figures provided earlier in this section, improving the energy efficiency of America's drinking water and wastewater systems by 10 percent could save more than 10 billion kWh each year, representing a cost savings of approximately $750 million annually.

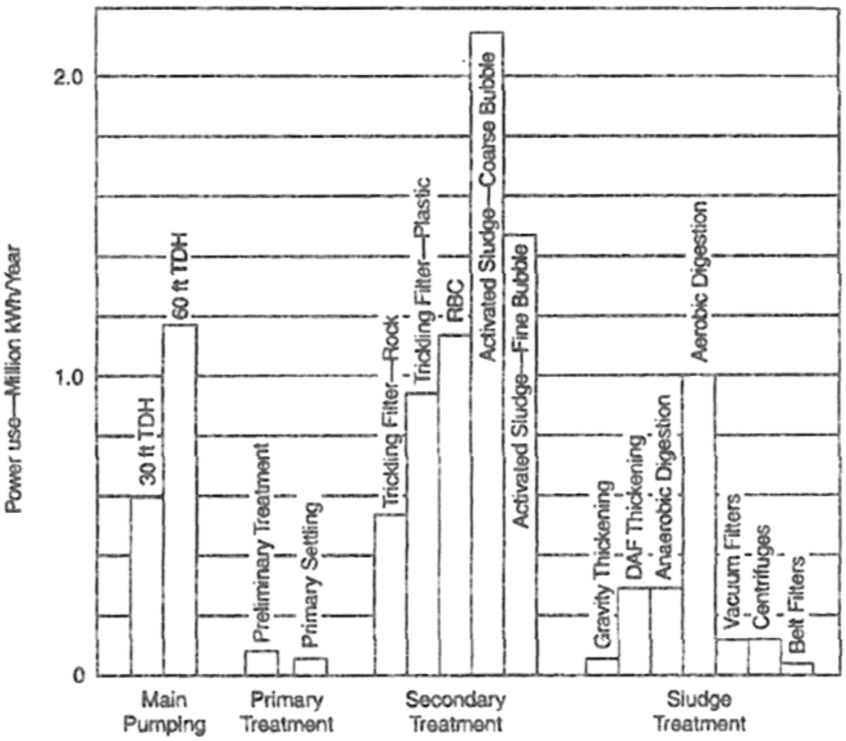

Figure 1-1. Typical Energy Use Profile for 10-mgd Secondary Treatment Processes.
Source: WEF 2009, Figure 7.1. Used with permission.
Note: energy use for various treatment processes will vary greatly from plant to plant. Advanced treatment processes may require more energy than conventional treatment processes and may not be represented in this figure.

1.2 Purpose and Audience

The purpose of this report is to encourage the implementation of ECMs at publicly owned treatment works (POTWs) by providing accurate performance and cost/benefit information for such projects. The report's focus is mainly on energy efficient equipment replacement, operational modifications, and process control enhancements that lead to improved energy efficiency and cost savings with reasonable payback periods (10 years or less). The scope of the report does not include cogeneration technologies (also known as combined heat and power, or CHP) or alternative/renewable energy technologies, as the information on these topics is being developed by EPA under separate projects. The main audiences for this report are POTW managers, owners, and operators who may be considering the implementation of ECMs and states or other agencies who may be interested in supporting such projects.

This report includes summary information on conventional ECMs that are in use in the U.S. and have a strong track record of success with respect to energy conservation; however, the focus is identification of innovative and emerging ECMs. For the purposes of this document, innovative and emerging are defined as follows:

- **Innovative**: technologies that may be established overseas and have either been tested in the U.S. as a full-scale demonstration project or installed at a U.S. wastewater treatment plant

(WWTP) for at least one year but not more than 5 years. For a technology that meets the above criteria to be considered innovative rather than emerging, independent test data showing energy savings must be presented in the literature or documented in this report in one of the facility case studies. Innovative technologies include modifications and new applications for established technologies.

- **Emerging**: technologies in the development or testing stage in the U.S. and that show potential for energy savings and relatively short payback periods, but for which independent full-scale demonstration or operating data are not yet available.

See Section 1.4 for a summary of innovative and emerging ECMs identified in this report.

This report builds upon an extensive literature review of the effectiveness and costs of ECMs for municipal wastewater treatment and solids processing. Additionally, a panel of technical experts provided input on the implementation of various ECMs. Detailed facility assessments of nine wastewater treatment facilities are provided, including detailed information on ECM implementation, energy savings, and cost data.

1.3 Report Organization

The report is organized into nine chapters and two appendices as follows:

- **Chapter 1, Introduction,** presents background, purpose, audience, and organization for the report.

- **Chapter 2, Recommended Approach to Energy Management,** presents a comprehensive approach to energy management at a wastewater treatment utility, including developing an energy management program. It lists available tools and financing resources that can help utilities implement their programs. It also lists other ECMs that should be considered by wastewater utilities but are not the focus of this report.

- **Chapter 3, Energy Conservation Measures for Pumping Systems** provides an overview of conventional ECMs related to pumping design, variable frequency drives (VFDs), and motors and refers the reader to industry standards and web links for additional guidance.

- **Chapter 4, Design and Control of Aeration Systems,** provides detailed information on ECMs related to the design of aeration systems and automated aeration control, including conventional control based on dissolved oxygen (DO) measurements and emerging control strategies. Innovative and emerging technologies for automated control of biological nitrogen removal are also discussed.

- **Chapter 5, Blower and Diffuser Technology for Aeration Systems,** describes innovative ECMs related to blower and diffuser equipment. It includes a summary of various blower types such as single-stage centrifugal, high-speed turbo, and screw compressors in addition to new diffuser technology.

- **Chapter 6, Innovative and Emerging Energy Conservation Measures for Selected Treatment Processes,** provides a discussion of ECMs for advanced technologies (UV disinfection, membranes, and anoxic zone mixing) and presents full-scale plant test results where available. For ECMs that are technically feasible and promising for the industry but where operating data are not available, manufacturer's information is provided.

- **Chapter 7 – Energy Conservation Measures for Solids Processing,** describes innovative EMS for digestion, incineration, and thermal drying and provides supporting data from case histories.

- **Chapter 8, Summary of Facility Case Studies,** describes the approach used to select the nine facility case studies and summarizes case study findings in narrative form and in summary tables.

- **Appendix A, Facility Case Studies,** contains detailed information and results from nine facility case studies.

- **Appendix B, Web Resources,** provides resources for further information. Categories of web resources include books available from online retailers; government publications through U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA); information available from nonprofit organizations, state programs, Water Environment Research Foundation (WERF) and Water Research Foundation (WaterRF); and online journals and conference proceedings.

1.4 Summary of Innovative and Emerging ECMs

Table 1-1 lists the innovative and emerging ECMs identified in this report and references the specific report section for more information. As stated in Section 1.2, independent demonstration or full-scale operating data documenting energy savings are required for a new technology to be considered "innovative;" otherwise, it was classified as "emerging" in this report. Note that this report describes many other conventional ECMs that can achieve significant energy savings.

Table 1-1. Innovative and Emerging ECMs

Chapter	ECM Name	ECM Categorization and Report Section
4 – Design and Control of Aeration Systems	Intermittent Aeration	Emerging – 4.2.1
	Dual Impeller Aerator (mechanical mixing)	Emerging – 4.2.2
	Integrated air flow control	Innovative – 4.3.1
	Automated SRT/DO Control	Innovative – 4.3.1
	Respirometry for aeration control	Emerging – 4.3.2
	Critical oxygen point control	Emerging – 4.3.2
	Off-gas monitoring and control	Emerging – 4.3.2
	Online monitoring and control of nitrification using nicotinamide adenine dinucleotide (NADH) (Symbio® process)	Emerging – 4.4
	Bioprocess Intelligent Optimization System (BIOS)	Emerging – 4.4
5- Blower and Diffuser Technology for Aeration Systems	High-speed gearless (Turbo) blowers	Innovative – 5.2
	Single-stage centrifugal blowers with inlet guide vanes and variable diffuser vanes	Innovative – 5.3
	Ultra-fine bubble diffusers	Emerging – 5.4
	New diffuser cleaning technology	Emerging – 5.5
6 – Innovative and Emerging Energy Conservation Measures for Selected Treatment Processes	Low-pressure high-output lamps for UV disinfection	Emerging – 6.2.1
	Automated channel routing for UV disinfection	Emerging – 6.2.2
	Membrane air scour alternatives	Emerging – 6.3
	Hyperbolic mixers	Innovative – 6.4.1
	Pulsed Large Bubble Mixing (e.g., Bio^{M}x)	Innovative – 6.4.2
7 –Energy Conservation Measures for Solids Processing	Vertical linear motion mixer	Innovative – 7.2
	Upgrading multiple hearth furnaces to incorporate waste heat recovery/combustion air pre-heating	Innovative – 7.3
	Solar drying	Emerging – 7.4

1.5 References

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Water Environment Federation (WEF). 2009. *Manual of Practice (MOP) No. 32: Energy Conservation in Water and Wastewater Facilities*. Prepared by the Energy Conservation in Water and Wastewater Treatment Facilities Task Force of the Water Environment Federation. McGraw Hill, New York.

USEPA. 2008. Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities. January 2008. Available online: http://www.epa.gov/waterinfrastructure/pdfs/guidebook_si_energymanagement.pdf

2. Recommended Approach to Energy Management

Chapter 2 covers:

2.1 Introduction

Equipment upgrades and operational modifications to reduce energy use should not be one-time events, but should be incorporated into a comprehensive energy review and management strategy. Section 2.2 presents EPA's recommended approach to energy management for wastewater utilities. On-line tools and financing resources are available to utilities interested in developing an energy management strategy and are described in Sections 2.3 and 2.4 respectively.

As explained in Chapter 1, the scope of this document is energy conservation measures (ECMs) related to equipment upgrades and operations strategies, with a focus on innovative and emerging technologies. These are only a subset, however, of the ECMs available to wastewater utilities. Section 2.5 lists other types of ECMs (mainly conventional) and provides references for additional information.

2.2 Recommended Approach

To optimize energy savings at a wastewater treatment plant (WWTP) now and in the future, ECMs should be evaluated and implemented as part of a comprehensive energy management program. In order to assist utilities in developing such a program, the EPA Office of Wastewater Management developed a guidebook entitled *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities* (USEPA, 2008a) http://www.epa.gov/waterinfrastructure/pdfs/guidebook_si_energymanagement.pdf, which notes that:

> *More and more utilities are realizing that a systematic approach for managing the full range of energy challenges they face is the best way to ensure that these issues are addressed on an ongoing basis in order to reduce climate impacts, save money, and remain sustainable* (EPA 2008, p. 3).

This EPA guidebook recommends the plan-do-check-act management system approach for energy conservation and management as shown in Figure 2.1. This basic approach is applicable to all utility operations and not solely to energy management activities. However, the approach has been expanded and tailored to water and wastewater utilities in a simple 9-step approach shown in the text box following Figure 2.1. These key steps for success are based on experience of water and wastewater utilities that have gone through the process of identifying and implementing ECMs. Note that in the 9-step approach, identifying ECMs does not come into play until Step 6, Devise a Plan.

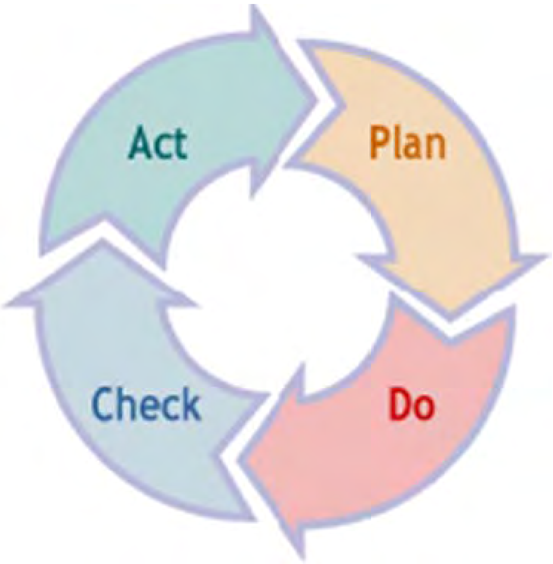

Figure 2-1. Steps in the Plan-Do-Check-Act Management Systems Approach
Source: USEPA 2008b

Recommended 9-Step Approach to Energy Management

1. **Create an Energy Sustainability Team**. Identify an energy program management team with responsibility for implementing the improvement program from start to finish. Create a core team with representatives from all aspects of operations, maintenance and management. Consider appointing an Energy Manager whose only responsibility is energy conservation (and possibly recovery) for your facility.

2. **Gather Data**. Gather data on energy use (e.g., from gas, fuel oil and electricity bills). Make this data available to the team.

3. **Benchmark Performance**. Create a baseline of energy performance against which you can measure improvements over time. You can do this using ENERGY STAR's Portfolio Manager for wastewater treatment plants, available online at http://www.energystar.gov/index.cfm?c=water.wastewater_drinking_water. Portfolio Manager has the benefit of converting all types of energy use (e.g., natural gas, fuel oil, and electricity) to a common unit so that they can be added together, and provides an estimate of greenhouse gas emissions. You may also be able to compare your utility's performance to similar utilities if you meet certain criteria.

4. **Conduct an Energy Audit**. Determine the energy use of various processes and identify opportunities for energy use reduction.

5. **Develop Goals**. Identify quantifiable energy improvement goals that complement your utility's mission, goals, and strategic direction.

6. **Devise a Plan**. Identify ***Energy Conservation Measures (ECMs)*** and develop a plan for implementing them. Start with "low hanging fruit" and focus on energy intensive operations such as aeration and pumping. Consider renewable energy options and opportunities for energy generation using alternative methods. Determine costs and payback periods for various options.

7. **Implement Improvements.** Assign responsibilities and establish deadlines. Consider alternative financing approaches. Fully engage and train your operations staff.

8. **Monitor and Measure Results.** Track performance, review progress towards energy goals, and develop a plan for maintaining energy efficient equipment. Re-evaluate your goals in light of new information and priorities, and make changes to your program as necessary.

9. **Communicate Success.** Communicate the successes of your energy management program to employees, utility management, and your community.

2.3 Tools for Energy Management

A number of tools have been developed to help wastewater utilities implement an energy management program. Data management tools that are available online include:

- The ENERGY STAR benchmarking tool *Portfolio Manager* provides a way for utilities to track their energy use as well as compare their performance to utilities with similar size and treatment goals. It is available free online at http://www.energystar.gov/index.cfm?c=water.wastewater_drinking_water. See http://www.energystar.gov/index.cfm?c=business.bus_internet_presentations for details regarding regular web-based training.

- Pump and motor management tools (see Chapter 3 for more information):

  - The Pumping System Assessment Tool (PSAT), developed by the Department of Energy (DOE) and available free online at http://www1.eere.energy.gov/industry/bestpractices/software_psat.html can help users determine the efficiency of their existing pumping systems and calculate energy and cost savings for upgrades.

  - MotorMaster+ is a motor selection and management tool, available for free online at http://www.motorsmatter.org/. It includes inventory management features, maintenance logging, efficiency analysis, savings evaluation, and energy accounting. It includes a catalog of 17,000 motors from 14 manufacturers, including NEMA Premium® efficiency motors, and motor purchasing information.

2.4 Financing Resources

Funding energy conservation projects is an important component of an energy management program, particularly due to limited resources available to utilities and the need to meet multiple environmental objectives and regulatory requirements. A number of funding options, however, are available to a utility. The California Energy Commission (CEC) notes that:

> *A shortage of internal funds need not be a "barrier" to implementing energy efficiency projects. There are plenty of financing sources, programs and options available to serve you. Real barriers are due to the lack of awareness or understanding of the:*
>
> 1) *many benefits of investing in energy efficiency projects. These benefits include energy cost savings, increased revenues, improved worker comfort and productivity, reduced maintenance cost of old, inefficient equipment, and reduction of environmental degradation and*

2) many programs for financing energy efficiency projects (CEC 2000)[1].

Capital projects for publically-owned wastewater utilities have historically received funding from grants and loans; however, third party financing (e.g., state energy offices, energy services companies) is becoming more common. In many parts of the U.S., energy performance contracting (EPC) has been used to finance energy efficiency improvements (Zobler 2009). Properly structured performance contracts can be considered in the utility's operating budget instead of as a capital expense. Examples include energy service provider-based financing and tax exempt lease-purchase agreements.

One option to streamline the audit, financing, and implementation steps of an energy management program is to hire an Energy Services Company (ESCO). ESCOs usually develop and manage EPCs, manage a wide range of tasks, and assume some or most of the technical and performance risk associated with the project. See the National Association of Energy Service Companies (NAESCO) website at http://www.naesco.org/ for more information and a list of service providers in your area. Additional guidance is available in the CEC's Handbook, "How to Hire an Energy Services Company " (CEC 2000), available online at http://www.energy.ca.gov/reports/efficiency_handbooks/400-00-001D.PDF.

In addition to the above resources, other free tools and resources are available to help wastewater utilities finance ECMs. Examples are provided below.

- The Clean Water State Revolving Fund (CWSRF), offering low interest loans (average 2.2 percent) for wastewater treatment improvements. The program is administered by individual states – A list of regional and state contacts is available online at http://www.epa.gov/owm/cwfinance/cwsrf/contacts.htm.

- Financing guidance from ENERGY STAR, available online at http://www.energystar.gov/index.cfm?c=business.bus_financing. Includes a spreadsheet-based Cash Flow Opportunity (CFO) Calculator that can help plant managers calculate simple payback as well as cost of delay, which is the lost opportunity cost if the project is delayed 12 months or more.

- Database of State Incentives for Renewables and Efficiency (DSIRE), available online at http://www.dsireusa.org/ is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council, which is funded by the U.S. Department of Energy (DOE).

- Report by the CEC titled "How to Finance Public Sector Energy Efficiency Projects" (CEC 2000), available online at http://www.energy.ca.gov/reports/efficiency_handbooks/400-00-001A.PDF. Includes a description of cost-effectiveness criteria and options for financing energy efficiency projects.

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[1] For more information, see the CEC report, *How to Finance Public Sector Energy Efficiency Projects.* January 2000. Available online at http://www.energy.ca.gov/reports/efficiency_handbooks/400-00-001A.PDF

2.5 Other ECMs and Resources

Although the focus of this document is to report on innovative and emerging equipment and operations related ECMs, other ECMs (both innovative and conventional), have been used successfully at WWTPs to save energy and associated costs, such as:

- Lighting, HVAC, and other building improvements.
- Reducing the loading to the WWTPs by:
  - Collection system improvements to reduce infiltration and inflow to reduce storm-related peaks
  - Water conservation
  - Use of equalization basins to attenuate peak flows and loadings
- Use of Supervisory Control and Data Acquisition (SCADA) software for process monitoring and operational control. SCADA has many operational benefits, including:
  - It can provide data for process modeling and energy use optimization
  - It can provide immediate detection of problems through diagnostic displays, enabling quick intervention for fast resolutions
  - It can allow operators to compensate for seasonal flow and wet weather by automatically adjusting setpoints (USEPA 2006).
- Implementing cogeneration technology to generate electricity and recoverable heat onsite using methane off-gas from anaerobic digesters.
- Implementing energy management strategies such as
  - Hiring an energy manager
  - Real-time power monitoring
  - Peak electric demand reduction
  - Submetering to identify the most energy intensive processes

Other ECMs that can offer modest improvements and may be easy for a system to implement include pump coatings to reduce friction or installing a vortex grit removal system instead of one that uses aeration.

ECMs should always be considered when a plant is facing a major 20 or 30 year upgrade. At this time, there are opportunities to reconfigure the plant for energy savings. Noted in Chapters 3 and 4 of this document but worth reiterating is the importance of properly designing for energy efficiency. Maximizing equipment (blower and pump) turndown capacity and designing for plant upgrades in stages (i.e., “right sizing”) can go a long way to meet energy efficiency goals. Another important design concept is to use hydraulic head whenever possible to reduce the need to pump. The Consortium for Energy Efficiency (CEE) has recently issued guidance on how to include energy efficiency in requests for qualifications (RFQs) and Requests for Proposals (RFPs). This guidance is available free online at http://www.cee1.org/ind/mot-sys/ww/rfp/index.php3.

Appendix B of this report provides a comprehensive list of web references for energy conservation. Other important technical references include the Water Environment Federation (WEF) *Manual of Practice* (*MOP) No. 32: Energy Conservation in Water and Wastewater Facilities* (WEF 2009) and the report by the Electric Power Research Institute (EPRI), *Quality Energy Efficiency Retrofits for Wastewater Systems* (EPRI 1998). The WEF MOP 8, *Design of Municipal Wastewater Treatment Plants* (WEF and ASCE 2010) provides guidance on designing energy efficient wastewater treatment plant components. The WERF report, *Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches*, provides recommendations on energy efficiency improvements both through optimization of current processes and through adoption of novel approaches. The report is scheduled to be published in January 2011. Lastly, the WERF report, *Best Practices for Sustainable Wastewater Treatment: Initial Case Study Incorporating European Experience and Evaluation Tool Concept* (2009), highlights European case studies related to energy efficiency in wastewater treatment.

Additional online resources for comprehensive energy management include:

- *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities* (USEPA 2008a). This document provides a step-by-step method for energy conservation based on the Plan-Do-Check-Act management approach. It is available online at: http://www.epa.gov/waterinfrastructure/pdfs/guidebook_si_energymanagement.pdf

- EPA's Wastewater Management Fact Sheet: Energy Conservation (USEPA 2006), available online at: http://www.epa.gov/owm/mtb/energycon_fasht_final.pdf. This 7-page fact sheet describes possible practices that can be implemented to conserve energy at a WWTP.

- The *Flex Your Power Best Practices Guide for Local Governments, Wastewater Sector*, available online at: http://www.fypower.org/bpg/module.html?b=institutional&m=Water_Use. This guide contains a 4-step approach to reducing energy use at a WWTP and includes links to additional online resources.

- Wisconsin Focus on Energy's *Water and Wastewater Energy Best Practice Guidebook* (Focus on Energy 2006), available online at: http://www.werf.org/AM/Template.cfm?Section=Home&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=10245. This guidebook contains benchmarking results from selected Wisconsin wastewater facilities, best practice approaches to on-going management of energy use, best practice funding and financing opportunities, and references for further opportunities in water/wastewater system energy efficiency and power demand reduction.

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3. Energy Conservation Measures for Pumping Systems

Chapter 3 covers:

3.1 Introduction

Pumping operations can be a significant energy draw at wastewater treatment plants (WWTPs), in many cases are second only to aeration. Pumps are used for many applications. At the plant headworks, they may be used to provide hydraulic head for the treatment processes. Within the plant, they are used to recycle and convey waste flows, solids, and treated effluent to and from a variety of treatment processes. Pumps are also found in remote locations in the collection system to help convey wastewater to the plant.

The overall efficiency of a pumping system, also called the “wire-to-water” efficiency, is the product of the efficiency of the pump itself, the motor, and the drive system or method of flow control employed. Pumps lose efficiency from turbulence, friction, and recirculation within the pump (WEF 2009). Another loss is incurred if the actual operating condition does not match the pump’s best efficiency point (BEP).[1] The various methods for controlling flow rate decrease system efficiency. Throttling valves to reduce the flow rate increases the pumping head, flow control valves burn head produced by the pump, recirculation expends power with no useful work, and VFDs produce a minor amount of heat. Of these methods, VFDs are the most flexible and efficient means to control flow despite the minor heat loss incurred. Table 3-1 summarizes typical pump system efficiency values – note that inefficiency in more than one component can add up quickly, resulting in a very inefficient pumping system.

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[1] BEP is the flow rate (typically in gallons per minute or cubic meters per day) and head (in feet or meters) that gives the maximum efficiency on a pump curve. For basic information on pump system design, see the WEF Manual of Practice No. 32, *Energy Conservation in Water and Wastewater Facilities* (WEF 2009), or the six-part series, Understanding Pump System Fundamentals for an Energy Efficient World (Pump-Zone 2008 and 2009), available online at http://www.pump-zone.com/pumps/pumps/understanding-pump-fundamentals-for-an-energy-efficient-world.html

Table 3-1. Pump System Efficiency

Pump System Component	Efficiency			
	Range Low		Avg	High
Pump	30 – 85 %	30 %	60 %	75 %[1]
Flow Control[2]	20 – 98 %	20 %	60 %	98 %
Motor[3]	85 – 95 %	85 %	90 %	95 %
Efficiency of System		5 %	32 %	80 %

1. For pumping wastewater. Pump system efficiencies for clean water can be higher.
2. Represents throttling, pump control valves, recirculation and VFDs.
3. Represents nameplate efficiency and varies by horsepower. See Section 3.4 for more information

Inefficiencies in pumping often come from a mismatch between the pump and the system it serves due to improper pump selection, changes in operating conditions, or the expectation that the pump will operate over a wide range of conditions. Signs of an inefficient pumping system include:

- Highly or frequently throttled control valves
- Bypass line (recirculation) flow control
- Frequent on/off cycling
- Cavitation noise at the pump or elsewhere in the system
- A hot running motor
- A pump system with no means of measuring flow, pressure, or power consumption
- Inability to produce maximum design flow

For more information, refer to the Pump System Basic Assessment Guide (Pump Systems Matter™ 2010), available online at http://www.pumpsystemsmatter.org/content_detail.aspx?id=3334.

The literature provides several examples of plants reducing pumping energy by as much as 50 percent through pump system improvements (Focus on Energy 2006). Energy savings result from lowering of pumping capacity to better match system demands, replacing inefficient pumps, selecting more efficient motors, and installing variable speed controllers. Generally speaking, energy conservation measures (ECMs) for pumping are conventional and do not represent an area where recent technology innovation has played a part in improving energy conservation and efficiency. Pumping ECMs are, however, still extremely important to reducing and optimizing energy use at wastewater treatment plants. This chapter provides an overview of conventional ECMs related to pumping design, variable frequency drives (VFDs), and motors and refers the reader to industry standards and web links for additional guidance.

Wastewater utilities should consider implementing pumping ECMs as part of a long-term pump testing and maintenance program. Pumps should be tested every two to three years to ensure that they are operating efficiently. Utilities should test for flow, head, and power consumption and then calculate efficiency for each pump system. If overall system efficiency is low (less than 60 or 70 percent for centrifugal wastewater pumps, less than 72 percent for clean water pumps[2]), a more detailed evaluation is warranted. This type of program can give the plant early warning when pump components are failing and can prevent catastrophic failures. It is important that all components be evaluated and addressed

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[2] E-mail communication from Ken Henderson, September 8, 2010.

holistically so that the entire system is energy efficient. State and local requirements for redundancy (e.g., the common requirement that a pump station can pump peak flows with the largest pump out of service) and safety factors may limit available efficiencies in some cases.

Several tools are available free online to assist wastewater utilities in developing a pump testing and maintenance program. Pump Systems Matter^{TM}, an education program conceived by the Hydraulic Institute, provides technical references, downloadable tools, tip sheets, and white papers on their website at http://www.pumpsystemsmatter.org/default.aspx. The Department of Energy (DOE) has developed and supports the Pump System Assessment Tool (PSAT), available free online at http://www1.eere.energy.gov/industry/bestpractices/software_psat.html, to help users determine the efficiency of their existing pumping systems and calculate energy and cost savings for upgrades. The Water Environment Federation (WEF) provides guidance on life cycle costing, operation and maintenance practices, and measurement equipment in their MOP No. 32 (WEF 2009).

3.2 Pumping System Design

Appropriate sizing of pumps is key to efficient operation of wastewater treatment plants. Pumps sized for peak flow conditions that occur infrequently or, worse, in the future towards the end of the pump's service life operate the majority of the time at a reduced flow that is below their BEP. Peak flow is typically several times greater than average daily flow and can be an order of magnitude different than minimum flow, especially for small systems or systems with significant inflow and infiltration (I&I). In some systems, these projected future flows are never reached during the design life of the pump.

For existing treatment plants, utilities should evaluate the operation of existing pumps and identify opportunities for energy reduction. A good starting point is to determine the efficiency of existing pumping systems, focusing first on pumps that operate for the most hours and have potential problems as identified by the bullet list in Section 3.1 (presence of bypass lines, throttled valves, etc.). Plants should collect performance information on the flow rate, pressure, and delivered power to the pumps. Field measurements may be necessary if the plant does not regularly record this information. Pump and system curves can then be constructed to determine the actual operating points of the existing system. Operating points more than 10 percent different than the BEP signal room for improvement. Detailed guidance on pump system assessment is provided in the Pump Systems Matter publication, *Pump System Basic Assessment Guide*, available online at http://www.pumpsystemsmatter.org/content_detail.aspx?id=3334

To improve efficiency, utilities should consider replacing or augmenting large capacity pumps that operate intermittently with smaller capacity pumps that will operate for longer periods and closer to their BEP. When replacing a pump with a smaller unit, both the horsepower and efficiency change. A quick way to estimate the annual energy cost savings is to approximate cost before and after the improvement and determine the difference using the following equation:

$$\text{Annual Energy Savings (\$)} = [hp_1 \times L_1 \times 0.746 \times hr \times E_1 \times C] - [hp_2 \times L_2 \times 0.746 \times hr \times E_2 \times C] \qquad \textit{Eq. 3-1}$$

Where:

hp_1 = horsepower output for the larger capacity pump

hp_2 = horsepower output for the smaller capacity pump

L_1 = load factor of larger capacity pump (percentage of full load / 100 - determined from pump curve)

L_2 = load factor of smaller capacity pump (percentage of full load / 100 - determined from pump curve)
hr = annual operating hours
C = energy (electric power) rate ($ / kWh)
E_1 = efficiency of the larger capacity pump
E_2 = efficiency of the smaller capacity pump

See Example 3-1 for how the Town of Trumbull was able to save more than $1,500 per year by adding a small pump to one of its existing sewage pumping stations. When applied correctly, replacement of standard drives with VFDs can also yield significant improvements (see Section 3.3 for additional discussion).

Example 3-1 Town of Trumbull, CT, Improves Efficiency at Reservoir Avenue Pump Station

BACKGROUND: Wastewater from the Town of Trumbull, in southwestern CT, is collected and conveyed to a WWTP in Bridgeport via ten sewage pump stations. One of these, the Reservoir Avenue Pump station, consisting of two 40-hp direct-drive pumps designed to handle an average daily flow of 236 gallons per minute (gpm). Each pump was operated at a reduced speed of 1320 rpm at 50.3 feet of total dynamic head (TDH) with a duty point of approximately 850 gpm. A bubbler-type level control system was used to turn the pumps off and on. One pump can handle the entire peak inflow (usually < 800 gpm) with the second pump operating only during peak flow conditions.

ENERGY EFFICIENCY UPGRADES: To reduce energy use, the town installed a new 10-hp pump and modified the system control scheme. The new pump handles the same volume as the original pump but operates for a longer time between standby periods. In addition, the speed control was eliminated and the original pumps, when used, are run at full speed of 1750 rpm. This allowed the impellers of the original pumps to be trimmed from 11.25 inches in diameter to 10 inches. The original pumps are used for infrequent peak flows that cannot be handled by the new 10 hp pump. Under normal operating conditions, the operating point for the new pump is 450 gpm at 40.7 TDH compared to 850 gpm at 50.3 feet of head for the whole system. Improvements were made to the lighting and control systems resulting in additional energy savings.

ENERGY SAVINGS: Annual energy savings were 17, 643 kWh from modifying the pumping system. Total energy savings were 31,875 kWh/yr, or approximately $2600/yr based on a rate of 8¢/kWh. Total implementation costs were $12,000, resulting in a simple payback of 4.6 years.

FOR MORE INFORMATION:
http://www1.eere.energy.gov/industry/bestpractices/case_study_sewage_pump.html (USDOE 2005b)

For greenfield plants and/or new pump stations, utilities should consider and plan for staging upgrades of treatment capacity as part of the design process. For example, multiple pumps can be specified to meet a future design flow instead of one large pump so that individual pumps can be installed as needed, say at year zero, year ten, and year twenty. The State of Wisconsin's Focus on

Energy best practices guidebook (Focus on Energy 2006) estimates that staging of treatment capacity can result in energy savings between 10 and 30 percent of total energy consumed by a unit process.

3.3 Motors

The cost of running electric motors can be the largest fraction of a plant's total operating costs. WEF estimates that electric motors make up 90 percent of the electric energy consumption of a typical wastewater treatment plant (WEF 2009). Inefficient motors, operation outside of optimal loading conditions, and mechanical or electrical problems with the motor itself can lead to wasted energy at the plant and are opportunities for savings.

The percent energy savings resulting from replacing older motors with premium motors is modest, typically between 4 and 8 percent (NEMA Standard MG-1. 2006). Savings can be higher when energy audits reveal that existing motors achieve very low efficiencies, or when existing motors are oversized and/or under loaded. Many plants have coupled motor replacements with upgrades from fixed speed to variable speed drives for significantly higher energy savings.

In general, upgrading motors is a conventional ECM that has been practiced at wastewater treatment plants for some time. Because the main focus of this report is innovative rather than conventional technologies, this section contains only a brief overview of material, and directs the reader to other publically available websites and references for detailed information. Specifically, Section 3.3.1 describes motor efficiency and summarizes current motor efficiency standards, and Section 3.3.2 provides links to motor management tools and software. The exception to conventional practices is the emergence of new, ultra-efficiency motors, which are described in Section 3.3.3.

In addition to tools and references identified in subsequent sections, the reader is referred to the following websites for technical information on motors:

- The U.S. DOE provides extensive information as part of their Motor Challenges Program. Publications include downloadable books, tip sheets, and fact sheets on technical and economic topics related to motors. See http://www1.eere.energy.gov/industry/bestpractices/techpubs_motors.html for a list of published material and relevant web links.

- The Consortium for Energy Efficiency (CEE) provides technical material, links, and fact sheets under its Motors and Motor Systems Industrial Program (http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3).

3.3.1 Motor Efficiency and Efficiency Standards

Motor efficiency is a measure of mechanical power output compared to electrical power input, expressed as a percentage.

$$\text{Motor efficiency} = P_m/P_e \qquad \text{Eq. 3-2}$$

Where:
P_m = mechanical power output of the motor in Watts
P_e = electrical power input to the motor in Watts (WEF 2009)

No motor is 100 percent efficient – all motors experience some power loss due to friction, electrical resistance losses, magnetic core losses, and stray load losses. Smaller motors generally experience higher losses compared to larger motors.

The United States Congress, in the Energy Policy Act (EPACT) of 1992, set minimum efficiency standards for various types of electric motors manufactured in or imported to the United States. Minimum nominal, full-load efficiencies typically range from 80 to 95 percent depending on size (i.e., horsepower) and other characteristics. Motors manufactured since 1997 were required to comply with EPACT standards and to be labeled with a certified efficiency value.

The National Electrical Manufacturers Association (NEMA) premium efficiency standard has existed since 2001 (NEMA 2006) as a voluntary industry standard and has been widely adopted due to its power (and thus cost) savings over EPACT 1992 compliance standards. The 2007 Energy Act raised efficiency standards of motors to NEMA premium efficiency levels and set new standards for motors not covered by previous legislation. The 2007 act, which comes into force in December 2010, is summarized online at http://www.motorsmatter.org/resources/gen_legislation.html.

Submersible motors are commonly used in wastewater treatment plants. They serve specialized applications in environments that are not suited for NEMA motors. There is currently no efficiency standard for submersible motors and their efficiency is less than NEMA motors. Additionally, their power factor is usually lower. Their selection is usually driven by the application, though some applications have alternatives that use NEMA motors. Efficiency should be considered in the evaluation of alternatives in these applications as it affects the life-cycle cost used in the selection process.

Operating efficiency in the field is usually less than the nominal, full-load efficiency identified by the motor manufacturer. One reason for this is the operating load. As a rule of thumb, most motors are designed to operate at between 50 and 100 percent of their rated load, with maximum efficiency occurring at about 75 percent of maximum load. For example, a motor rated for 20 horsepower (hp) should operate between 10 and 20 hp and would have its best efficiency around 15 hp. Larger motors can operate with reasonable efficiency at loads down to the 25 percent range (USDOE 1996). Motors operated outside of the optimal loading lose efficiency. Other factors that reduce efficiency in the field include power quality (I.e., proper voltage, amps, and frequency) and temperature. Motors that have been rewound typically are less efficient compared to the original motor.

Accurately determining the efficiency of motors in service at a plant is challenging because there is no reliable field instrument for measuring mechanical output power. Several methods are available, however, to approximate motor efficiency. For a summary, see the U.S. Department of Energy fact sheet on the subject (USDOE 2005), available online at http://www1.eere.energy.gov/industry/bestpractices/pdfs/estimate_motor_efficiency_motor_systemts2.pdf. One method is to use field measurements and technical data in the MotorMaster+ software tool to estimate efficiency. Section 3.3.2 provides additional information on this tool.

3.3.2 Motor Management Programs

Wastewater utilities should consider purchasing new energy efficient premium motors instead of rewinding older units when replacing equipment and when making major improvements at the plant (see the text box in this section for additional recommendations). Motor replacement is best done as part of a plant-wide motor management program. A first step in program development is to create an inventory of all motors at the plant. The inventory should contain as much information as possible including manufacturers' specifications, nameplate information, and field measurements such as voltage, amperage, power factor, and operating speed under typical operating conditions. Following the data gathering phase, plant managers should conduct a motor replacement analysis to determine which motors to replace now and which are reasonably efficient and can be replaced in the future or at time of failure.

When Should Plants Consider Buying New Energy Efficient Motors?

- For new installations
- When purchasing new equipment packages
- When making major modifications to the plant
- Instead of rewinding older, standard efficiency units
- To replace oversized and/or underloaded motors
- As part of a preventive maintenance or energy conservation program

Source: Motor Challenge Fact Sheet: Buying an Energy Efficiency Electric Motor. Available online at http://www1.eere.energy.gov/industry/bestpractices/pdfs/mc-0382.pdf

A key input to any motor replacement analysis is economics. A simple approach is to calculate the annual energy savings of the new motor compared to the old unit and determine the payback period in years (in other words, when will the cumulative energy savings exceed the initial costs). The following simple equation can be used to determine annual energy savings:

$$\text{Annual Energy Savings (\$)} = hp \times L \times 0.746 \times hr \times C \times (E_p - E_e) \qquad \text{Eq. 3-3}$$

Where:

hp = horsepower output of motor
L = load factor (percentage of full load / 100)
0.746 = conversion from horsepower to kW units
hr = annual operating hours
C = energy (electric power) rate ($/kWh)
E_e = existing motor efficiency as a percentage
E_p = premium motor efficiency as a percentage

Simple payback in years can then be calculated as the new motor cost (capital plus installation) divided by the annual energy savings. When comparing buying a premium motor instead of rewinding an existing one, the cost of rewinding the existing motor should be subtracted from the motor cost. Any cash rebate from your local electric utility or state energy agency should also be subtracted from the cost of the new motor. When replacing pumps, motors, or control systems, upgrading the electrical service, wiring, transformers, and other components of the electrical system should be considered in calculating energy savings and life cycle costs. Utilities should also consider the importance of reliability and environmental factors when making motor replacement decisions. More robust economic analyses such as net present value life cycle cost analysis should be considered, especially for large expenditures.

The ENERGY STAR® Cash Flow Opportunity (CFO) calculator is an easy-to-use spreadsheet tool that can help plant managers calculate simple payback as well as cost of delay, which is the lost opportunity cost if the project is delayed twelve months or more. The last sheet of the workbook provides a summary that can be given to senior managers and decision makers to help convince them of the financial soundness of energy efficiency upgrades. The CFO calculator and other financial tools are available for free download at http://www.energystar.gov/index.cfm?c=assess_value.financial_tools.

The task of motor inventory management and replacement analysis is made significantly easier by publically available software tools. Developed by the DOE Industrial Technologies Program, MotorMaster+ is a motor selection and management tool, available free online at http://www.motorsmatter.org/. It includes inventory management features, maintenance logging, efficiency analysis, savings evaluation, and energy accounting. It includes a catalog of 17,000 motors from 14 manufacturers, including NEMA Premium® efficiency motors, and motor purchasing information. In addition to MotorMaster+ software, the sponsors of the Motor Decisions Matter campaign developed a spreadsheet tool to assist plant managers with motor replacement/repair decision making. The tool is titled the “1*2*3 Approach to Motor Management” and is available for free download at http://www.motorsmatter.org/tools/123approach.html.

3.3.3 Innovative and Emerging Technologies

Siemens Energy and Automation in cooperation with the Copper Development Association has developed “ultra-efficient” copper rotor squirrel cage-type induction AC motors. These motors exceed NEMA premium full-load efficiency standards by up to 1.4 percent; however, they are only currently available in outputs up to 20 hp. In addition to using high-conductivity copper rotors in place of aluminum, the new motors have the following efficiency improvements:

- Optimized rotor and stator design
- Low-friction bearings
- Improved cooling system
- Polyurea-based grease
- Dynamically balanced rotors
- Precision-machined mating surfaces for reduced vibration

The motor’s insulation is designed to be compatible with VFD’s (USDOE 2008).

The U.S. Department of Energy (USDOE), in cooperation with Baldor Electric Company and other private partners, is developing a new grade of Ultra-Efficient and Power-Dense Electric Motors, with the goal of a 15 percent reduction in motor energy loss over NEMA premium motors. For example, if a

NEMA premium motor with particular characteristics and output horsepower was 92 percent efficient and thus had 8 percent loss, this new grade of motor would reduce loss by 0.15* 8% = 1.2 percent, for a new overall efficiency of 93.2 percent. The new grade of motor will also be 30 percent smaller in volume and 30 percent lower in weight, leading to decreased motor cost due to lower materials costs (USDOE 2009). For more information, see DOE's website at http://www1.eere.energy.gov/industry/intensiveprocesses/pdfs/electric_motors.pdf .

3.4 Power Factor

Power factor is important because customers whose loads have low power factor require greater generation capacity than what is actually metered. This imposes a cost on the electric utility that is not otherwise recovered by the energy and demand charges. There are two types of power that make up the total or *apparent* power supplied by the electric utility. Their relationship is shown in Figure 3-1. The first is the *active* power. Measured in kW, it is the power used by the equipment to produce work. The second is the *reactive* power. This is the power used to create the magnetic field necessary for induction devices to operate. It is measured in kVARs.

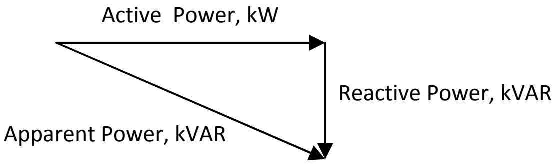

Figure 3-1. Vector Relationship of AC Power

Power factor is the ratio of the *active* power to the *apparent* power. The power factor of fully loaded induction motors ranges from 80 to 90 percent depending on the type of motor and the motor's speed. Power factor deteriorates as the load on the motor decreases. Other electrical devices such as space heaters and older fluorescent or high discharge lamps also have poor power factor. Treatment plants have several motors, numerous lamps, and often electric heaters, which, combined, lowers the facility's overall power factor.

Power factor may be leading or lagging. Voltage and current waveforms are in phase in a resistive AC circuit. However, reactive loads, such as induction motors, store energy in their magnetic fields. When this energy gets released back to the circuit it pushes the current and voltage waveforms out of phase. The current waveform then lags behind the voltage waveform. When the load is capacitive, the opposite occurs, and the current waveform leads the voltage waveform.

Improving power factor is beneficial as it improves voltage, decreases system losses, frees capacity to the system, and decreases power costs where fees for poor power factor are billed. Power factor can be improved by reducing the reactive power component of the circuit. Adding capacitors to an induction motor is perhaps the most cost effective means to correct power factor as they provide reactive power. Synchronous motors are an alternative to capacitors for power factor correction. Synchronous motors can be run at lagging, unity, or leading power factor by controlling their field excitation. When the field excitation voltage is decreased, the motor runs in lagging power factor. This condition is called under-excitation. When the field excitation voltage is made equal to the rated voltage, the motor runs at unity power factor. The motor runs at leading power factor when the field excitation voltage is increased above the rated voltage. This condition is called over-excitation. When over-excited, they can provide system power factor correction. Synchronous motors above 300 hp and below 1200 rpm are often less expensive than a comparable induction motor (Thumann and Dunning, 2008).

The feasibility of adding capacitors depends on whether the electric utility charges for low power factor. Corrective measures are infrequently installed since many electric utilities do not charge small customers for poor power factor but rather price it into the electrical rates as a cost of business. A cost evaluation is needed to determine the type of correction equipment to use. The evaluation should include motor type, motor starter, exciter (for synchronous motors), capacitors and switching devices if needed, efficiency, and power factor fees (IEEE 1990). Manufacturers should be consulted before installing capacitors to reduced voltage solid-state starters and VFDs as there can be problems if they are not properly located and applied.

3.5 Variable Frequency Drives (VFDs)

VFDs are used to vary the speed of a pump to match the flow conditions. They control the speed of a motor by varying the frequency of the power delivered to the motor. The result is a close match of the electrical power input to the pump with the hydraulic power needed to pump the water. As illustrated by the red areas in Figure 3-2, other methods used to control flow expend more electrical power than the hydraulic power needed. Throttling valves decrease flow by moving the operating point on the pump’s curve to the left. This is achieved by artificially increasing the head against which the pump works. Bypass control returns a portion of the water pumped back to the suction side of the pump, which wastes a portion of the energy used to recirculate the water with no useful work. Stop/start control is indicative of an over-sized pump that pulses to “match” flow. While this achieves the same amount of work as a smaller pump operating continuously, it does so at a higher power (kW) demand. VFDs are a proven technology that is more efficient than these control methods and are ideally suited in situations where the flow rate is highly variable.

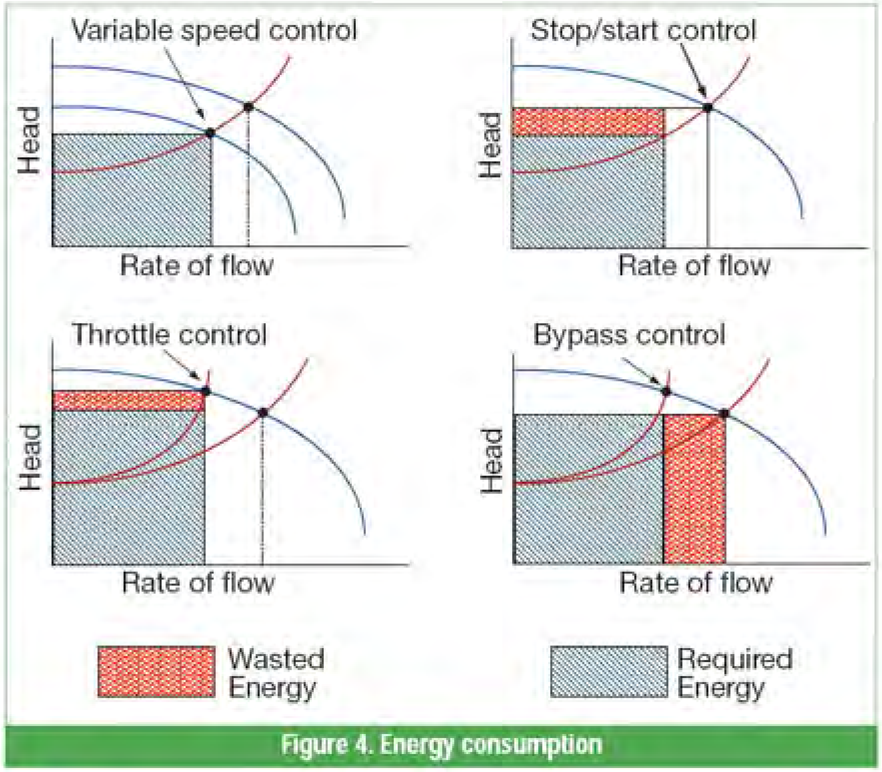

Figure 3-2. Wasted Energy in Alternative Control Schemes Compared to Variable Frequency Drives
Source: provided courtesy of Pump Systems Matter™ and the Hydraulic Institute, Parsippany, NJ
www.PumpSystemsMatter.org

3.5.1 Energy Savings

VFDs have been used by many wastewater utilities to conserve energy and reduce costs. A literature review found numerous success stories with energy savings ranging from 70,000 kWh/yr for smaller WWTPs (i.e. average daily flow of 7-10 mgd) to 2,800,000 kWh/yr for larger WWTPs (i.e. average daily flow of 80 mgd) (EPRI 1998; Efficiency Partnership 2009; USDOE 2005c). VFDs are now more available and affordable, and paybacks for VFDs range from six months to five years depending on the existing level of control and annual hours of operation (Focus on Energy, 2006).

To approximate the potential energy savings, utilities should develop a curve of actual flow in hourly increments during a day. Using the curve, energy consumed by a constant speed motor and throttling valve can be estimated and compared to energy consumed by a VFD system that match the hourly flow rate to power used.

3.5.2 Applications

VFDs can be installed at remote collection system pumping stations, at lift stations, on blowers, and on oxidation ditch aeration rotor drives. A common application of VFDs is for pumps that experience a large variation in diurnal flow, such as at wastewater pumping stations. However, if VFDs are not selected and applied correctly, they can waste energy. Operating below 75% for full load, VFDs can have very low efficiencies. In selecting a VFD, information should be obtained from the VFD manufacture showing the efficiency at different turn down rates.

VFDs are not applicable in all situations. VFDs may not be effective when a large static head must be overcome or where there is little variation in the flow rate (WEF 2009). Additionally, some motors are not suited for use with VFDs. When the drive reduces the frequency to the motor the voltage decreases. However, the amperage increases which can generate heat. More commonly, voltage spikes that develop from the non-sinusoidal wave form produced by VFDs can damage motor insulation if not properly filtered. Conductors within the motor should be properly insulated and the motors should be capable of dissipating the heat.

3.5.3 VFD Strategies for Wastewater Pumping Stations

VFDs can be costly to install in an existing pump station and require space in the electrical room. The range of flow, number of pumps, and hours of operation also need to be considered when evaluating the implementation of VFD control. Although equipping all pumps with VFDs provides maximum operational flexibility, this can be costly and, in retrofit projects, not always feasible. Often the rewards of having VFDs can be achieved at less cost with half or as few as one pump being equipped.

One VFD can be feasible in small stations where two pumps are run in duty/standby mode because the duty pump runs the majority of the time, reaping the savings with the VFD. In situations where both pumps are run in the lead/lag mode to cover the range of flow encountered it is usually beneficial to have both pumps equipped with VFDs. This allows the pumps to alternate the lead position, which balances their hours, and it simplifies the controls as both pumps can be operated in the same manner.

In the case of larger stations with three or more pumps of the same size operated in lead/lag mode, the number of VFDs needed depends on the range of flow and the space available. If one pump runs the majority of the time with infrequent assistance from the others, then one VFD would likely suffice. However, if the second pump operates frequently, then at least two VFDs are recommended. In the two-VFD scenario, when an infrequent peak flow is needed, the third constant-speed pump can provide the base load while both VFD-driven pumps adjust to meet the demand. Depending on the size of the pumps, it could be more beneficial to install a smaller pump instead and run it with a VFD. This maximizes the efficiency of the system because when the large pumps are run, they are near their BEP without the heat losses generated by VFDs.

Large stations with multiple pumps of different sizes need to be evaluated on a case-by-case basis. Typically, VFDs are placed on the smaller pumps so that they can be used to fill in the peaks before another large pump is turned on. The controls are simple and sequencing is easy to maintain when a pump is down for service. Additionally, the cost is lower as small VFDs are less expensive than large ones.

It is important to run each pump periodically. Bearings in pumps that sit too long can be damaged from brinnelling and stuffing boxes can dry out and leak. It is beneficial from an O&M standpoint to exercise equipped at intervals recommended by the equipment manufacturer to ensure their reliability when called upon. Energy-wise, it is best to do this during off-peak electric hours such as morning or on weekends.

3.6 References

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4. Design and Control of Aeration Systems

Chapter 4 covers:

4.1 Introduction

The aeration process can account for the largest energy demand of any operation at the facility. Although the demand is site-specific and can vary widely from plant to plant, the fraction of energy used for aeration ranges from 25 to as much as 60 percent of total plant energy use (WEF 2009). Because of the high energy use associated with aeration, energy savings can be gained by designing and operating aeration systems to match, as closely as possible, the actual oxygen demands of the process. Through improved understanding of the oxygen demands of a particular wastewater and how those demands fluctuate with time of day and season, wastewater treatment plants (WWTPs) can build flexibility into their aeration systems so that operation can address real-time demands efficiently.

Section 4.2 in this chapter describes energy conservation measures (ECMs) for aeration systems. Section 4.3 follows with a discussion of aeration control, including conventional control based on dissolved oxygen (DO) measurements and innovative control strategies. Innovative and emerging technologies for control of biological nitrogen removal are discussed in Section 4.4. See Chapter 5 for innovative ECMs related to new commercially available blower and diffuser equipment.

4.2 ECMs for Aeration Systems

Wastewater is aerated by either bubbling air or high-purity oxygen through it or by mixing it so that oxygen is transferred through contact with the atmosphere. The two most common types of aeration systems are diffused aeration and mechanical surface aeration. Hybrid systems that combine diffused air and mechanical mixing include jet systems, U-tube aerators, and submerged turbine aerators. For more information on aeration system components and configuration, see Chapter 14 of Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants (WEF and ASCE 2010), Chapter 2 of MOP No. 32, Energy Conservation in Water and Wastewater Facilities (WEF 2009), or the EPA Design Manual for Fine Pore Aeration Systems (USEPA 1989).

Energy efficiency of an aeration system depends on several key factors, including:

- ***Diffuser flux rate:*** The rate of airflow per unit surface area of the diffuser (e.g., in standard cubic feet per minute per square foot of diffuser area). A minimum rate is typically required to uniformly distribute air to diffusers.

- ***Oxygen transfer rate (OTR)****:* The mass of oxygen dissolved in the mixed liquor per unit of time (e.g., in lbs/hr). The OTR for clean water as determined by the manufacturer following standard test protocols is the standard OTR, or SOTR. The oxygen transfer rate under field conditions is designated by the subscript *f* (OTR_f).

- ***Oxygen transfer efficiency (OTE):*** The mass of oxygen transferred to the liquid from the mass of oxygen supplied, expressed as a percentage. Similar to OTR, the transfer efficiency as determined by the manufacturer for clean water at a given gas flow rate and power input is called the standard oxygen transfer efficiency (SOTE). The transfer efficiency for field conditions is often designated by the subscript *f* (OTE_f).

- ***Alpha:*** The ratio of oxygen transfer efficiency in wastewater versus clean water.

- ***Mixed Liquor DO Concentration***: Although not strictly a design factor, one of the most significant and controllable factors affecting aeration energy efficiency is mixed liquor dissolved oxygen concentration. The closer the dissolved oxygen concentration is to saturation, the greater the resistance for dissolved oxygen dissolution and the lower the OTE. See Section 4.3 for guidance on determining the target mixed liquor DO concentration and implementing automated control.

Designers try to maximize the OTE_f under most operating conditions so that the plant will operate efficiently. OTE_f depends on a number of external factors including water temperature and site elevation. It decreases with increasing concentration of solids and surfactants. Within the basin itself, it increases from the inlet to the outlet as organic material is biodegraded. It increases with decreasing flux rate and is generally higher for deeper basins. Although commercially available aeration equipment has a wide variety of SOTEs, fine-pore diffusers have the highest efficiency compared to any other diffused air or mechanical aeration system.

There are many different basin configurations and a variety of aeration equipment that can be used to improve aeration efficiency. No single approach is right for every system. Life-cycle cost analysis should always be conducted to ensure that ECMs are appropriately factored into the decision making process.

Overall design of aeration systems and considerations for energy efficiency are well covered in existing literature (USEPA 1989, WEF and ASCE 2010, WEF 2009). The purpose of this section is to provide an overview of ECMs that can be incorporated into a new design or as part of a retrofit project to an existing basin. Sections 4.2.1 and 4.2.2 provide ECMs for diffused air systems and mechanical aeration, respectively.

4.2.1 ECMs for Diffused Aeration Systems

Diffused aeration systems introduce air below the wastewater surface. Major components of diffused aeration systems are the air intake system, blowers, the air piping system, diffusers, and controls. Air intake systems are typically equipped with filters to protect blowers and diffusers from airborne particulates. Blowers are essentially low pressure, high volume air compressors. Common types are positive displacement and centrifugal (see Chapter 5 for detailed discussion of blower equipment). Air piping systems deliver air from blowers to the diffusers. Headloss within the air piping system is typically a small portion (< 10%) of total system pressure (WEF and ASCE 2010). Aeration control systems are key to keeping the aeration system operating efficiently over the system's entire operating range. Note that control systems are discussed in Section 4.3.

Conventional ECMs for aeration systems include (1) proper sizing of blowers, (2) dedicated blowers for channel aeration, and (3) configuration of diffusers within a basin. A forth method emerging is intermittent aeration. Each is discussed separately below.

Proper Sizing of Blowers

There are many blower configurations that can operate efficiently, especially in larger plants. In general, blower systems should be designed for a minimum 5:1 turndown ratio, meaning that a system should be capable of operating at 1/5th of its full capacity (Cantwell et al. 2009). Some common arrangements that provide for efficient blower operation with back-up are to design for four blowers at 33 percent each of design flow, or two blowers at 25 percent each of design flow plus two blowers at 50 percent each of design flow.

Many plants have more capacity in their aeration system than needed because the population growth projected during the design phase (a factor in designing treatment plant capacity for a 20year future projected loading) has not yet occurred or will never occur. In other cases, changes in local industries or aggressive pre-treatment programs may have resulted in decreased organic loading and reduced aeration requirements. In these situations and others, it may not be possible for the existing aeration system to operate efficiently to meet the existing load. Using an aeration system to supply parasitic loads, such as channel air and air lift pumps, further increases the design capacity of the system. These applications, which typically require lower pressure, can often be more efficiently served by a smaller blower. Determining the actual process air requirements without parasitic loads enables a more efficient system to be designed.

The energy savings associated with retrofits to increase blower turndown depends on many factors including where the plant is within its design life and how closely projected growth matched actual growth. If the original design was oversized, energy savings can be significant. Several methods are available to reduce energy use in these situations, such as replacing larger blowers with one or more smaller units or installing variable frequency drives (VFDs). Inlet throttling may be applicable, depending on the blower type, to modulate the air flow rate of existing blowers. Example 4-1 shows how one utility was able to reduce energy use by approximately 1,000,000 kWh/yr by installing smaller blowers.

Example 4-1: City of Waukesha, Replaced Existing Blowers with Smaller Units to Improve Efficiency

BACKGROUND: The City of Waukesha is a medium-sized community of approximately 70,000 residents located 15 miles west of Milwaukee, WI. The City's conventional activated sludge wastewater treatment facility treats between 10 and 12 million gallons per day (mgd) and has a design flow of 18.5 mgd. The plant chemically removes phosphorus by adding ferric chloride in a tertiary treatment process prior to filtration, UV disinfection, and discharge to the Fox River.

The plant's six aeration basins were equipped with ceramic fine-bubble diffusers. Five 700 hp, inlet throttled centrifugal blowers provided air to the aeration system. Since the original plant design, the City began aggressively enforcing their industrial pretreatment program. In addition, some industries closed or moved out. The combined effect was a significant reduction in organic loading to the plant. With just one blower running, dissolved oxygen concentrations were high, between 4.5 and 8.0 milligrams per liter (mg/L). The facility could not achieve sufficient turndown of the blower prior to implementing energy efficiency improvements.

ENERGY EFFICIENCY UPGRADES: In July 2003, the plant replaced two 700 hp blowers with two 350 hp blowers so that they could operate at a lower DO concentration. They also upgraded their DO probes with new membrane units and replaced the existing single loop PID DO control system with an integrated direct flow control system with most open valve control (MOV) logic. During the upgrade, they took three of the six basins out of service.

ENERGY SAVINGS: Total energy savings from the blower replacement were substantial at approximately 1,000,000 kWh per year (approximately 9 % of total plant energy use) with an associated annual energy cost savings of more than $65,000. Total implementation costs were $approximately $200,000, resulting in a simple payback of about three years.

SOURCE: Cantwell et al. 2009

Dedicated Blowers for Channel Aeration or Air Lift Pumps

The air for channel aeration or air lift pumps processes is often tapped from the main aeration system air header. However, particularly for channel aeration, the pressure required is significantly lower than the main aeration system pressure. This excess pressure is usually reduced by throttling the air through a flow control valve. By providing a small blower rated at the specific pressure required for the service, the energy requirement can be reduced. This approach is usually viable only for large plants as the payback period to implement it in smaller plants is usually too long to make the change feasible.

Configuration of Diffusers

The configuration of diffusers within an aeration basin should allow for maximum operational flexibility to respond to varied conditions and treatment goals. It is also important that their layout promotes plug flow within the basin and reduces short-circuiting. A common approach is to use tapered aeration to reduce the rate of oxygen supply along the length of a basin (WEF and ASCE 2010). It can be accomplished by placing more diffusers at the inlet to the basin where the organic loading is highest and decreasing the number of the diffusers along the basin's length. Tapered aeration better matches the oxygen demand across the basin by providing more air to the head of the basin where it is needed and less air near the end of the basin where the food-to-microorganisms (F/M) ratio is lower, thereby saving energy.

If an existing aeration system is under-performing, utilities should examine the configuration of diffusers to identify possible causes and potential improvements. Changes in number of diffusers and diffuser configuration could lead to increased energy efficiency. For example, the Waco Metropolitan Area Regional Sewer System (WMARSS) treatment facility in Waco, Texas was not meeting its nitrification goals with the plant's existing fine bubble aeration system. An analysis of the facility operations revealed that the aeration system was being operated in excess of the diffusers' maximum air flow rate, producing coarse bubbles instead of fine bubbles, which reduced the oxygen transfer efficiency. The analysis also concluded that additional diffusers were required to effect nitrification. The utility installed 700 additional diffusers in each of the plant's five aeration basins, bringing the total number of diffusers in each basin to 3,500. This modification, along with the implementation of automated DO control, has reduced energy consumption by an average of 4,643,000 kWh per year (an average 33% reduction) and had a payback period of less than three years. See the case study summary in Chapter 8 and the full case study with detailed energy and cost information in Appendix A for more information.

Intermittent Aeration

Intermittent aeration saves energy by reducing the number of hours that an aeration system operates or the aeration system capacity. It is not appropriate for all facilities, especially those at or near capacity, and needs to be evaluated on a case-by-case basis so as not to adversely impact the treatment process. The methodology involves momentarily stopping air flow to an aeration zone or cycling air flow from zone to zone. The cycle length can be controlled with DO concentration or can be strictly time based. When controlling with the DO concentration, air flow is turned off at a set high level and turned back on based on a lower limit. The cycle length on time-based systems is strictly controlled by a set maximum time. Many basins are limited by mixing, which must be considered when setting the maximum length of time that the air can be turned off. Additionally, settling of solids within the basin should be factored in the cycle length.

4.2.2 ECMs for Mechanical Aerators

Mechanical surface aerators vigorously agitate the wastewater, transferring oxygen from the air by increasing the water-atmosphere interface. Common types of equipment include low-speed mechanical aerators, direct drive surface aerators, and brush-type surface aerators. Slow speed mechanical aerators are used in both pond systems and in the activated sludge process. In ponds, they are mounted on floats and held in position using guy wires. Mechanical aerators are mounted above the wastewater on a platform in the middle of aeration basins. A shaft extends down through the platform into the tank to mix the wastewater. Brush aerators are used in oxidation ditches where, in addition to providing mechanical aeration, they impart a horizontal velocity that is needed to keep the ditches' contents moving and particles in suspension.

In general, ECMs for mechanical aerators are conventional retrofits. One ECM identified in the literature is the ability to adjust the submergence of fixed mechanical mixers through the use of adjustable weirs. Oxygen transfer can be improved and energy use is reduced by installing motor-operated weirs that change the submergence of the impeller based on the dissolved oxygen concentration (WEF 2009). Thus, the submergence of the impeller delivers more or less oxygen in response to real time conditions, resulting in energy savings. WEF and ASCE (2010) report that, in general, radial-flow low-speed mechanical aeration systems can provide higher aeration efficiency than high-speed machines.

Cycling aerators off during night-time hours can be effective in reducing aeration energy use in pond systems with multiple surface aerators. As the influent load to the plant decreases in the evening, the DO concentration rises. This is a potential opportunity to decrease surface aeration. Operationally, it is better to cycle the aerators so that each aerator is only off for a short time before another is put in service. As ponds come in different shapes and sizes, the number of aerators and determination of which aerators to turn off must be carefully evaluated on a case-by-case basis to prevent settling and the generation of odor.

A new development in mechanical aerators is the use of multiple impellers. Single impeller mechanical aerators are limited in their turn down due to the need to keep the contents of the basin from settling. A dual impeller aerator by Eimco Water Technologies, shown in Figure 4-1, includes a lower impeller near the bottom of the basin floor to augment the surface impeller. This provides additional mixing energy near the floor of the basin, permitting greater power turndown when a VFD is used and an associated energy savings. Data from full-scale installations were not identified through a literature review; thus, potential energy savings have not been quantified and this technology remains classified as an emerging ECM.

Figure 4-1. Eimco Water Technologies Carrousel® System Excell® Aerator II
Source: Eimco Water Technologies. Used with permission.

4.3 Control of the Aeration Process

Control of the aeration process is critical to efficient operation of wastewater treatment plants as both over- and under-aeration have detrimental effects. The energy wasted on over-aeration mounts quickly as the energy expended increases exponentially with increasing DO concentrations. The DO concentration needed to maintain stable biological activity is site-specific but usually ranges from 1.0 to 2.0 milligrams per liter (mg/L) for activated sludge systems and as low as 1.0 mg/L for nitrification. As noted previously, operating at DO concentrations closer to saturation increases the resistance of dissolved oxygen to dissolution. This both lowers the oxygen transfer efficiency (OTE) and increases the energy expended to drive oxygen into solution. In addition to wasting energy, the following operational problems have been reported in association with excess dissolved oxygen:

- Poor sludge settling
- Increased foam caused by filamentous organisms (can also occur at low DO)
- Negative impacts on the anoxic zone of a biological nitrogen removal system due to high DO levels in the recycle flow

Under-aeration can lead to underperformance of the activated sludge process, bulking issues, and, in some cases, issues with struvite (a phosphorus precipitate) formation in sludge processing resulting from unwanted biological phosphorus removal. The key point is to have good control over dissolved oxygen levels so that the aeration system supplies only what is needed.

This section presents ECMs for automated DO control including new advances in DO instrumentation, emerging DO control technologies, and emerging technologies using control parameters other than DO.

4.3.1 Automated DO Control

Automated control of the aeration process is an important ECM that can save a plant considerable energy by quickly adjusting to variable conditions within the basin. The oxygen required to maintain biological processes (i.e., the oxygen demand) within the aeration basin is proportional to organic and ammonia loading in the influent wastewater. Oxygen demand for aeration, therefore, follows the same diurnal pattern, dipping in the middle of the night and peaking in the morning and evening. The ratio of peak to minimum oxygen demand can typically be 2:1 (Cantwell et al. 2009), although it can be much higher for small systems and resort communities. Intermittent discharge of ammonia-rich supernatant from sludge dewatering operations can also dramatically increase the oxygen demand in the basin. Conversely, dilution from stormwater flow can reduce oxygen needs. In addition to fluctuating oxygen demand of the wastewater itself, the oxygen transfer efficiency in the basin also varies in response to changing air and water temperature and other wastewater characteristics such as concentrations of solids and surfactants.

In the past, wastewater treatment operators took field measurements to determine the DO concentration in the aeration basins. Based on the results, operational modifications were made (e.g., to blowers or aeration system valves) to increase or decrease the oxygen being delivered to the basins based on target setpoints. This was typically done only a few times (or once) per day and would not closely reflect diurnal variations in DO demand. In addition, a high safety factor was often applied to ensure that the DO level did not decrease below the target concentration should the influent wastewater characteristics change quickly.

To more closely match the air delivered to the biological process oxygen demand, utilities now commonly install automated control systems. Some new blowers come with automated control for reliable operations and enhanced energy savings (blower technologies are discussed in Chapter 5). Because energy required increases exponentially as the DO concentration increases, energy savings from automated DO control can be significant. For example, WEF and ASCE (2006) estimate that tight control of DO in the aeration process can save a wastewater plant between ***10 and 30 percent*** of ***total energy costs***. Energy savings will be site specific and are highly dependent on the control system in place prior to the upgrade to automated process control. WEF (2009) reports that for medium to large WWTPs, the payback period for installing automated DO control is generally within a few years.

How it Works

Automated DO control systems use real-time dissolved oxygen (DO) concentration readings from DO probes located within the aeration basins as inputs to a process controller. The process controller provides control output to the aeration system that responds by adjusting the brush rotor or blower speed, the position of variable vane diffusers on the blower, and/or the position of the drop-leg control valves at the basin to deliver the proper amount of air needed to maintain the target DO concentration. A simple control system might use one DO probe and one target DO concentration for all aeration basins. A more complex control strategy involves individual DO probes and air header control valves for each basin and/or stages within each basin. Individual target DO concentrations for each basin or stage can further increase energy savings.

Major components of an automated DO control system include:

- ***DO Probes***. Typical configurations are membrane (most common), galvanic, or new optical technology (see Section 4.3.1.1 for a detailed discussion). Probes should be installed in each aeration basin near the center or close to the inlet of a plug-flow basin.

- ***Blower Air Flow Control***. The total air flow supplied to the system is controlled by modulating the air flow rate delivered by the blowers. The control mechanism depends on the type of blower. Positive displacement blowers can use VFDs to modulate air flow. Air flow for multi-stage centrifugal blowers is often controlled by inlet throttling; however, VFDs also can be used to improve efficiency and turndown. New single-stage centrifugal blowers use variable speed, inlet guide vanes and variable discharge diffusers to modulate flow for enhanced energy efficiency. See Chapter 5 for more information on blower technology and air control.

- ***Basin Air Flow Control***. The total air flow supplied by the blowers is divided between multiple aeration tanks and multiple grids in each tank. The air flow in each zone should be proportional to process demand in each zone. In small facilities, basin air flow control is often done manually. In larger facilities, automatically controlled air flow valves can be used to continuously modulate air flow as DO concentrations change. In the largest facilities, automatic control may also be provided for individual zones. Most Open Valve (MOV) control can be used to automatically adjust header pressure so as to maintain a most open valve at an essentially full open position and minimize system pressure and energy.

- ***Process Control System.*** The aeration system process controllers receive information from the DO probes, process results (i.e., compares the basin readings to set point(s)), and sends signals to air control mechanisms to make a change if needed. Most systems are composed of programmable logic controllers (PLCs), usually networked together by a Supervisory Control and Data Acquisition System (SCADA). In larger facilities Distributed Control System (DCS) are sometimes used, combining local controllers and computer-based operator interface

Automated DO control systems typically use some form of a feedback control loop, whereby blower and aeration basin air flow rates are manipulated in response to changes in the DO level in the aeration basin. Control strategies can be very simple, such as an on-off or setpoint control, or complex based on proprietary algorithms. A common strategy for automated DO control is a cascaded control system. In the first loop of cascade control, the process controller sends a signal to the basin air flow control loop based on the DO probe readings in a basin. For example, if the DO reading is below the target, the controller will require more air into the basin. In some cases, the basin flow control valve is manipulated directly by the DO control loop. In most cases, a flow meter and separate air flow controller are provided. In this type of system, the output of the DO control loop is the setpoint for the air flow controller.

The second loop is established between a pressure transducer on the main header and the blower system. Pressure in the line will naturally increase or decrease based on modulations of the basin air flow control valve. If the basin valve is opened, the header pressure will decrease and the pressure control loop will send a signal to the blower controller to increase blower air flow. That is, the output of the pressure control loop is the setpoint for the blower air flow controller. Figure 4-2 provides a schematic of this common control system.

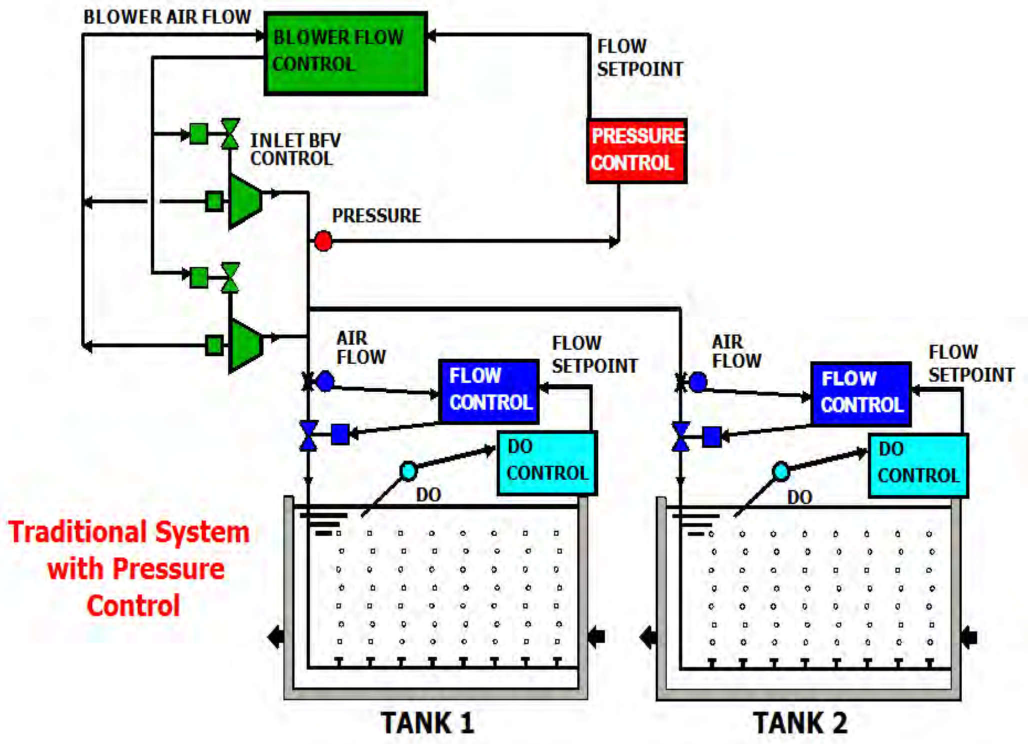

Figure 4-2 Common Cascade System for Automated DO Control
Source: Reproduced courtesy of Dresser, Inc.

Recent advances in automated DO control are related to the probes themselves or the control strategy. Section 4.3.1.1 discusses new DO probe technology. Advanced DO control systems are presented in Section 4.3.1.2.

4.3.1.1 DO Measurement Equipment

DO can be measured by membrane electrodes, galvanic electrodes, and optical DO technology (fluorescence or luminescence). Membrane electrodes, historically the most common DO measurement device, are composed of two metal electrodes separated from a test solution by a membrane. As oxygen permeates the membrane, the cathode reduces it and creates a potential that can be correlated to the amount of dissolved oxygen in the system. They are fairly reliable but must be calibrated frequently, typically monthly or weekly depending on the manufacturer and site conditions. The membranes must also be replaced fairly frequently (often quarterly but can be more frequently) (WEF and ASCE 2006). See the text box on the next page for guidelines on diffuser maintenance. This can be a time-consuming and tedious activity for operators. Galvanic electrodes, such as the proprietary Zullig probe, apply a galvanic current to measure the oxygen. This type of probe has significantly less maintenance than membrane-style probes and can obtain a slightly better energy savings as it maintains its accuracy longer.

Calibration and Maintenance on Membrane-Type Dissolved Oxygen Probes

Most DO probes can be field calibrated to match a known DO concentration reading. A laboratory unit can be used to measure the mixed liquor DO concentration, and this value is entered into the transmitter using a menu setting. Membrane type DO probes also have an “air calibration” available. In this method, the clean probe is exposed to air and the transmitter automatically adjusts the display and output to match the known concentration of oxygen in ambient air.

In mixed liquor, all types of DO probes can accumulate deposits of biological growth or grease. These deposits cause inaccuracy in the DO concentration measurement. Frequency of cleaning varies from once per week to once per month depending on site conditions. Cleaning of most DO probes is accomplished by removing the probe from the mixed liquor and wiping it with a damp cloth. In installations with a large number of DO probes, utilities should consider the use of self-cleaning probes. These employ air blasts, water spray, or mechanical wipers to periodically and automatically remove deposits from the face of the probe.[1]

The newest technology on the market, the optical DO probe, measures changes in light emitted by a luminescent or fluorescent chemical and relates the rates of change in the emission to the DO concentration in solution. They work on the principle that DO quenches both the intensity and duration of the luminescence or fluorescence associated with certain chemical dyes (see Figure 4-3 for a depiction of sensor operation). Thus, the duration of the dye luminescence or fluorescence is inversely proportional to the dissolved oxygen concentration. Several manufacturers offer optical DO probes including Hach, Orion, YSI, Insite IG, Endress and Hauser, and Analytical Technologies, Inc.

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[1] E-mail communication from Tom Jenkins, August 4, 2010.

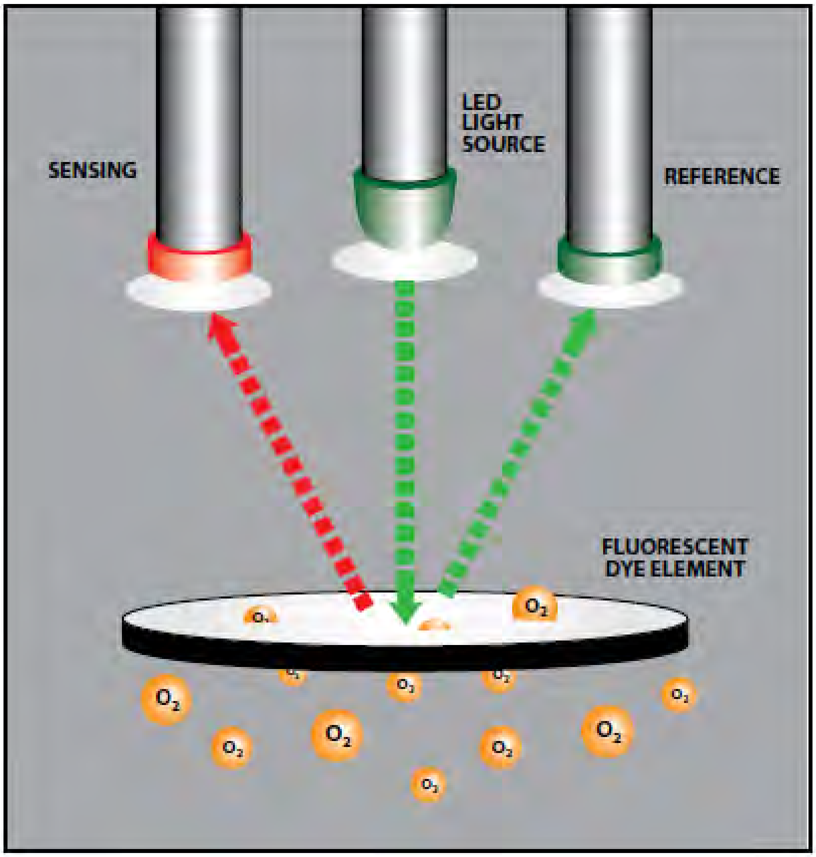

Figure 4-3. Optical DO Sensor Operation
Source: Analytical Technology, Inc. Brochure *Optical Sensor Reduces Maintenance Costs Model* for Q45 Optical Dissolved Oxygen Monitor. Used with permission

The optical DO probe has several advantages over the traditional membrane probe that make it a good candidate for automated DO control systems. The optical DO probe does not consume electrolyte and requires less frequent calibration There are no membranes to replace, so maintenance requirements are low with only the sensor cap requiring replacement approximately once per year (WEF and ASCE 2006). Accuracy and reliability are also generally greater for the optical DO probe compared to the membrane probe.

Using optical DO probes instead of traditional membrane probes in automated DO control systems is not considered an ECM itself; however, a more reliable and easy to use instrument could pave the way for increased automated DO control installations. For example, Brogdon et al. (2008) reports on energy savings realized by a Tennessee Valley Authority (TVA) demonstration project to advance the use of optical DO probes and variable speed drives for automated DO control among small to medium size utilities. Energy savings associated with the projects ranged from 14 to 40 percent.

Upgrading a system with optical DO probes is often combined with other aeration system upgrades to ensure reliable operation. For example, the Bartlett Wastewater Treatment Plant #1 in Tennessee implemented VFD control on one of the two operating rotors in each of the plant’s oxidation ditches using DO readings from optical probes. Prior to implementing this modification, one rotor in each ditch was operated at constant full speed and the second rotor in each ditch was manually activated during peak flow periods. Following implementation of the ECM, the need to run the second rotor during peak flow conditions was eliminated. The ECM reduced total plant electrical energy use by approximately 13 percent and saved the utility more than $9,000 per year. A case study of the Bartlett ECM project is presented in Appendix A.

4.3.1.2 Advances in DO Control Strategies

Although automated DO control is a significant improvement over manual control, it has some limitations. It takes time for the DO concentration in the basin to change in response to a change in organic or ammonia loading (at least a few minutes but it can be much longer). It also takes time for the process to reach equilibrium after the airflow is increased or decreased. This can cause the valve position to repeatedly open and close before DO in the basin has stabilized. For example, an increase in airflow could overshoot the DO target, causing a second manipulation of valve position and airflow rate to reach the target. Repeated adjustments to find the DO setpoint is commonly referred to as "hunting." Operators tune the control system to reduce hunting; however, conservative tuning can make the system unresponsive to changes within the basin. Tuning is made all the more challenging by the non-linear relationship between DO concentration and air flow to the basin.

New advances in DO control algorithms attempt to address these issues. Two proprietary ECMs that are emerging for automated DO control are discussed in this section: integrated air flow control and automated SRT/DO control. Also provided is a description of the most-open-valve control methodology. Alternatives to DO-based control are discussed in Section 4.3.2.

Most Open Valve (MOV) Control

The goal of MOV control is to avoid excessive throttling on the discharge side of the blowers since it is not energy efficient to build pressure and then waste it across throttling valves. The amount of throttling should be limited to what is required to properly split the air flow. This is accomplished by ensuring the control butterfly valve serving the zone with the highest oxygen demand is essentially full open.

MOV is now commonly integrated into new aeration control systems. It may not be cost-effective as an add-on to an existing control system, but utilities should consider specifying for it when upgrading blowers or aeration controls.

Integrated Air Flow Control

Integrated Air Flow Control is a proprietary aeration control system that was developed by ESCOR (Energy Strategies Corporation, now part of Dresser, Inc.) that eliminates the pressure control loop common in many automatic DO control systems. Particularly in smaller systems, the pressure control loop can cause instability in the operation of the blowers and control valves (cyclic oscillation, or hunting) as the control system attempts to adjust air flow and pressure in response to changes in the process and ambient air conditions.

Full-scale implementation of Integrated Air Flow Control has resulted in better stability and simplified tuning of the aeration process leading to more efficient blower operation. The Narragansett Bay (RI) Commission's Bucklin Point facility implemented an ESCOR aeration control system following an upgrade of their 46 mgd facility in 2005. As part of the upgrade, the aeration system was reconfigured to improve the plant's Modified Ludzack Ettinger (MLE) process to help meet biological nutrient (nitrogen) removal goals. The upgraded plant, operating with two of the plant's three 600 hp blowers (one in standby/spare status), had difficulty maintaining consistent nitrogen removal primarily due to inadequate air supply control. Implementation of the ESCOR Integrated Air Flow Control system, unlike the system's original pressure-based control system, employs direct flow control of the blowers. As the DO in the aeration basin varies from setpoint, the required incremental changes in air flow are used to modify both aeration drop leg air flow and blower air flow. The control system's MOV logic directly manipulates basin air flow control valve positions to insure that at least one valve is always at maximum open position, thereby minimizing system pressure without using a pressure control setpoint (See Figure 4-4). The reduced complexity compared to the pressure control system results in more robust and accurate control and elimination of the pressure control loop minimizes tuning.

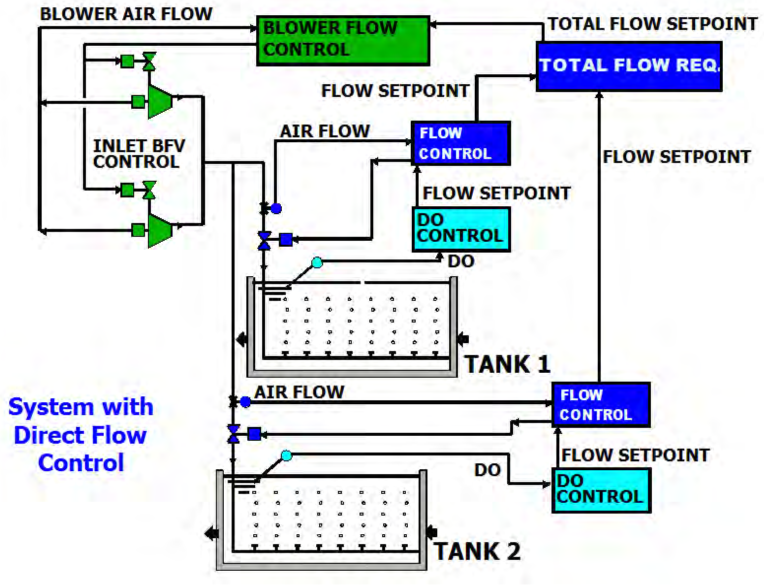

Figure 4-4 Integrated Air Flow Control System for Automated DO Control
Source: Reproduced courtesy of Dresser, Inc.

Implementation of the Integrated Air Flow Control provided the required DO control to meet the plant's total nitrogen discharge requirements and reduced electricity consumption at the facility an average of approximately 1,247,000 kWh per year (an average reduction of 12%) in the first three years of operation following commissioning at the end of 2006 (a savings of nearly $136,000). This energy savings was the result of eliminating the need to constantly run the second of the two plant's blowers. A case study presentation of the Bucklin Point aeration system control ECM project is provided in Appendix A.

Automatic SRT/DO Control

DO and sludge age (SRT) are two of the most important operating parameters in activated sludge treatment. Although reducing DO in the aeration process effects energy savings (i.e., less DO lowers the energy consumption of the blowers), it often requires increasing SRT to compensate for the deterioration in process performance. Increasing the sludge age in an activated sludge process, however, can lead to an increase in the sludge settling volume index (SVI), which can increase the plant's effluent total suspended solids (TSS).

Ekster Associates has developed a proprietary algorithm (OPTIMaster™), based on activated sludge modeling, plant historical data, and statistical process control that provides setpoint optimization for sludge age and DO and automates control of these parameters (through automatic sludge wasting and blower output adjustment) to optimize aeration. The algorithm selects sludge age and a range of mixed liquor suspended solids (MLSS) and DO concentrations to maintain the proper SVI at minimum aeration.

Oxnard, CA implemented the OPTIMaster™ system in 2006 and reported a reduction of approximately 20 percent in the total plant's electrical energy use. A case study presentation of the Oxnard plant's implementation of the OPTIMaster™ system is provided in Appendix A.

4.3.2 Emerging Technologies Using Control Parameters other than DO

Instead of monitoring and control based on DO concentrations in the aeration basin, another innovation is to take alternative measurements of biological activity and use this information for process control. This section describes three emerging ECMs for automated control of the aeration process using a measurement parameter other than DO: respirometry, critical oxygen point control, and off-gas monitoring.

Respirometry

Respirometry involves measuring the oxygen uptake rate (OUR) by a biological treatment culture. In bench-scale respirometry experiments, a sample of mixed liquor representing the biomass in the aeration basin, possibly amended with an organic substrate or ammonia, is placed in a sealed vessel. The rate of oxygen consumption within the vessel is monitored over time. A review of the literature revealed that online control of aeration using respirometry is possible, but has not been successfully implemented on a full-scale basis.

Online respirometers also require a representative sample of biomass from the aeration basin. This source is typically a fresh sample from the mixed liquor, the return activated sludge line, or from an off-line pilot reactor (Love 2000). The sample is contained in a well-mixed batch reactor or flow-through system. Oxygen consumption is measured over time (either for the liquid phase or a sealed gas phase). OUR is based on a mass balance on either the liquid phase or both the gas phase and the liquid and gas phases within the respirometer. It is important that sufficient oxygen be present in the liquid or gas phase to prevent oxygen limiting conditions (Love 2000). Figure 4-5 provides an example of a flow-through respirometric cell.

Figure 4-5. Flow–through Respirometry Cell
Source: Strathkelvin Instruments. Used with permission

Online respirometric control has a theoretical advantage over traditional automated DO control. Whereas DO is essentially an "after-the-fact" analysis once oxygen needs of the biomass have been met, OUR as measured by a respirometer is a more direct measure of biomass needs and can be used to predict oxygen requirements for wastewater as it enters the basin. A study at the James C. Kirie Water Reclamation Plant in Chicago showed that respirometric control is technically feasible using a feed-forward control strategy (Tata et al. 2000). On-line respirometers were installed in one aeration basin to determine OUR. Researchers used plant data and literature values to develop two semi-theoretical mathematical models to predict aeration rate as a function of average basin OUR. Side-by-side experiments were conducted to compare the plant's existing automated DO control strategy to an experimental control algorithm based on OUR. Reduced airflow based on the OUR control strategy caused a reduction in effluent quality, leading Tata et al. (2000) to conclude that even though online respirometric control is technically feasible, more work would be needed to configure an optimal control system.

Although respirometry has been used widely in the U.S. to determine kinetics of aerobic biological processes, online respirometric control of aerobic treatment processes is not common. Trillo et al. (2004) evaluated the use of respirometry and noted the following limitations:

- Most respirometry analytical devices do not provide true, real-time measurements but rely on cyclic sampling and analysis.

- The devices require high maintenance because they utilize sampling pumps and require replenishment of chemical reagents.

- The technique requires conditioning of samples or changes in mixed liquor conditions that may lead to results that are not representative of actual process conditions.

WEF and ASCE (2006) note that the most appropriate applications may be sequencing batch reactors and oxidation ditches. More commonly, respirometric measurements have been used to create diurnal load profiles, which are then used as an input to more common DO control strategies.

In 2002, the International Water Association (IWA) published a report titled "Respirometry in Control of the Activated Sludge Process: Benchmarking Control Strategies" (Copp et al. 2002). This report contains an evaluation of current control devices and a protocol for evaluating aeration control strategies using respirometry. The reader is directed to this report for detailed analysis and recommendations for online respirometric measurement.

Critical Oxygen Point Control Determination

Critical oxygen point control is a control method based on respirometric measurements. The theory is as follows: bacteria respire by diffusion of oxygen across their cell wall. Oxygen diffuses from a high concentration external to the bacterial cell wall to the low concentration internal to the bacterial cell. Diffusion will only take place once the oxygen concentration differential across the cell wall is sufficient to drive the oxygen through it. The minimum concentration at which this occurs is called the critical oxygen point. Below the critical oxygen point, the biodegradation rate will rapidly decrease. At the critical oxygen point, the biodegradation rate will be at a maximum for the available food source (i.e., organic compounds and ammonia in the wastewater being treated).

Exceeding the critical oxygen point will not materially affect the biodegradation rate. For carbonaceous bacteria, this critical oxygen point is very distinct. Accurately knowing the critical oxygen point for the active biomass allows the optimal DO setpoint to be determined.

Strathkelvin Instruments (Scotland, UK) has developed a proprietary software upgrade to their Strathtox line of respirometers that, in real time, determines the critical oxygen point of the wastewater under aeration and utilizes this data to change the DO setpoint to control the optimum delivery of oxygen in the aeration basins. Additional information is available on the manufacturer's webpage at http://www.strathkelvin.com/waste_water/applications.asp.

Off-Gas Analysis

Off-gas testing is a standard test for determining in-process oxygen transfer efficiency (OTE) based on a gas-phase mass balance of oxygen entering the aeration basin and oxygen leaving the basin at the wastewater surface. It has been historically used for evaluating aeration system performance, but has recently received attention as a parameter for aeration system control.

A feed-forward, off-gas monitoring and control system was tested successfully at the Grafton WWTP in Wisconsin (Trillo et al. 2004). The Grafton WWTP treats 1.1 mgd on average using two parallel aeration basins equipped with fine pore diffusers. Multistage centrifugal blowers provide the airflow to the system. The off-gas control system consists of a stainless steel hood for collecting a representative sample of the aeration system off-gas, a sample conditioning and transport system, gas sensors, and PLC.

In November 2001, the plant began operating the new off-gas control system in one of its two aeration basins. Trillo et al. (2004) reported the following advantages of the off-gas control system compared to operation of the conventional feedback-based DO control system:

- Resulted in smaller variations in basin DO (standard deviation of 0.12 mg/L compared to 0.36 mg/L for feedback-based DO control for typical 6-day performance).
- The effluent DO setpoint was reduced from 2.0 mg/L to 1.75 mg/L.
- Recovery time after power loss was reduced by 50 percent.

The authors did not present a side-by-side comparison of energy use for the two treatment trains, but postulated that the feed-forward off-gas control could reduce energy use by more than 20 percent compared to conventional feedback-based DO control systems. See Trillo et al. (2004) for additional information.

4.4 Innovative and Emerging Control Strategies for Biological Nitrogen Removal

The bacteria responsible for biological nitrification (referred to as "nitrifiers" or nitrifying bacteria) exhibit significant biological diversity. Many can operate at low DO concentrations, particularly following alternating anoxic and aerobic environments (Littleton et al. 2009). Thus, relying on automation of DO alone may not result in the most energy efficient system. Although advanced control of nitrification using multiple measurement parameters such as ammonia and nitrate and nitrite has been growing overseas, there are still few full-scale applications in the U.S. Still, several proprietary control systems are on the market and have been tested at full-scale WWTPs. The two described in this section are the SymBio process and the Bioprocess Intelligent Optimization System (BIOS).

SymBio®

The SymBio® process by Eimco Water Technologies uses online monitoring of nicotinamide adenine dinucleotide (NADH) to determine changes in biological demands. Based on the results, airflow to the basin is controlled to promote simultaneous nitrification-denitrification (SNdN) of wastewater. SNdN refers to a condition in an activated sludge or biofilm process in which the positive bulk liquid DO concentration is low enough (typically below 1.0 mg/L) that the DO diffusing into the floc is removed before it can penetrate the entire floc depth. Thus, nitrification is occurring on the exterior portions of the floc and denitrification is occurring in the anoxic, interior portion, allowing for total nitrogen removal.

The monitoring device, the NADH sensor, uses a fluorescence sensor to detect changes in NADH which in turn provides information on the status of biological wastewater treatment processes. Weerapperuma and de Silva (2004) report that the NADH sensor requires minimal maintenance and can provide real-time information for process control (article available at: http://www.eimcowatertechnologies.com/muniusa/index.php?option=com_content&view=article&id=72&Itemid=146).

The manufacturer claims a 25 to 30 percent energy savings compared to nitrifying plants without this control technology; however no independent data from full-scale facilities has been published to verify these claims.

Bioprocess Intelligent Optimization System (BIOS)

BIOS is a proprietary control algorithm, on-line process simulation program originally developed by Biochem Technology, Inc. to optimize the operation of a Modified Ludzack-Ettinger (MLE) biological nitrogen removal process. Since the de-nitrification and nitrification sections of the MLE process are an integral part of many other biological nutrient removal processes (e.g., 4- and 5- stage Bardenpho and A^2O processes), the BIOS control system can be applied to other processes having the MLE component.

BIOS is a feed-forward optimization that conducts simulation calculations based upon on-line measurement of temperature, ammonia, nitrate, and influent wastewater flow rate, integrating these process measurements with laboratory analytical results for mixed liquor suspended solids (MLSS) as inputs to the algorithm. The BIOS simulation provides a continuous output of DO setpoints for the biological treatment process according to the load entering the bioreactor. Additionally, the internal recirculation flow rate (IRQ) from the aerobic zone to the upstream anoxic zone in the MLE process or multi-zone BNR process is controlled to achieve optimal total nitrogen removal. Using BIOS to control the biological nitrogen removal process produces low effluent total nitrogen concentration while minimizing aeration energy consumption.

Specifically, an ammonia analyzer located in the anoxic zone provides the control system with the ammonia concentration in the aerobic zone influent and a nitrate analyzer located at the end of the aerobic zones provides the control system with the nitrate concentration in the internal recycle (IRQ) stream. BIOS conducts iterative biological and hydraulic simulations that predict the nitrification reaction rates in the aerobic zones and the de-nitrification reaction rates in anoxic zones under different DO and IRQ. The simulation iterative calculations take into account that the IRQ will dilute the ammonia concentration in the anoxic zone and decrease one pass hydraulic retention time in both the anoxic zone and aerobic zones. As a result, the simulation provides optimal DO set points (for controlling/optimizing aeration rate) and IRQ (for controlling the process recirculation pump rates) in real-time based on the changing characteristics of the wastewater. See Figure 4-6 for a diagram of the BIOS process.

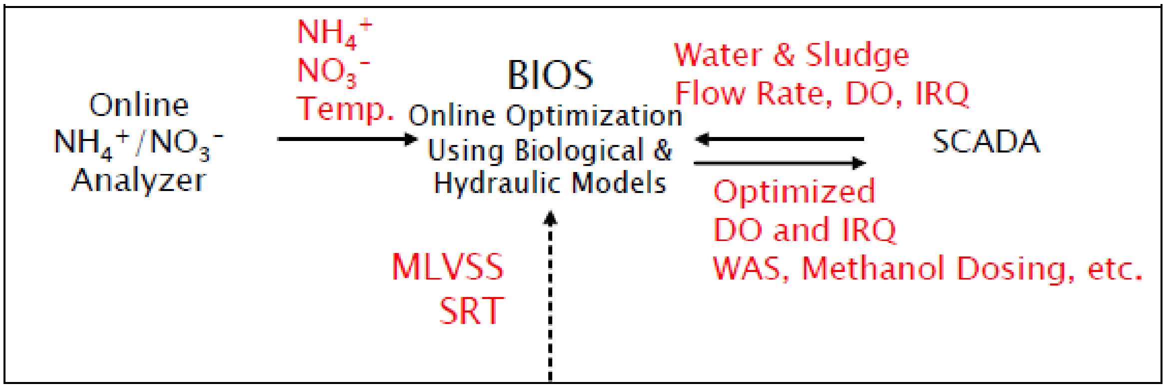

Figure 4-6. Representation of the BIOS process
Source: Lui et al. (2005). Provided courtesy of Biochem Technologies, Inc.

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5. Blower and Diffuser Technology for Aeration Systems

Chapter 5 covers:

5.1 Introduction and Comparison of Blower Types

As noted in Chapter 4, the aeration process can account for 25 to as much as 60 percent of total plant energy use (WEF 2009). This chapter builds on energy conservation measures (ECMs) for aeration system design and operation presented in Chapter 4 by providing technical information and cost/energy data for ECMs related to innovative and emerging blowers and diffuser equipment. Note that unlike other ECMs described in this report, blower and diffuser designs are often unique to manufacturers. Hence, this chapter contains information on proprietary systems as examples. As noted in the preface, the mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by EPA or the Federal government. The wastewater industry is constantly evolving and new equipment not identified in this chapter may be available or emerge in the future. When evaluating new equipment, design engineers and plant owners should work closely with their state regulatory agency to assess operating principals and potential energy savings.

Blowers are an integral piece of the aeration system. There are many configurations, but all consist of lobes, impellers, or screws mounted on one or more rotating shafts powered by a motor. As the shaft turns, the blower pulls in outside air and forces it through distribution pipes into aeration basins at pressures typically between 5 and 14 pounds per square inch (psi)[1]. The energy consumption of blowers is a function of air flow rate, discharge pressure, and equipment efficiency (WEF 2009). Blower efficiency varies with flow rate, pressure, speed, inlet conditions and actual design.

Blowers can be categorized as either (1) positive displacement blowers, which provide a constant volume of air at a wide range of discharge pressures, or (2) centrifugal blowers, which provide a wide range of flow rates over a narrow range of discharge pressure. Centrifugal blowers are either multi-stage with a sequence of impellers mounted along a single shaft directly connected to a motor with a flexible coupling, or single-stage with one impeller typically with speed increasing gears or a variable frequency drive (VFD). Single-stage centrifugal blowers can be conventional integrally geared blowers or gearless (also known as high speed “turbo”) blowers. Positive displacement or centrifugal blowers (multi-stage or new high speed turbo blowers) are well suited for small plants. Large plants more often use multi- or single-stage centrifugal blowers as high speed turbo blowers are not yet available in capacities suitable for large plants. Table 5-1 lists the types of blowers in each category and provides information on operation, air flow rates, advantages, and disadvantages.

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[1] Equivalent to psi gauge unless otherwise noted

Table 5-1 Overview of Blower Types for Aeration of Wastewater

Category	Description and Operation	Types	Typical Air Flow Ranges and Pressures	Advantages	Disadvantages
Positive Displacement	Provides fixed volume of air for every shaft revolution. Operates over a wide range of discharge pressures.	Most common is two counter-rotating shaft (rotary) with 2- or 3-lobed impellers on each shaft.	5 – 50,000 scfm, 1 – 14 psig	• Low capital cost, economical at small scale • Can achieve higher output pressure at same air flow rates • Simple control scheme for constant flow applications	• Difficult to operate at variable flow rates without VFD • Can be noisy (enclosures are commonly used for noise control) • Require more maintenance than other types • Typically least energy efficient
Centrifugal Multi-Stage	Uses a series of impellers with vanes mounted on rotating shaft (typically 3,600 rpm). Each successive impeller increases discharge pressure. Individual units operate at narrow range of discharge pressures at wide range of flow rates.	Number of stages dictates discharge pressure	500 – 30,000 scfm, 4 – 14 psig, can be higher with more stages	• Can be more energy efficient than positive displacement • Lower capital cost compared to single-stage centrifugal blowers • Can be quieter than single stage units	• Can be less energy efficient than single-stage centrifugal • Efficiency decreases with turndown.
Centrifugal Single-Stage Integrally Geared	Similar to multi-stage but uses a single impeller operating at high speed (typically 10,000 – 14,000 rpm) to provide discharge pressure. Uses gearing between motor and blower shaft.	Differences are in speed and type of control (e.g., one or two sets of variable vanes)	500 – 70,000 scfm, 4 – 24 psig	• Can be more energy efficient than multi-stage or positive displacement • Can maintain good efficiency at turndown. • Typically come with integral control system for surge protection	• More moving parts than multi-stage units. Surge can be more damaging • Can be noisy (enclosures are commonly used for noise control) • High er capital cost compared to multi-stage or positive displacement
Centrifugal Single-Stage Gearless (High-Speed Turbo)	Centrifugal single-stage blower uses special low-friction bearings to support shaft (typically ~ 40,000 rpm). Uses a single or dual impeller.	Magnetic or air bearing	400 – 10,000 scfm, 4 – 35 psig (Manufacturers are currently expanding their range of offerings)	• Small footprint • Efficient technology for lower air flow capacity ranges • Can maintain good efficiency at turndown • May come with integrated control systems to modulate flow and for surge protection • Can be easy to install (place, plumb, and plug in)	• Typically higher capital cost compared to multi-stage or positive displacement blower (although likely less expensive than integrally geared) • Limited experience (new technology) • More units required for larger plants (will change as manufacturers expand air flow range)

psi = pounds per square inch; scfm = standard cubic feet per minute. VFD = variable frequency drive; rpm = revolutions per minute

Source: WEF 2009; WEF and ASCE 2010

Installation costs for blowers depends on a number of factors including atmospheric pressure, temperature, and humidity of the site location and whether or not units are equipped with various accessories and controls. Typical cost ranges for a centrifugal multi-stage and turbo blowers as provided by two blower manufacturers are shown in Table 5-2.

Table 5-2. Manufacturer Cost Ranges for Select Blower Types

Blower Type	Range of Discharge Pressure, Flow, and Horsepower	Cost Range[1]
Positive Displacement Rotary Lobe Blower	8 psi and 8,000 scfm, 380 hp[2] 15 psi at 5,000 scfm, 400 hp[2]	Not provided[2]
Positive Displacement Rotary screw Compressor	15 psi at 5,000 scfm, 330 hp[2] Not	provided[2]
Centrifugal Multi-Stage	8 psi and 7,500 - 30,000 cfm, 600 - 2,500 hp	$150k to $250k[3]
	8 psi and 1,000 - 7,500 cfm, 50 - 700 hp	$50k to $150k[3]
	8 psi and 100 - 1250 cfm, 3 - 75 hp	$35k-$75k[3]
Centrifugal Single-Stage Integrally Geared	12 psi and 4,800 – 6,800 cfm, 200 – 700 hp	$350k - $400k[8]
	12 psi and 6,800 – 10,000 cfm, 250 – 1,250 hp	$380k - $450k[8]
	12 psi and 10,000 – 22,100 cfm, 600 – 2,100 hp	$440k - $550k[8]
	12 psi and 22,400 – 33,200 cfm, 900 – 3,500 hp	$490k - $600k[8]
High Speed Turbo	8 psi and 2,500 - 8,000 cfm, 200-300 hp	$120k to $175k[3]
	8 psi and 1,000 - 2,500 cfm, 75 - 150 hp	$75k to $120k[3]
	8 psi and 100 - 1,000 cfm, 5 - 50 hp	$35k-$75k[4]
	10 psi and 600 - 1,500 cfm, 30 - 75 hp	$50k-$90k[4]
	10 psi and 2,000 - 4000 cfm, 100 - 200 hp	$115k-$160k[4]
	10 psi and 5,000 - 8,000 cfm, 250 - 400 hp	$180k-$275k[4]
	10 psi and 10,000 - 15,000 cfm, 500 - 700 hp	$325k-$450[4]
	ABS, Inc. – 330 HP with Automated Control System	Approximately $141,700[5]
	K-Turbo, Inc. – 50 HP with Automated Control System	Approximately $102,000[6]
	K-Turbo, Inc – 50 HP with Multiple DO Probes and Integrated Control Systems	Approximately $56,000[7]

Notes:

1) Costs are for estimating only - actual equipment cost may vary depending on model, control system, and other specific requirements. Installation will vary depending on specific project location and site conditions.
2) Information on available models provided by AERZEN USA, 108 Independence Way, Coatesville PA. (contact manufacturer for cost information at 484-288-6329)
3) Information supplied by HSI, 7901 Hansen, Houston, Texas 77061. Non standard blowers are available in larger sizes (contact manufacture for details at 713-947-1623)
4) Information supplied by APG-Neuros, Inc., 3200 Cours Le Corbusier, Boisbriand, Quebec, J7JG-3E8, Canada. Non standard blowers are available in larger sizes (contact manufacture for details at 450-739-0799)
5) Information extracted from the Green Bay, WI, De Pere WWTP case example in Section 5.2. See Appendix A for full case study details.
6) Information provided by the Mukilteo Water and Wastewater District.
7) Information extracted from the Burlington, VT, WWTP case example. See Section 5.2 for more details.
8) Information supplied by Atlas Copco Compressors, LLC, 1800 Overview Drive Rock Hill, South Carolina 29730. Visit www.atlascopco.com for more details.

Table 5-3 presents typical ranges of isentropic (nominal) energy efficiency and turndown for different blower types. Note that there is significant variation from small to large blowers of any type; the values presented are general rules of thumb and may vary with the application.

Table 5-3 Typical Blower Efficiencies

Blower Type	Nominal Blower Efficiency (percent)	Nominal Turndown (percent of rated flow)
Positive Displacement (variable speed)	45 – 65	50
Multi-Stage Centrifugal (inlet throttled)	50 – 70	60
Multi-Stage Centrifugal (variable speed)	60 - 70	50
Single-Stage Centrifugal, Integrally Geared (with inlet guide vanes and variable diffuser vanes)	70 – 80	45
Single-Stage Centrifugal, Gearless (High-Speed Turbo)	70 - 80	50

Note: values may vary with the application.
Source: Adapted from Gass, J.V. (Black & Veatch) 2009. Used with permission.

Controlling positive displacement blowers is typically done by varying blower speed with a variable frequency drive (VFD) or use of multiple blowers operating in parallel. Throttling air flow through the machine is not possible for this type of blower. Multi-stage centrifugal blowers can be controlled through a variety of techniques, the most efficient being VFDs followed by suction air flow throttling using inlet butterfly valves. WEF (2009) reports that VFD operation of multi-stage centrifugal blowers is 15 to 20 percent more efficient than throttling.

This chapter identifies several innovative and emerging ECMs related to blower and diffuser equipment:

- Turbo blowers are a significant area of innovation in blower design offering energy savings for the wastewater industry. They emerged in the North American market around 2007 and have been or are being tested and installed at many plants. Section 5.2 provides detailed information on turbo blower technology as an innovative ECM, including full-scale plant data from the literature and case studies.

- Single-stage centrifugal integrally geared blowers are controlled using inlet guide vanes and variable diffuser vanes. This control technique has the advantages of managing air flow and pressure independently. See Section 5.3 for discussion of new single-stage centrifugal blower technology.

- Where fine bubble diffusers were once considered the standard for energy efficiency, new materials and configurations capable of producing “ultra-fine” bubbles (1 mm or less) are now available. See Section 5.4 for a discussion of emerging diffuser ECMs.

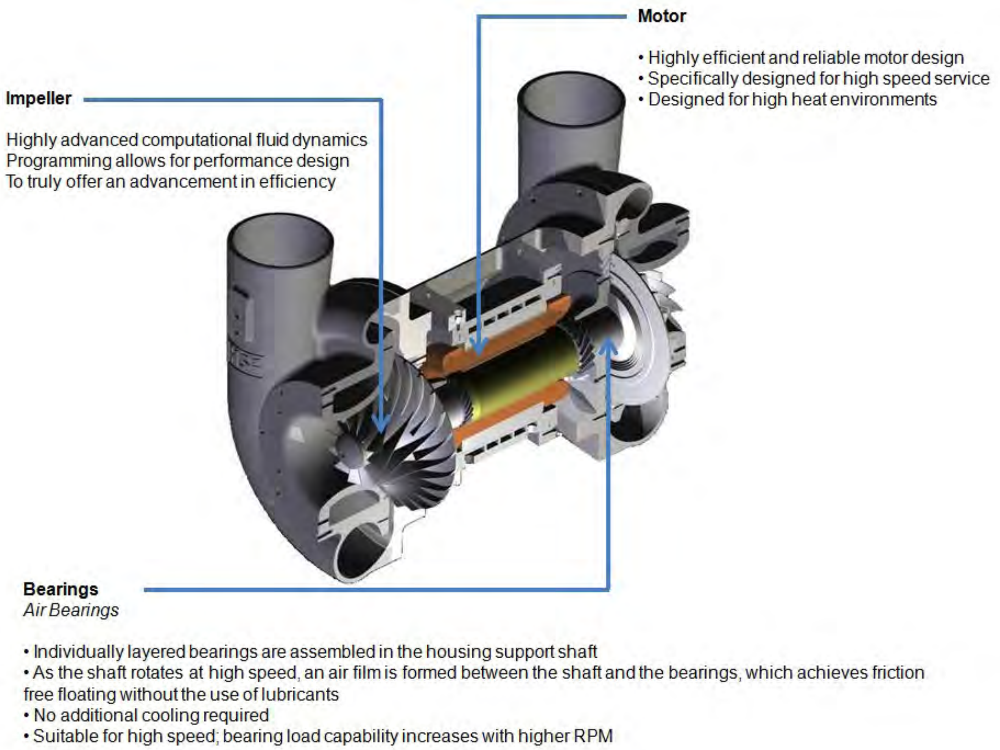
- Technological advances are also progressing in the area of diffuser cleaning. See Section 5.5 for recommendations for preventing diffuser fouling.

A very new technology is the rotary screw compressor. The technology was released to the U.S. Market in the summer of 2010. The manufacturers claim significant energy savings of up to 50 percent compared to rotary lobe blower technology. Units are being manufactured by Atlas Copco, AERZEN, Inc., and Dresser Roots. Because information has only been available for a short while, it was not possible to conduct a complete evaluation of the technology by industry experts prior to the publication of this report. For information on the rotary screw compressor technology, the reader is referred to the manufacturer's website http://www.efficiencyblowers.com/efficiencyblowersus/, http://www.rootsblower.com/ and https://info.aerzenusa.com.

5.2 High-Speed Gearless (Turbo) Blowers

High-Speed Gearless, or "Turbo," blowers use advanced bearing design to operate at higher speeds (upwards of 40,000 revolutions per minute [rpm]) with less energy input compared to multi-stage and positive displacement blowers. Some turbo blowers come in package systems with integrated VFDs and automated control systems to optimize energy efficiency at turndown.

Turbo blowers are available in two primary configurations based on the manufacturer: (1) air bearing or (2) magnetic bearing. In an air bearing turbo blower, an air film is formed between the impeller shaft and its bearings as the shaft rotates at high speed, achieving "friction free" floating of the shaft. Air bearing technology is offered by several manufacturers including K-Turbo, Neuros, Turblex, and HSI. In a magnetic bearing design, the impeller shaft is magnetically levitated to provide friction free floating of the shaft. Turbo blowers featuring magnetic bearing design are offered by ABS Group, Atlas Copco, and Piller TSC. A magnetic bearing high speed turbo blower is also being developed by Dresser Roots. Figures 5-1 and 5-2 show features of a common air bearing and magnetic bearing unit, respectively. The friction free bearing design coupled with high efficiency motors contributes to the comparative high energy efficiency of the turbo blower technology.



Motor

- Highly efficient and reliable motor design
- Specifically designed for high speed service
- Designed for high heat environments

Impeller

Highly advanced computational fluid dynamics
Programming allows for performance design
To truly offer an advancement in efficiency

Bearings
Air Bearings

- Individually layered bearings are assembled in the housing support shaft
- As the shaft rotates at high speed, an air film is formed between the shaft and the bearings, which achieves friction free floating without the use of lubricants
- No additional cooling required
- Suitable for high speed; bearing load capability increases with higher RPM

Figure 5-1. Example of High-Speed Turbo Blower with Air Bearings (HSI). Used with permission.

Figure 5-2. Example of High-Speed Turbo Blower with Magnetic Bearings (Atlas Copco) Used with permission.

Turbo blowers have many practical advantages (Gass 2009; Jones and Burgess 2009):

- Typically 10 to 20 percent more energy efficient than conventional multi-stage centrifugal or positive displacement equipment for their current size range based on manufacturers' data. Good turndown capacity (up to 50 percent) with little drop in efficiency. It is important to note that efficiencies of turbo blowers at turndown are not yet well documented because the technology is so new.

- Some include a dynamic control package with integrated variable speed drive, sensors, and controls that automatically adjust blower output based on real-time dissolved oxygen (DO) demand in the aeration basin.

- Small footprint and lightweight.

- Quiet, low vibration. Sound enclosures are standard equipment.

- Few moving parts, low maintenance requirements.

Disadvantages of the turbo blower are that it is a new technology with relatively few installations, capital costs tend to be higher compared to other blower types, and multiple units may be needed for larger installations. Moreover, testing methods are not consistent among different manufacturers and some efficiency claims are not yet well documented.

A detailed literature review and input from industry experts identified seven manufacturers of turbo blowers in the North American wastewater market. Table 5-4 provides a link for each manufacturer's home page, capacity of available modes, and example installations (if available).

Because turbo blowers are relatively new to the U.S. market, full-scale operating data are limited. However, detailed cost and operating data have been collected for this report as part of two facility case studies: (1) Green Bay Metropolitan Sewerage District De Pere WWTP installation of six ABS magnetic bearing turbo blowers, and (2) The Big Gulch WWTP in Mukilteo, WA installation of three air bearing turbo blowers by K-Turbo. A summary of the case studies follows Table 5-4. Technical information and performance data from an installation in Burlington, Vermont follow the case study summaries.

Table 5-4. Examples of Turbo Blower Manufacturers in the North American Market[1]

Manufacturer	Manufacturer Web Site	Origin of Manufacture[2]	Bearing Type	Operating Ranges Available	Example Installations[3]
Neuros	http://www.apg-neuros.com/	Korea (marketed from Canada). Substantial transformation - manufacturing in US.	Air	• Flow rates up to 4,500 scfm • Discharge pressures to 35 psig • Motor hp from 30 to 300	• Franklin, NH • Manufacturer claims 108 installations in North America
K-Turbo	http://www.kturbo.com/english/main.html	Korea (marketed from Canada). Substantial transformation - manufacturing in US.	Air	• Flow rates up to 4,700 cfm for single impeller, 11,600 cfm for twin impeller • Discharge pressures to 21 psig for single impeller, 28.5 for twin impeller • Motor hp from 25 to 600	• First test model began operation in Oregon in April 2008 • Burlington North Plant in Vermont [4] • Big Gulch Wastewater Treatment Plant, Mukilteo, WA [5] • Delphos, OH (to be commissioned in 2010)
Houston Services, Inc. (HSI)	http://www.hsiblowers.com/	USA	Air	• Flow rates up to 10,000 scfm • Discharge pressures to 25 psig • Motor hp from 5 to 300	• Essex Junction, VT (to be commissioned in 2010)
ABS	http://www.absgroup.com/	Germany (marketed from UK)	Magnetic	• Flow rates up to 10,200 scfm • Discharge pressures between 5.8 and 12.4 psig • Motor hp from 400 to 540	• Green Bay Metropolitan Sewerage District De Pere WWTP [5] • City of Livermore, CA
Atlas Copco	http://www.atlascopco.us/usus/	Belgium	Magnetic	• Flow rates up to 3,400 scfm • Discharge pressures to 22 psig • Motor hp from 135 to 215 (100 to 160 kW)	None identified
Piller TSC	http://www.piller-tsc.com/index.php?id=20	Germany	Magnetic	• Flow rates up to 7,000 cfm • Discharge pressure to 17 psig • Motor hp to 400 hp	• Nashua, NH
Dresser Roots	http://rootsblower.com/	USA	Magnetic	• Flow to 10,000 scfm • Discharge pressure to 15 psig	None identified

1. Based on information provided on manufacturer's website as of February 25, 2010. Other manufacturers may be available.
2. Information on substantial transformation is based on results of Buy American waiver applications for the American Reinvestment and Recovery Act
3. Based on literature review and input from technical expert panel and peer reviewers
4. Performance data provided in this section
5. One of nine facility case studies presented in this report. Performance data are summarized in this section. See Chapter 8 for a summary of all case studies and Appendix A for detailed case study results.

Green Bay, WI, De Pere WWTP (Case Study No. 1)

The Green Bay (Wisconsin) Metropolitan Sewerage District's (GBMSD) De Pere WWTP is a 14 million gallon per day (mgd) two-stage activated sludge plant with biological phosphorus removal and tertiary effluent filtration. When their existing multi-stage centrifugal blowers reached the end of their useful life, the District decided to replace the five existing multi-stage units with magnetic bearing turbo blowers. Six ABS, Inc. HST 330 hp magnetic bearing turbo blowers were installed in October 2004 at a total capital cost[2] of $850,000. The turbo blower project (along with automated controls) saved the plant more than 2 million kWh per year (a 50 % savings) and $63,758 per year in electrical energy costs. The project had a simple payback of approximately 13 years. In addition to the energy savings, the new blowers require significantly less maintenance.

For more information, see the Case Study Summary in Chapter 8 and the detailed facility assessment including schematics, influent and effluent data, and energy and cost data in Appendix A.

Big Gulch WWTP in Mukilteo, WA (Case Study No. 3)

The Big Gulch WWTP, owned and operated by the Mukilteo Water and Wastewater District, is a 2.6 mgd oxidation ditch plant operating two parallel oxidation ditches. To address increases in BOD and TSS loadings, the oxidation ditch aeration system has been upgraded as follows:

- The existing mechanical brush (rotor) aeration systems in each ditch were replaced with Sanitaire fine bubble diffusers and air bearing turbo blowers (three blowers total).
- DO probes with a PLC based control system were installed to automate blower operation.
- A dNOx Anoxic control system was installed to detect the nitrate knee, which is defined as the point in the nitrogen conversion process where complete denitrification has occurred (i.e., NO_3^- has been converted to N_2). With the dNOx control system, the blowers are allowed to go idle as loading increases and automatically switch on when the nitrate knee is detected.

The aeration systems were replaced sequentially with the first ditch (Ditch A) being upgraded in 2008 and second (Ditch B) in 2010.

The total capital and installation cost of the Ditch A upgrade including removal of one rotor aerator and implementation of one turbo blower, diffusers, air piping, probes, and controls was $487,066. The Big Gulch WWTP received a $39,191 grant from its electric utility to offset the cost of the project resulting in a total cost for the Ditch A upgrade of $447,875 dollars. The total capital and installation cost of the Ditch B upgrade including removal of four rotor aerators and installation of two turbo blowers, diffusers, air piping, probes, controls and a blower building was $1,045,023. The Big Gulch WWTP received a $46,594 grant from its electric utility to offset the cost of the project resulting in a total cost for the Ditch B upgrade of $998,429.

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[2] The blower replacement project was implemented as part of a larger $2 million plant infrastructure project. Installation costs related exclusively to the blower implementation are not available. See Appendix A for more information.

The energy savings from the Ditch A aeration system upgrade was 143,940 kWh based on comparison of energy use in 2009 to average energy use from 2004 through 2008. At the electricity rate of $0.070 / kWh (in 2009), the resultant electricity cost savings was $10,076. The energy savings from the combined Ditch A/Ditch B aeration system upgrade was 148,900 kWh for 2010 compared to average energy use from 2004 through 2008. At the electricity rate of $0.072 / kWh (in 2010), of the resultant electricity cost savings was $10,721. The simple payback for the entire construction cost of the project ($1,446,304) is more than 135 years.

While the aeration system upgrade project does not meet the case study selection criteria for a reasonable payback period described in Chapter 1, the project case study is a good example of energy savings derived as a collateral benefit from a major plant upgrade and expansion. The primary driver of this project was to increase the plant's capacity to restore permit compliance. Reducing energy consumption was a secondary consideration. Replacement of the existing mechanical brush aerators in the oxidation basins with new fine bubble diffusers and turbo blowers did, however, result in overall energy savings at the facility while accommodating a nearly 40 percent increase in the plant's organic loading.

If an alternative payback analysis is considered that accounts for the 40 percent increase in the plant's organic loading during the construction and commissioning of the Ditch A and Ditch B upgrades, the project shows a significantly lower payback of 33 years. In the year following commissioning of the total project (2010), the plant removed approximately 34 percent more Carbonaceous Biological Oxygen Demand (CBOD) compared to the period 2004 through 2008 (prior to the implementation of the oxidation ditch upgrades) while consuming less electrical power (an average of 1.59 kWh/lb CBOD during the period 2004 through 2008 compared to an estimated 1.06kWh/lb CBOD in 2010). This translates to a savings in electricity cost of $0.037 per pound of CBOD removed and an estimated $43,756 for 2010 (a 33 year payback for the total project cost of $1,446,304).

In addition to improved treatment at lower electric consumption, the Big Gulch WWTP experienced other benefits from the aeration system improvements. Labor and maintenance costs decreased because diffusers do not require the level of maintenance required for the mechanical brush system. The rotor aerators had created aerosol deposits on the railings and equipment which no longer need to be cleaned with the diffused air system. Chlorine use following the diffused air system is lower due to improved settling, and the WWTP has eliminated the use of lubrication grease for the aerators. For more information, see the Case Study Summary in Chapter 8 and the detailed facility assessment including schematics, influent and effluent data, and energy and cost data in Appendix A.

Burlington, VT

The Burlington Main Wastewater Treatment Plant, located on the eastern shore of Lake Champlain in Vermont, has a design flow of two mgd but routinely treats approximately one mgd. The original aeration system was powered by three 75 hp multi-stage centrifugal blowers. The local electric utility tested one of the blowers and found a relatively consistent power draw of approximately 53 kW. In July of 2009, the City replaced one existing 75 hp blower with a 50 hp K-Turbo blower and a new luminescent DO probe for automated control. The installed cost for the blower was approximately

$56,000. The City was able to obtain a rebate from the local electric company for $21,000, making the total project cost only $35,000[3].

The new blower has easily met the plant's target DO concentration of 2.5 milligrams per liter (mg/L) with no operational problems. The Chief Operator reported that the new blower draws between 30 and 70 percent less energy than the original blower. See Figure 5-3 for a comparison of instantaneous power readings for the new 50 hp turbo blower and power requirements for the replaced 75 hp multi-stage centrifugal blower. Based on operation to date, the estimated total annual energy savings of the new K-Turbo blower is 250,000 kWh[3]. This translates to a cost savings of approximately $34,500 per year based on an average electricity rate of $0.13/kWh and a simple payback of less than 1 year.

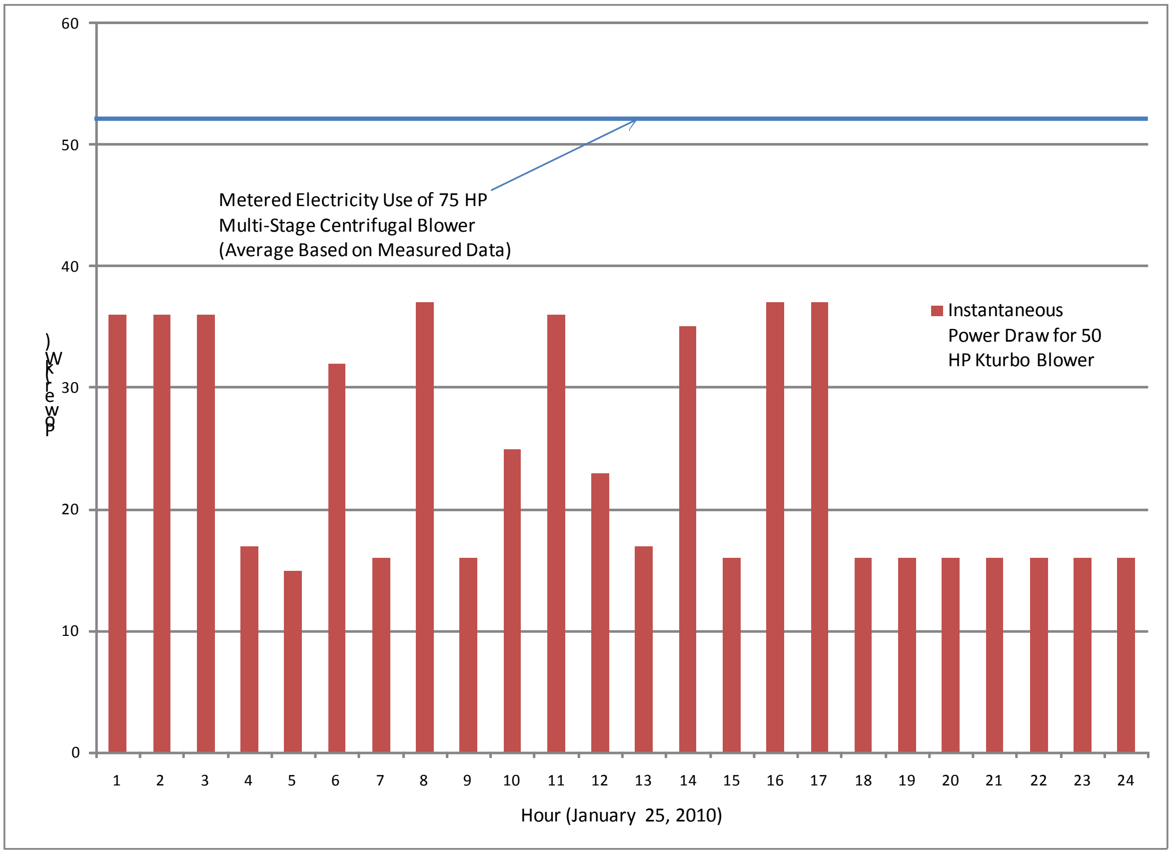

Figure 5-3. Comparison of Power Draw for Old and New Blower at Burlington, VT
Source: Data provided by Tim Grover, Chief Operator for the Main and North Plants, Burlington Department of Public Works, Burlington, VT on March 1, 2010.

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[3] E-mail communication with Tim Grover, Chief Operator, City of Burlington Department of Public Works. March 1 and March 4, 2010

5.3 Single-Stage Centrifugal Blowers with Inlet Guide Vanes and Variable Diffuser Vanes

Single-stage centrifugal blowers equipped with inlet guide vanes pre-rotate the intake air before it enters the high speed blower impellers. This reduces flow more efficiently than throttling. Blowers that are also equipped with variable outlet vane diffusers have improved control of the output air volume. Utilizing inlet guide vane and discharge diffusers on a single-stage centrifugal blower makes it possible to operate the blower at its highest efficiency point, not only at the design condition but also within a greater range outside of the design condition. PLC control can be used to optimize inlet guide vane operation (i.e., positioning) based on ambient temperature, differential pressure, and machine capacity. Automated DO and variable header pressure control can increase efficiency. See Figures 5-4 and 5-5 for example blower configurations and see Figure 5-6 for a picture of the variable outline vane diffusers.

Figure 5-4. Example of Single-Stage Centrifugal Blower with Inlet Guide Vanes and Variable Diffuser Vanes by Turblex®. Used with permission.

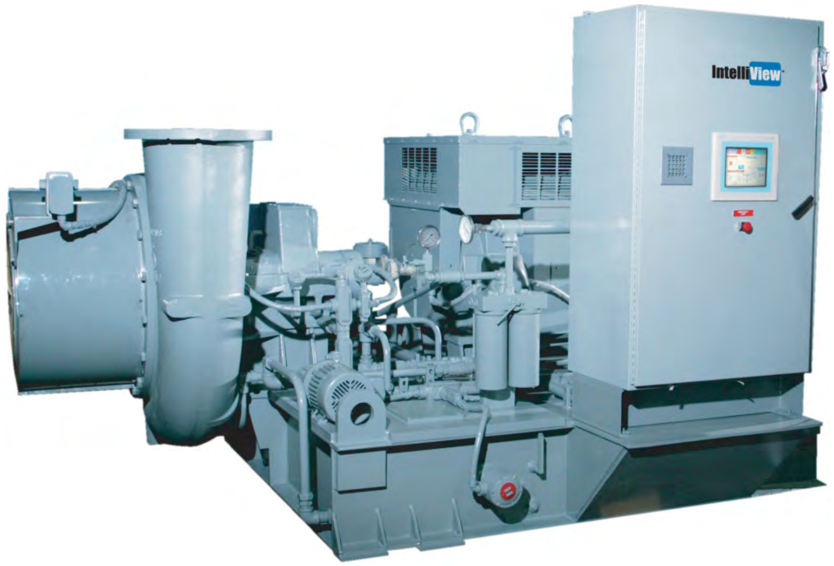

Figure 5-5. Example of Single-Stage Centrifugal Blower with Inlet Guide Vanes and Variable Diffuser Vanes by Dresser Roots
Source: Dresser, Inc. June 28 2010. Used with permission.

Figure 5-6. Variable Outlet Vane Diffuser from Turblex®. Used with permission.

Single-stage blowers with inlet guide vanes and variable diffuser vanes are currently available from the following manufacturers: Turblex (owned by Siemens), Dresser Roots, Atlas Copco, and Howden. Prior to Turblex, single-stage installations were few, largely because there were not many manufacturers of this technology (most of the Dresser Roots blowers were previously designed for industrial application).

Although most installations of single-stage blowers with inlet guide vanes and variable diffuser vanes are relatively new compared to positive displacement and multi-stage blower installations, some full scale operating data are available. The following is a summary of available data for three full-scale installations: Oneida, NY; Cape Coral, FL; and Sheboygan, WI, the latter of which is also the subject of a detailed facility assessment in Appendix A to this report. Other wastewater utilities that have installed or are planning to install single-stage centrifugal blowers include the City of Rome, NY WWTP (funded under a performance contract with Johnson Controls), and the City of Conroe, TX WWTP.

City of Oneida, NY

The City of Oneida, located in the geographic center of New York State, operates a 2.5 mgd two-stage conventional activated sludge WWTP. The city has faced many compliance challenges due to high wet weather flows, high intermittent BOD loadings from nearby dairy processing plants, regional growth, and high energy prices. In response to these challenges, the city developed a sustainability model that began with an energy audit, completed in 2005, to identify energy efficiency measures and a phased approach to address a long list of projects to improve energy efficiency as well as treatment capacity and effluent water quality. Phase 1B of the project was to install new energy efficient aeration equipment to replace existing 20-year old multi-stage centrifugal blowers along with replacement of coarse bubble diffusers with fine bubble diffusers.

The city considered several blower and diffuser choices, basing final selection on a 10-year life cycle cost analysis. They considered ceramic disk, two tube membranes, and strip membrane diffusers. While the strip membrane diffusers had the second highest capital costs, they had the lowest net present value costs and were selected for full-scale installation. The city considered five types of blowers: three multi-stage centrifugal blowers, one positive displacement blower, and the Turblex single stage centrifugal blower. Table 5-5 summarizes the City's capital cost analysis of the blowers.

Table 5-5. Net Present Worth of Blower Selections for the City of Oneida (2003$) [1]

Equipment Manufacturer (Type)	Equipment Capital Cost	Annual Energy Costs	Net Present Value	Number of Units and Horsepower, Air Capacity for Each
Continental Blower (multistage centrifugal)	$118,000	$93,800	$1.16M	3 operating/1 standby, 100 hp/unit, 1200 scfm/unit
HSI (multistage centrifugal)	$159,600	$98,900	$1.26M	3 operating/1 standby, 100 hp/unit, 1200 scfm/unit
Gardner Denver (multistage centrifugal)	$158,000	$104,000	$1.31M	3 operating/1 standby, 100 hp/unit, 1200 scfm/unit
Turblex (single-stage centrifugal)	$423,750	$58,000	$1.07M	2 operating/1 standby, 100 hp/unit, 2250 scfm/unit
Roots (positive displacement)	$104,800	$97,200	$1.19M	3 operating/1 standby, 75 hp/unit, 1200 scfm/unit

Notes:
1) Assumed 10-year life span, 4% inflation, $0.12/kWh
Source: Greene and Ramer (2007), used with permission of Mark Greene.

Although the Turblex blower's capital cost was nearly three times that of the multi-stage centrifugal unit and four times the capital cost of the positive displacement blower, the net present value was the lowest due to the reduction (approximately 40 percent or more) in yearly energy cost compared to the other blower models. Greene and Ramer (2007) cited turndown rates of 40 percent of the maximum capacity for the Turblex blower without significant reduction in operating efficiency for 5,000 to 7,000 rpm units.

The new blowers and aerators became operational in April 2006. The City of Oneida initially realized a 49 percent reduction in total plant electrical costs following the installation and start-up of the new Turblex blowers and fine bubble diffusers. The City was unable to differentiate the energy savings of the Turblex blowers from the energy savings of switching from coarse bubble to fine bubble diffusers since both changes were made simultaneously. Note that since 2006, the city has reportedly experienced operational problems (plugging) of strip diffusers and is replacing them (Greene and Ramer 2007).

Cape Coral, FL

The Everest Parkway Water Reclamation Facility in Cape Coral, FL, has been expanding and upgrading operations to keep pace with the city's growing population. The plant recently expanded from a 4-stage biological nutrient removal system to a 5-stage modified Bardenpho system, increased its capacity from 8.5 mgd to 13.4 mgd, and upgraded and automated its aeration system. As part of this expansion, the City replaced an older multi-stage centrifugal blower with a single stage 300-hp Turblex blower. The single-stage blower came on-line in June of 2008 for two of the City's new aeration basins. The old blower had an annual electricity cost of approximately $96,500 per year, compared to an expected annual energy cost of $69,700 per year for the Turblex blower, a 28 percent savings. Limited side by side testing revealed even higher savings. In a 24-hour period, the multi-stage blower consumed 5,089 kWh. The Turblex blower used 2,928 kWh in the same time frame, a 42 percent savings.

For more information, see the article by Doug Day in the March 2010 issue of Treatment Plant Operators magazine, available online at http://www.tpomag.com/editorial/view/2604/In-Control (Day 2010).

City of Sheboygan, WI (Case Study No. 2)

The Sheboygan Regional Wastewater Treatment Plant is an 18 mgd activated sludge plant with biological phosphorus removal. The plant had been running four 250 hp positive displacement blowers for the aeration basins. Faced with the need to rebuild existing blowers, plant managers decided to replace them with two, 350 hp high efficiency motor Turblex centrifugal blowers equipped with inlet guide vanes and variable diffuser vanes. The capital cost was approximately $504,000 with an installation cost of approximately $286,000. The plant received a $17,000 energy efficiency grant to help offset costs, bringing the total costs (capital plus installation minus the grant) to $773,000.

Following commissioning of the Turblex blowers, the plant operators experienced difficulty controlling DO in the individual aeration basins. DO levels reached 6 mg/L during evening hours especially in winter months. To correct this problem, air flow control valves were installed on the headers to each aeration basin along with a programmable logic controller (PLC) for automated control. The capital cost of the control valve upgrade was approximately $60,000 with an installation cost of approximately $68,000 for a total cost (capital plus installation) of $128,000.

Measured energy savings from the Turblex blowers was initially low due to DO control problems. Based on data provided by the Sheboygan WWTP, the average annual energy savings from 2006 through 2008 from the new blowers was 358,000 kWhr/yr (a 13% reduction) with an associated average cost savings of $25,644. The total annual energy savings in 2009 following the installation of air flow control valves and automated control was approximately 817,000 kWh/yr (a 30% reduction) with an associated cost savings of approximately $64,000. If the two projects are taken as a whole, the payback period for the project is 14 years. Although the plant had delayed installing the air control valves because of cost issues, the absence of control valves limited the ability of the new blowers to achieve their full potential in energy savings.

For more information, see the Case Study Summary in Chapter 8 and the detailed facility assessment including schematics, influent and effluent data, and energy and cost data in Appendix A.

5.4 New Diffuser Technology

The development of fine bubble diffuser technology in the 1970s led to significant reductions in aeration energy consumption over mechanical and coarse bubble aeration due to the increased oxygen transfer rates afforded by the high surface area of the fine bubbles. Focus on Energy (2006) estimates that using fine bubble diffusion can reduce aeration energy from 25 to as high as 75 percent. Estimated energy savings of 30 to 40 percent are common (USEPA 1999; Cantwell et. al 2009).

There are many different types of fine bubble diffusers available including ceramic/porous plates, tubular membranes, ceramic disks, ceramic domes, and elastomeric membrane disks, each with distinct advantages and disadvantages. In general, most diffusers are one of two types: (1) rigid ceramic material configured in discs or (2) perforated membrane material. Ceramic media diffusers have been in use for many years and are considered the standard against which new, innovative media are compared. Membrane diffusers consist of a flexible material with perforated pores through which air is released. Most often configured in tubes, discs or panels, they comprise the majority of new and retrofit installations.

Fine bubble aeration has been implemented at many WWTPs and is considered a common conventional ECM. The focus of this section is ECMs related to new diffuser equipment that can achieve enhanced energy reduction over fine bubble technology. Note that ECMs related to the configuration of diffusers within a basin are presented in Chapter 4 of this report.

Recent advances in membrane materials have led to ultra-fine bubble diffusers, which generate bubbles with an average diameter between 0.2 and 1.0 mm. The primary appeal of ultra-fine bubble diffusion is improved oxygen transfer efficiency (OTE). Additionally, some composite materials used in the manufacture of ultra-fine bubble diffusers are claimed to be more resistant to fouling, which serves to maintain the OTE and reduce the frequency of cleaning. Concerns about ultra-fine bubble diffusion include slow rise rates and the potential for inadequate mixing. Two proprietary ultra-fine bubble diffuser designs, panel diffusers by Parkson and Aerostrip® diffusers by the Aerostrip Corporation, are discussed below.

Panel diffusers are membrane type diffusers built onto a rectangular panel (see Figure 5-7). They are designed to cover large areas of the basin floor and lay close to the floor. Panel diffusers are constructed of polyurethane and generate a bubble with a diameter of about one mm. OTE is a function of floor diffuser coverage, which translates to improved efficiency for panel diffusers. The advantages of panel diffusers include the increased OTE and the even distribution of aeration. Disadvantages include a higher capital cost, a higher head loss across the diffuser, increased air filtration requirements, and a tendency to tear when over-pressurized.

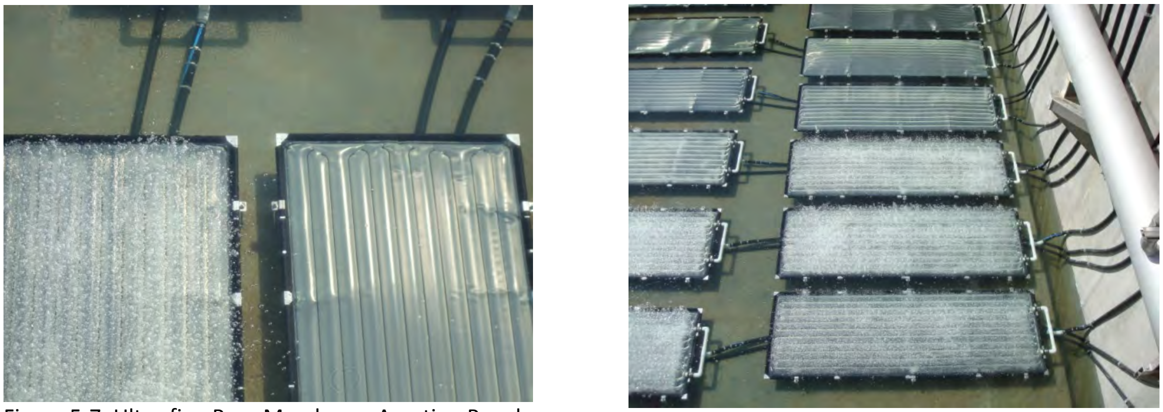

Figure 5-7: Ultra-fine Pore Membrane Aeration Panel
Source: Parkson. Used with Permission

AeroStrip® is a proprietary diffuser design manufactured in Austria by Aquaconsult. The device is a long strip diffuser with a large aspect ratio (Figure 5-8). According to the manufacturer, "…it is a homogenous thermoplastic membrane held in place by a stainless steel plate." The AeroStrip® diffuser provides many of the same advantages and disadvantages as panel diffusers; however, it appears to be less prone to tearing. Also, the smaller strips allow tapering of the diffuser placement to match oxygen demand across the basin. AeroStrips may be mounted at floor level or on supports above the floor.

Manufacturer's claims regarding the strip membrane diffuser include:

- Energy efficiencies between 10 percent and 20 percent greater than the traditional ceramic and elastomeric membrane diffuser configurations.
- Uniform bubble release across the membrane surface.
- Bubbles resist coalescing.
- Membrane not prone to clogging.
- Diffusers are self cleaning, although Aerostrip panels have been reported to be susceptible to frequent fouling requiring bumping and flexing of the membrane to dislodge.[4]

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[4] E-mail communication from David Redmond, July 11, 2010.

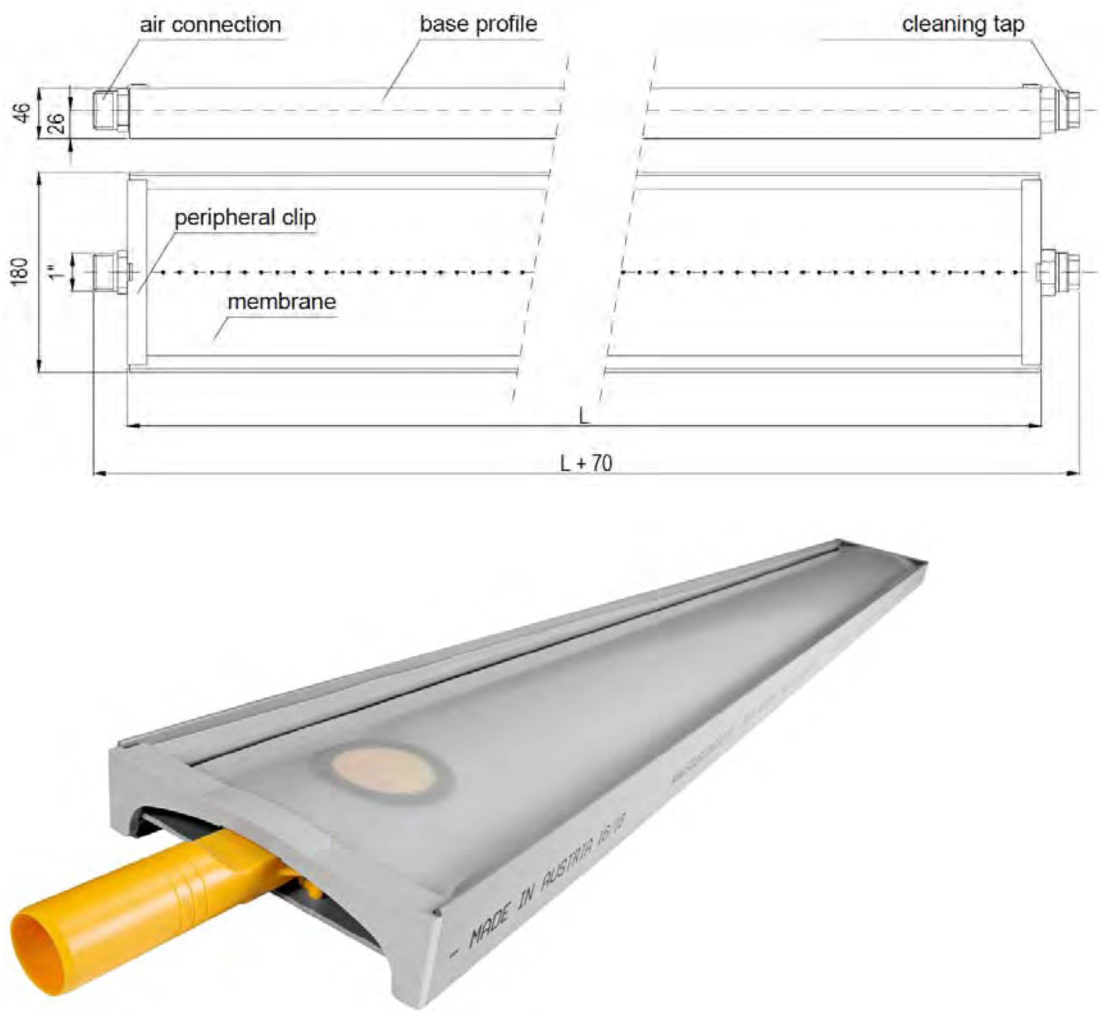

Figure 5-8: AeroStrip® Diffusers by the Aerostrip Corporation. Used with permission

5.5 Preventing Diffuser Fouling

Diffuser fouling can reduce OTE and thereby increase the energy needed to operate the aeration system. In general, fine bubble diffusers have shown to be more susceptible to fouling than coarse bubble diffusers. Most require periodic maintenance, and some must be replaced regularly. Ceramic diffusers require periodic pressure washing or acid cleaning depending on the severity of the fouling. Pressure washing is often sufficient to remove fouling, including chemical precipitates, and can restore the diffuser to near-new condition. Occasionally, acid cleaning is needed to remove precipitates. Intrusion of mixed liquor into the body of ceramic diffuser nearly always necessitates their replacement. Membrane diffusers attract slime and precipitates. Where slime can be scrubbed off removal of precipitates require an acid bath.

Some manufacturers of perforated membrane diffusers claim their products are more resistant to fouling than porous plastic or ceramic diffusers. The susceptibility to fouling is impacted by the membrane material used. A commonly used membrane material is ethylene propylenediene rubber (EPDM), which has been shown to be susceptible to biological fouling, while polyurethane or silicone materials appear to be more resistant (Wagner and Von Hoessle, 2004). New PTFE composite membranes made by Ott, SSI, and EDI were developed to minimize fouling. However, since these materials are relatively new, there is insufficient data to support this claim.

Sanitaire® by ITT Water and Wastewater has developed an in-place gas cleaning system that can be used to clean ceramic fine bubble diffusers without interruption of process or tank dewatering. It can be added as a retrofit or included as part of new installations. The system is designed to inject anhydrous HCl gas into the process air stream. At the gas/liquid interface inside the diffusers, the anhydrous HCL combines with water to form hydrochloric acid. The acid mixture reacts with and dissolves soluble minerals and removes biological foulants by decreasing the pH. Additional information from the manufacturer is available online at http://www.sanitaire.com/3117913.asp. Although many Sanitare® clean-in-place systems exist, their use is limited to existing ceramic diffusers.

A recent publication by Southern California Edison and the University of California, Los Angeles documents the development of a new monitoring device to help predict cleaning when diffused air systems require cleaning (Larson 2009). The device measures oxygen transfer efficiency and is characterized by the study as low-cost ($3,000 - $5,000) and easy-to-use. It is auto-calibrated and does not require trained experts. Prototype analyzers were installed and tested at a 10 mgd WWTP and plans are in place to install additional devices at several other plants in California. Larson (2009) estimated an average energy efficiency improvement of 15 percent with the installation of an on-line analyzer. The full report is available online at http://www.energy.ca.gov/2009publications/CEC-500-2009-076/CEC-500-2009-076.PDF .

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6. Innovative and Emerging Energy Conservation Measures for Selected Treatment Processes

Chapter 6 covers:

6.1 Introduction

Unlike energy conservation measures (ECMs) for aeration and pumping, ECMs for advanced treatment technologies such as ultraviolet (UV) disinfection and membrane bioreactors (MBRs), and for other process functions, such as anoxic zone mixing are emerging and generally not yet supported by operating data from full-scale installations. They are very important, however, because wastewater treatment plants (WWTPs) are increasingly employing these technologies. This chapter provides a discussion of ECMs for advanced technologies and presents full-scale plant test results where available. Where operation data are not available for manufacturer's information is provided.

6.2 UV Disinfection

Because of concerns related to security, safe handling, and effluent toxicity associated with chlorine, UV radiation has become increasingly popular over the years as an alternative to chemical disinfection. Leong et al. (2008) estimated that as of 2007, approximately 21 percent of municipal WWTPs were using UV for disinfection. That number is only expected to rise as manufacturers continue to improve UV equipment designs and decrease costs, and as more and more WWTPs gain experience with the technology.

UV radiation at certain wavelengths (generally between 220 to 320 nanometers [nm]) can penetrate the cell walls of microorganisms and interfere with their genetic material. This limits the ability of microorganisms to reproduce and, thus, prevents them from infecting a host. UV radiation is generated by passing an electrical charge through mercury vapor inside a lamp. Low-pressure, low-intensity lamps, which are most common at WWTPs, produce most radiation at 253.7 nm. Medium-pressure high-intensity lamps emit radiation over a much wider spectrum and have 15 to 20 times the UV intensity of low-pressure low-intensity lamps. Although fewer lamps are required as compared to low-pressure systems, medium-pressure lamps require more energy.

Components of UV disinfection equipment include the UV lamp (mercury and inert gas inside a lamp envelope with electrodes on either side to emit a charge), a quartz sleeve around the lamp to protect it and prevent breakage, a lamp cleaning system, sensors, and a control system. The most common configuration for wastewater treatment is for open channel flow and modular design (WEF and ASCE 2010). Lamps are either parallel or perpendicular to the direction of flow and arranged horizontally or vertically. The perpendicular to flow configuration is more commonly used for wastewater treatment applications, whereas the parallel to flow configuration is typically used for potable water applications.

Some UV systems are manufactured in a closed channel pressure vessel configuration. Figure 6-1 shows examples of UV lamp designs. For more information on UV disinfection for wastewater, see the USEPA Technology Fact Sheet on UV disinfection (USEPA 1999), available online at http://www.epa.gov/OWM/mtb/uv.pdf and Chapter 19 of the Water Environment Federation (WEF) *Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants* (WEF and ASCE 2010).

(a) (b)

(c) (d)

Figure 6-1. Example UV Lamp Configurations for Wastewater Treatment (a) Calgon $C^3$150 for open channel flow, horizontal and parallel lamp arrangement (b) TrojanUVFit for closed channel flow (c) TrojanUV4000Plus for open channel flow, horizontal and parallel lamp arrangement, and (d) Aquaray® 3X Vertical Lamp System for open channel flow, perpendicular lamp arrangement. Used with permission.

Energy requirements for UV depend on the number, type, and configuration of lamps used to achieve the target UV dose for pathogen inactivation. One of the most important factors affecting UV dose delivery is UV transmittance (UVT) of the water being disinfected. UVT is defined as the percent of light passing through a wastewater sample over a specific distance (1 centimeter). It takes into account the scattering and adsorption of UV by suspended and dissolved material in the water. UVT is affected by level of pretreatment – filtered wastewater has a much higher UVT than unfiltered water. Microorganisms that move quickly through the reactor far from the lamp will receive a lower dose than microorganisms that have longer exposure to the UV radiation and are closer to the lamp. Other factors affecting UV dose delivery are temperature, lamp age, and lamp fouling. Because UV disinfection is complex and based on many factors, dose estimation methods are complicated and typically involve computational fluid dynamic modeling or bioassays. Dose can be maintained at a minimum level or can be controlled based on water quality (i.e., lowered during periods of improved quality) which can save energy.

A study funded by the Pacific Gas and Electric (PG&E) company found that the energy consumed by UV disinfection can account for approximately ***10 to 25 percent*** of total energy use at a municipal wastewater treatment facility (PG&E 2001)[1]. Energy required for low-pressure lamps ranged from approximately 100 to 250 kilowatt hours (kWh) per million gallons (MG). Energy required for medium-pressure systems ranged from 460 to 560 kWh/MG, with one plant requiring 1,000 kWh/MG to achieve a very high level of coliform inactivation. PG&E (2001) reported that UV disinfection performance in relation to input energy is not linear. An increasing amount of energy is required to obtain marginal reductions in most probable number (MPN) per milliliter for total coliforms.

ECMs for UV disinfection are fairly new, and energy savings/cost data are not well documented in the literature. Still, growing experience with UV disinfection has revealed practical design, operation, and maintenance strategies that can reduce the energy use of UV disinfection. The following sections summarize these ECMs and provide detailed information on upgrades and associated energy savings for several WWTPs as reported in the literature.

6.2.1 Design

Pretreatment

Pretreatment to remove suspended solids from wastewater, such as tertiary sand filtration or membranes, can increase UVT and allow a plant to reach the same level of treatment at a lower UV dose, thereby saving energy. If a plant uses iron or aluminum compounds for chemical precipitation of phosphorus, it is important to minimize residual iron and aluminum concentrations to prevent acceleration of UV lamp fouling (Leong et al. 2008).

Lamp Selection

Medium-pressure lamps require two to four times more energy to operate than low-pressure, low-intensity lamps. In some cases, WWTPs can save on energy costs by specifying low-pressure low-intensity lamps. Tradeoffs are (1) a larger footprint for the same disinfection level, which can be

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[1] Based on a detailed evaluation of seven wastewater treatment plants ranging in flow rate from 0.4 to 43 million gallons per day (mgd). Data set included plants with low-pressure low-intensity lamps and high-pressure high-intensity lamps in a variety of configurations.

significant because as many as 20 low-pressure low-intensity lamps are needed to produce the same disinfecting power as one medium-pressure lamp, and (2) higher operating costs for maintenance and change out of additional lamps.

Low-pressure high-output lamps are similar to low-pressure low-intensity lamps except that a mercury amalgam is used instead of mercury gas so they can operate at higher internal lamp pressures. Thus, the UV output of a low-pressure high-output lamp is several times that of a low-pressure low-output lamp (Leong et al. 2008). Low-pressure high-output lamps have significant advantages of:

- Reducing lamp requirements (i.e., quantity) compared to traditional low-intensity lamps, and

- Reducing energy requirements compared to medium-pressure lamps.

Leong et al. (2008) reported that the energy demand for low-pressure high-output systems is similar to that of low-pressure low-intensity systems. Thus, low-pressure high-output lamps may be a good option for reducing the number of lamps and footprint while keeping the energy requirements low.

Salveson et al. (2009) presented results of a pilot test at the Stockton, CA WWTP comparing design conditions and operation of medium pressure and low-pressure high-output lamps. Results are shown in Table 6-1. The power draw for the low-pressure high-output lamps was between 20 and 30 percent of the power draw for the medium pressure lamps, reducing annual O&M costs significantly. These results are similar to information reported from one manufacturer for a 30 mgd plant treating secondary effluent. A low-pressure high output system would use 60 kW at peak flow compared to 200 kW for a medium pressure system (Faber 2010).

Table 6-1. Disinfection Equipment Power and Cost Estimates (55 mgd Peak Flow, 38 mgd Average Flow, 65% Design UVT)

Dose (mJ/cm^2)	Lamp Type	Total No. of Lamps	Power (kW)[1]	Annual Energy Costs[2]	Life Cycle Cost[3]
50 Medium	Pressure	216	648	$681,000	$20,427,000
	Low Pressure High Output	768	143	$150,000	$14,248,000
70 Medium	Pressure	324	1,058	$1,120,000	$31,741,000
	Low Pressure High Output	1,152	219	$231,000	$19,726,000
110 Medium	Pressure	540	1,512	$1,589,000	$46,988,000
	Low Pressure High Output	1,792	415	$437,000	$30,615,000

1. Power draw is based on operational values (kW).
2. Based on operational values and energy cost of $0.13 per kWh.
3. Life Cycle Cost = 13.01 (20 years annual cost at 4.5% discount rate) * annual O&M cost + project cost

Source: Salveson et al. 2009; Supplemental information provided in e-mail communication to the author from Nitin Goel, March 24, 2010. Used with permission.

System Turn-Down

Similar to the design of blowers for aeration systems, it is important that designers allow for sufficient UV system turn-down to respond to changes in flow and wastewater quality. Flexibility and control in design is a key factor in operating efficiently from the day the technology is commissioned until the end of its design life.

The configuration of the lamps dictates the approach for lamp turn-down. In systems with vertical lamp configurations, the water level can vary during operation (with respect to the submerged portion of the lamp), whereas in a horizontal lamp configuration, the water levels should remain relatively constant (with respect to lamp submergence). Individual rows of lamps can be turned on and off in vertical configurations. In horizontal arrangements, channel control is more typically used to respond to varying flows (Leong et al. 2008). Regardless of configuration, the number of channels should be selected to maintain a velocity that has been tested and is known to provide the required dose delivery.

System Hydraulics to Promote Mixing

As noted previously, UV dose delivery inside a UV reactor depends on the hydraulics. Optimized longitudinal and axial mixing of the water is critical to maintaining a minimum UV dose throughout the reactor. In general, this is achieved by operating at a sufficiently high approach velocity to ensure turbulent flow conditions (WEF and ASCE 2010). WWTPs should conduct full-scale, pilot testing before installation to ensure that mixing effects are addressed in design. Flow equalization prior to the UV reactor can also stabilize hydraulic conditions and prevent high or low flows from causing reduced UV disinfection performance. It is important to note that mixing is a balancing act. Extreme agitation of the wastewater can create bubbles that shield pathogens from exposure to the UV radiation.

6.2.2 Operation and Maintenance

Automation

Automation can reduce the number of lamps and/or channels operating based on real-time flow and wastewater characteristic data, thereby reducing energy use and also extending UV lamp life. Controls can be designed to turn off lamps or divert flow to a few operating channels depending on the UV system design. Control is most commonly flow-paced control or dose-paced control. Flow-paced is the simplest with number of lamps/channels in service based strictly on influent flow rate. Dose-paced control is based on the calculated dose, which is derived from the following online monitoring data (Leong et al. 2008):

- Flow rate
- UVT
- Lamp power (including lamp age and on-line intensity output data)

Dose-paced control more closely matches the UV dose delivered to wastewater conditions. For example, during periods of high solids removal, UVT will increase and UV output can be decreased to achieve the same dose. During wet weather events or other periods of low effluent quality, lamp output can be increased in response to reduced UVT.

At the University of California, Davis Wastewater Treatment Plant, process controls were implemented to divert flow automatically to one of two channels during low flow conditions (Phillips and Fan 2005). This change provided the flexibility to operate at 33, 50, 67 and 100 percent of maximum power. The original design limited operation to 67 and 100 percent of maximum power. The annual energy use at the UC Davis WWTP is expected to decrease by 25 percent once the process changes are fully implemented in the fall of 2010[2].

Lamp Cleaning and Replacement

The effectiveness of UV disinfection systems depends on the intensity of the ultraviolet radiation to destroy the microorganisms in the treated wastewater. Two factors that affect UV intensity during operation are lamp age and quartz sleeve fouling.

After an initial burn-in period, the lamp output decreases gradually toward the end of lamp life. The "end of lamp life" is defined by the manufacturer and is operating hours at which the lamp reaches a specified minimum output. The operating life of UV lamps is provided below (WEF and ASCE 2010):

- Low-pressure, low-intensity lamps: 7,500 to 8,000 hours
- Low-pressure, high-intensity lamps: 12,000 hours
- Medium-pressure lamps: 5,000 hours

WWTPs can provide a relatively consistent level of lamp output by establishing a schedule for staging lamp replacements.

Algal growth, mineral deposits, and other materials can foul the lamp sleeve and subsequently decrease UV intensity and disinfection efficiency. Cleaning and maintaining quartz sleeves are critical to ensuring the optimum performance of UV disinfection and can result in substantial energy savings. Most equipment suppliers provide automatic cleaning mechanisms which consist of chemical cleaning, mechanical cleaning, or both. One study found that a combination of mechanical and chemical cleaning was superior to mechanical cleaning alone (Peng et al. 2005, cited in Leong et al. 2008).

The Efficiency Partnership (2001) presents an example of energy savings due to increased attention to UV system cleaning and lamp replacement. At the Central Contra Costa Sanitary District (CCCSD), lamp cleaning and maintenance is particularly important because they are disinfecting secondary effluent with fairly low water quality. CCCSD found that increased maintenance of the UV lamps (i.e. the cleaning and replacement of UV bulbs) at its wastewater treatment facility resulted in a reduction in the number of UV banks required for the disinfection system from nine to six banks. Efficiency Partnership (2001) reported that this new maintenance strategy resulted in a power savings of 105 kW. Additional information is available online at http://www.fypower.org/pdf/CS_Water_CCCSD.pdf.

6.3 Membrane Bioreactors (MBRs)

Membrane bioreactors (MBRs) are becoming more common as WWTPs are required to meet increasingly stringent effluent limits and in some cases, reuse requirements in smaller footprints. The unique feature of MBRs is that instead of secondary clarification, they use membrane treatment, either as vacuum-driven systems immersed in a biological reactor or pressure-driven membrane systems located external to the bioreactor, for solids separation. Membranes are typically configured hollow tube fibers or flat panels and have pore sizes ranging from 0.1 to 0.4 microns. Although MBRs have

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[2] Readers may contact David Philips (530-754-8214, dxphillips@ucdavis.edu) or Michael Fan (530-752-7553, mmfan@ucdavis.edu) for additional information.

many operational advantages, they use more energy than conventional processes in order to move water through the membrane and for membrane scouring and cleaning. WEF (2009) reports that energy requirements of MBR systems may be twice that of conventional activated sludge systems.

Because the technology is not widespread, ECMs for MBRs are emerging. The emerging ECM identified in this report is membrane air scour alternatives.

Membrane fouling has been identified as the most significant technical challenge facing this technology (Ginzburg et al. 2008). Fouling occurs when the membrane pores become obstructed with the mixed liquor suspended solids being filtered, causing a loss in permeability. The main causes of membrane fouling are initial pore blocking where particles smaller than the membrane pore size plug the openings, followed by cake fouling, where particles accumulate on the membrane over time forming stratified "cake" layers (Peeters et al. 2008; Lim and Bai 2003). Although different membrane manufacturers use different techniques to control for fouling, the primary method to address cake fouling is aeration along with periodic chemical cleaning. Peeters et al. (2007) report that membrane aeration to control fouling accounts for 35 to 40 percent of total power consumption of an MBR.

In recent years, several membrane manufacturers have modified operational strategies to reduce air scour fouling control requirements (Wallis-Lage and Levesque 2009). For example, Kubotavaries the volume of air used for aeration based on the flux (e.g., lower air scour rates are used for lower flux values). The manufacturer of the Huber system claims reduced energy consumption for air scour due to a centrally positioned air intake and low pressure.[3] . Siemens uses a combination of air and water to scour the membrane (Wallis-Lage and Levesque 2009). General Electric (GE) implemented "cyclic" air scour whereby aeration would turned on and off in 10 second intervals. A newer innovation is their 10/30 Eco-aeration where the membrane is scoured for 10 seconds on, 30 second off during non-peak flow conditions. GE claims that the 10/30 Eco-aeration can reduce energy consumption by up to 50 percent compared to the standard 10/10 aeration protocol (Ginzburg et al. 2008).

The literature includes pilot- and full-scale test data for a membrane fouling controller and algorithm used to clean the GE ZENON ZeeWeed MBR. They system uses real-time analysis of the membrane's filtration operating conditions to determine the fouling mechanism present in the MBR system. The information obtained from the algorithm dictates the implementation of specific control actions to respond to the particular fouling mechanism (e.g., membrane aeration, backwash, chemical cleaning – the biggest impact on energy consumption being membrane aeration). When aeration is identified as the control action, the fouling controller/algorithm provides the MBR Programmable Logic Controller (PLC) system the information to select between the traditional 10/10 (air scour On/Off) protocol and a 10/30 Eco Aeration energy saving protocol. The algorithm was piloted and later full-scale tested at a 3 million gallon per day (mgd) plant in Pooler, Georgia (Ginsburg et al. 2008). Ginzburg (2008) concluded that additional research is required to further develop the on-line fouling controller to include additional control parameters such as membrane aeration flow rate, backwash flow rate, and backwash duration.

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[3] For more information, visit the manufacturer's website at http://www.huber.de/products/membrane-bioreactor-mbr/huber-vrmr-bioreactor.html

6.4 Anoxic and Anaerobic Zone Mixing

Many WWTPs are implementing biological nutrient removal (BNR) for nitrogen and /or phosphorus to protect receiving waters and prevent eutrophication, particularly in coastal regions. Biological nitrogen removal is a two step process consisting of nitrification to convert ammonia to nitrate (NO_3) followed by denitrification to convert nitrate to nitrogen gas. Nitification of ammonia is an aerobic process and can occur in the aerated zone with sufficient solids residence time (SRT). Significant energy can be required for complete nitrification of ammonia. Denitrification is an anoxic process accomplished in the absence of dissolved oxygen so that the microorganisms will use nitrate as their oxygen source. Dentrification can be accomplished in a denitrifying filter, but most often, it occurs in a suspended growth anoxic zone where the denitrifying microorganisms can use organic material present in the wastewater instead of or in addition to an external carbon source. A common configuration of the suspended growth nitrification-denitrification process is the Modified Ludzack-Ettinger (MLE) process, which has an initial anoxic zone followed by an aerobic zone. Nitrification occurs in the aerobic zone from which pumps recycle nitrate-rich mixed liquor to the anoxic zone for denitrification.

Biological phosphorus removal works by exposing the biomass first to anaerobic conditions. As long as a sufficient food source (i.e., volatile fatty acids) is present, microorganisms called phosphate accumulating organisms (PAOs) will release stored phosphorus in the anaerobic zone, which conditions them to uptake larger amounts of phosphorus when they enter the aerobic zone. Phosphorus is removed when biomass is wasted from the aerobic zone.

It is important to mix the wastewater in the anoxic zone to maintain suspension of solids and ensure that denitrifying microorganisms come into contact with nitrate. Similarly, it is important to mix the wastewater in the anaerobic zone to maintain suspension of the solids and PAIs. The mixers, however, cannot impart oxygen to the water (this would cause them to use oxygen as their electron exceptor instead of nitrate). Similarly for the anaerobic zone in biological phosphorus removal systems, mixers are needed to contact waste and microorganisms but must not transfer oxygen to the water (oxygen would promote growth of microorganisms other than PAOs which would compete with them for the food source). Low-speed submersible mixers are commonly used for these processes.

Two emerging ECMs have been identified to reduce the energy required to mix anoxic and anaerobic zones: hyperbolic mixers and pulsed large bubble mixing.

6.4.1 Hyperbolic Mixer

A new hyperboloid mixer has undergone full-scale testing at two large wastewater treatment plants in the U.S. and has shown significant energy savings compared to traditional submersible mixers. The mixer is a vertical shaft-type mixer with a hyperboloid-shaped stirrer located close to the bottom of a tank. The stirrer is equipped with transport ribs that cause acceleration of the wastewater in a radial direction to promote complete mixing (see Figure 6-2 for a schematic). The hyperboloid mixer has been used in Europe for more than ten years with installations in Germany, Holland, and Belgium (Gidugu et al. 2010).

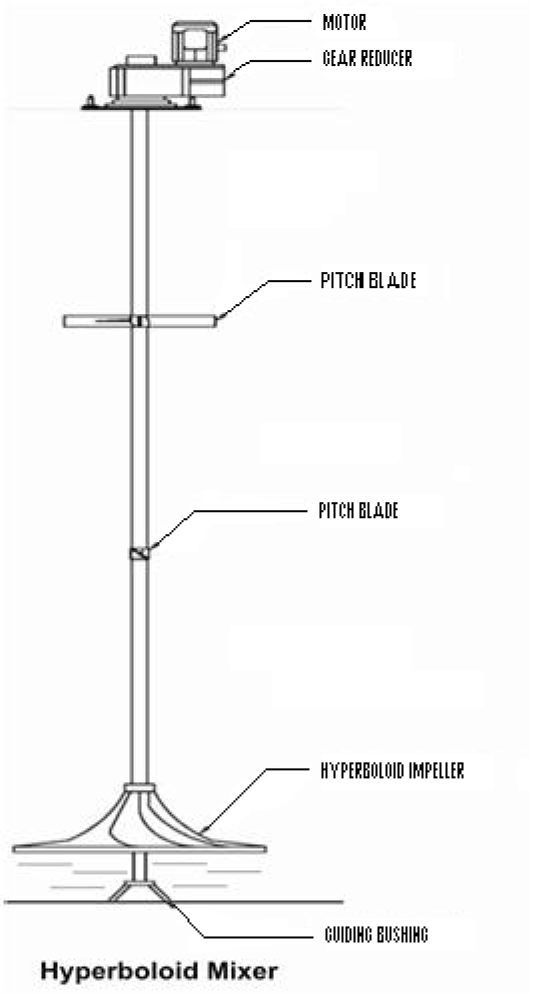

Figure 6-2. Typical Installation of a Hyperboloid Mixer
Source: Gidugu et al. 2010. Used with permission.

A recent study at the Bowery Bay Water Pollution Control Plant (WPCP) in New York City compared the performance of traditional submersible mixers (specifically 2 blade propeller mixers mounted to the side of the tank) to a hyperbolic mixer, the HYPERCLASSIC HC RKO 2500® (Fillos and Ramalingam 2005) for anoxic zone mixing. Researchers evaluated the two mixers based on their ability to:

- Sustain uniform distribution of suspended solids in the basin,
- Maintain a low DO concentration (< 0.3 milligrams per liter), and
- Maintain a hydraulic profile supportive of denitrification (as determined using tracer tests).

Although both mixers at the Bowery Bay WPCP were able to achieve good distribution of solids with low DO, the Hyperclassic mixer had a superior hydraulic profile. Moreover, the authors reported lower energy needs for the Hyperclassic mixer due to its design: 2.2 brake horsepower (bhp) for the Hyperclassic mixer compared to 6.0 bhp for the submersible mixer. The authors reported a total energy cost of $1,131 for the Hyperclassic mixer compared to $3,075 for the submersible mixer per anoxic zone per year, for a savings of close to $2,000 based on a current energy rate of $0.039 per kWh[4]. The capital cost of the Hyperclassic mixer is approximately $10,000 more than the uniprop mixer, so simple payback would be approximately five years per anoxic zone.

Gidugu et al. (2010) reported results of side by side testing of the new hyperboloid mixer and a conventional hydrofoil mixer at the Blue Plains WWTP in Washington, D.C. The hydrofoil mixer, which is widely used in the U.S., has a vertical shaft and a hydrofoil impeller with four angled stainless steel blades (Gidugu et al. 2010). See Figure 6-3 for a schematic of the hydrofoil mixer. Two 20 hp hydrofoil mixers were installed in one of the anoxic zones at the Blue Plains WWTP in October 2004 for evaluation. Six 10 hp hyperboloid mixers were installed in three anoxic zones (two per zone) for testing in October 2008. Researchers collected data to create DO and TSS profiles in all four anoxic zones in June 2008 to evaluate mixing.

Results showed similar results to Bowery Bay WPCP, with the hyperboloid mixer achieving good distribution of solids with low DO. TSS concentrations within the hyperboloid mixer were spread out over a smaller range of values than within the traditional hydrofoil mixer, indicating more uniform mixing. Gidugu et al. (2010) present a comparison of energy use, citing 9.7 bhp per unit for the 10 hp hyperboloid mixer compared to 17.3 bhp for the hydrofoil mixer. Based on an electricity cost of $0.10/kWhr, they estimated energy savings potential of over $5,000 per year per mixer. At a cost difference of only $2,000 more for the hyperboloid mixer compared to the hydrofoil mixer, simple payback would be less than one year.

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[4] Based on this information, energy use for the Hyperclassic mixer would be 29,000 kWh/yr compared to 78,850 kWh/yr for the submersible mixer for an energy savings of 49,850 kWh/yr per anoxic zone.

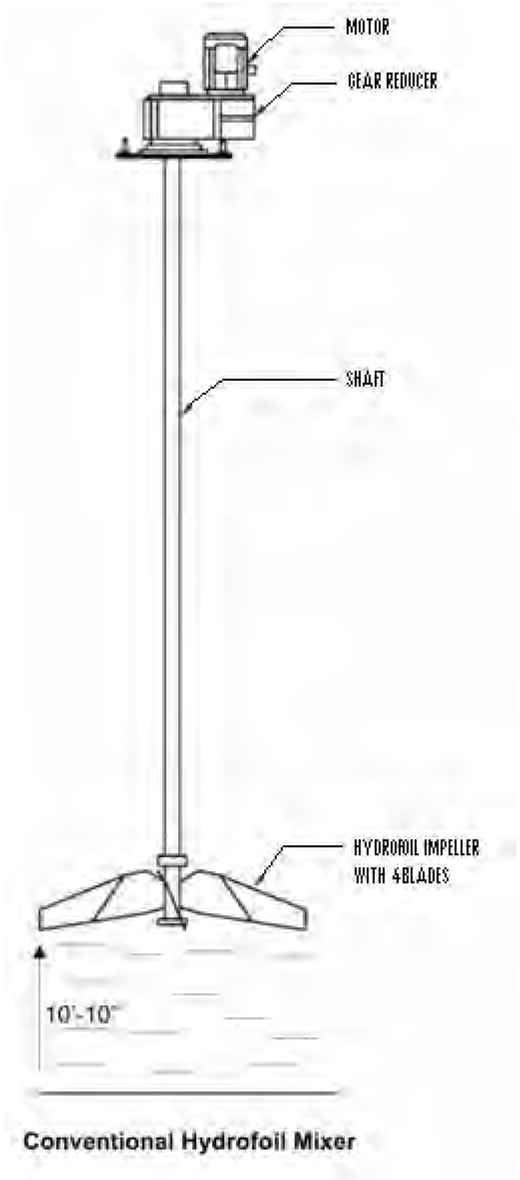

Figure 6-3. Conventional Hydrofoil Mixer
Source: Gidugu et al. Used with permission.

6.4.2 Pulsed Large Bubble Mixing

An innovative mixing technology by Enviromix called Bio^{M}x reduces energy required for anoxic or anaerobic zone mixing by firing short bursts of compressed air into the zone instead of mechanically mixing it. Uniquely designed nozzles produce a mass of large air bubbles, ranging from marble to softball size, which mix the water as they rise to the surface (Randall and Randall 2010). The large air bubbles, much larger than those made by coarse bubble diffusers, are designed to minimize oxygen transfer and maintain anoxic or anaerobic conditions. The system includes a PLC to manage the timing of the air control valve firing, which gives the operator flexibility to respond to different conditions within the tank. The manufacturer reports that the system has non-clogging, self cleaning in-tank components that require no maintenance. See Figure 6-4 for a typical installation and the manufacturer's website for additional information (http://www.enviro-mix.com/biomx.php).

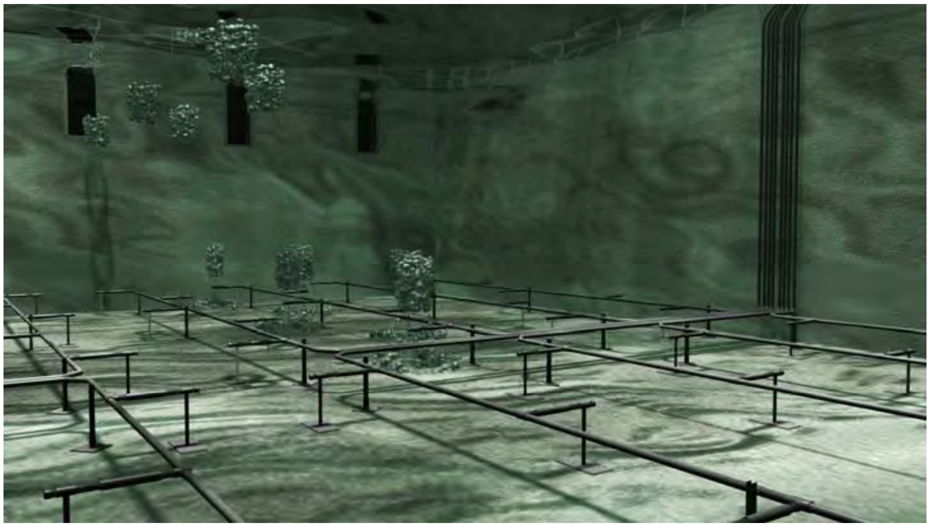

Figure 6-4. Typical BioMix^{TM} Installation
Source: EnviroMix. Used with permission

An independent study at the F. Wayne Hill Water Resources Center in Gwinnett County, Georgia compared the performance and energy use of Bio^{M}x to submersible propeller mixers (Randall and Randall 2010). The plant, treating 30 mgd on average with a design flow of 60 mgd, operates up to 10 parallel treatment trains each with anaerobic, anoxic, and aerobic zones for biological nitrogen and phosphorus removal. In the spring of 2009, the Bio^{M}x system was installed in two anaerobic cells of one treatment train. The system consisted of an Ingersoll Rand 5 – 15 hp variable speed rotary screw compressor, piping, controls, and floor mounted nozzles. Findings from the technology evaluation performed in January 2010 are summarized below.

- Dye tracer tests showed similar mixing for the Bio^{M}x and submersible mixer systems.
- Total suspended solids (TSS) profiles showed that the Bio^{M}x unit is capable of mixing to homogeneity similarly to the submersible mixing units, although variability in the Bio^{M}x cells was slightly higher.

- Continuous oxidation reduction potential (ORP) measurements over periods of 12 to 28 hours showed 95th percentile ORP values of less than -150 millivolts (mv), which is indicative of anaerobic environments. Given the success in anaerobic environments (< -100 mv), the technology is also applicable for use in anoxic environments.

- Power analyzer readings taken simultaneously showed that energy (in kW) required to mix one anaerobic cell using the Bio^{M}x system was 45 percent less than the energy required by a submersible mixer. When operated in three cells using the same compressor, 60 percent less energy was required (0.097 hp/1000 cf)

The manufacturer also presents test results conducted from April 2009 through February 2010, available online at http://www.enviro-mix.com/documents/FWayneHillEnergySuccessStory2009-091001.pdf.

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7. Energy Conservation Measures for Solids Processing

Chapter 7 covers:

7.1 Introduction

Wastewater utilities use a variety of treatment techniques to convey, store, and process solids. Biological, chemical, or thermal stabilization processes are used to reduce pathogens, vector attraction, and odors. These are commonly followed by dewatering techniques to concentrate the solids before disposal. Concentrating the solids removes excess liquid that can be recycled to the head of the treatment plant and reduces the hauling and disposal expense. The final treated product is either sent to a landfill (which is becoming less common), incinerated, or reused as land-applied biosolids or biosolids products. The energy used to process residual solids at a wastewater treatment plant (WWTP) varies greatly depending on the treatment and dewatering techniques used.

Sections 7.2 and 7.3 identify innovative energy conservation measures (ECMs) for digestion and incineration, respectively, and provide supporting data from case histories. Section 7.4 describes an emerging ECM for thermal drying: solar drying. Although several sources cite a growing use of solar drying beds, full scale operating data have not been identified (thus, it's categorization as emerging). The reader is referred to the Water Environment Federation (WEF) Manual of Practice (MOP) No. 32, *Energy Conservation in Wastewater Treatment Facilities* (2009) for general guidance on designing and operating solids treatment processes to reduce energy use.

7.2 Digestion

Aerobic and anaerobic digestion are common methods used to stabilize sludge at wastewater treatment plants. Aerobic digestion is an energy intensive process that breaks down organic material in the presence of oxygen. It generally produces less residual solids than anaerobic digestion and is easy to operate; however, in addition to being energy intensive, it produces a sludge that is difficult to dewater and may further decompose, potentially causing odor problems (WEF 2009). Anaerobic digestion is a fairly energy efficient process that breaks down volatile organic matter into methane, carbon dioxide, ammonia, and water in the absence of oxygen. The biogas produced by anaerobic digestion can be captured and used to generate electricity and heat.

WEF (2009) describes the following ECMs that can be used to conserve energy during aerobic digestion:

- Aerobic-anoxic operation
- Operation at low dissolved oxygen (DO) concentrations

- Reducing digestion time by meeting vector attraction criteria using the specific oxygen uptake rate (SOUR)
- Assessing optimal solids concentration

Because methods for introducing oxygen to aerobic digesters are similar to methods used for aeration, ECMs for aeration as described in Chapters 4 and 5 of this report can also be considered for aerobic digestion. For example, replacing coarse bubble with fine bubble diffuser systems and use of automated DO control can reduce aerobic digestion energy requirements by 20 to 50 percent.[1] ECMs are most effective if the digester is oxygen limited rather than mixing limited (i.e., the air flow rate needed to supply oxygen exceeds the air flow rate needed to maintain proper solids suspension). Engineers should use caution because some plants have observed premature wear of fine bubble diffusers due to the abrasive nature of the thickened solids. Wear of the diffusers can be minimized by incorporating proper grit removal in the influent treatment process.

Many techniques can be used to optimize biogas production by anaerobic digesters. For example, increasing the primary solids concentration and adequate mixing can aid in digester gas production. Adding fat, oil, and grease from restaurant and factory grease traps will yield, perhaps, the largest increase in gas production. EPA is evaluating various technologies for combined heat and power used at wastewater facilities and will publish the results as a separate report. The remainder of this section describes a relatively new ECM for anaerobic digestion: use of the vertical linear motion mixer.

Vertical Linear Motion Mixer

Effective mixing of the digester contents is important for process stability, to prevent solids deposition, and to minimize scum and foam formation. Mixing is commonly achieved with recirculation pumps, gas mixers that bubble digester gas up through the tank, or conventional propeller-type mixers that stir the digester contents. A new technology called the vertical linear motion mixer from Enersave Fluid Mixers, Inc., mixes digester contents by moving a thin steel disk in an up and down motion to create axial and lateral agitation. An internal Cam-Scotch-Yoke drive electric motor operating system converts the rotary motion of a motor to the vertical (up and down) motion of the drive shaft. See Figure 7-1 for a schematic of the mixer. The manufacturer claims as much as 90 percent energy reduction from the vertical linear motion mixer compared to conventional mixing technologies. Additional information on the technology can be found on the manufacturer's website at http://www.enersavemixers.com/.

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[1] E-mail communication with Thomas E. Jenkins, August 4, 2010.

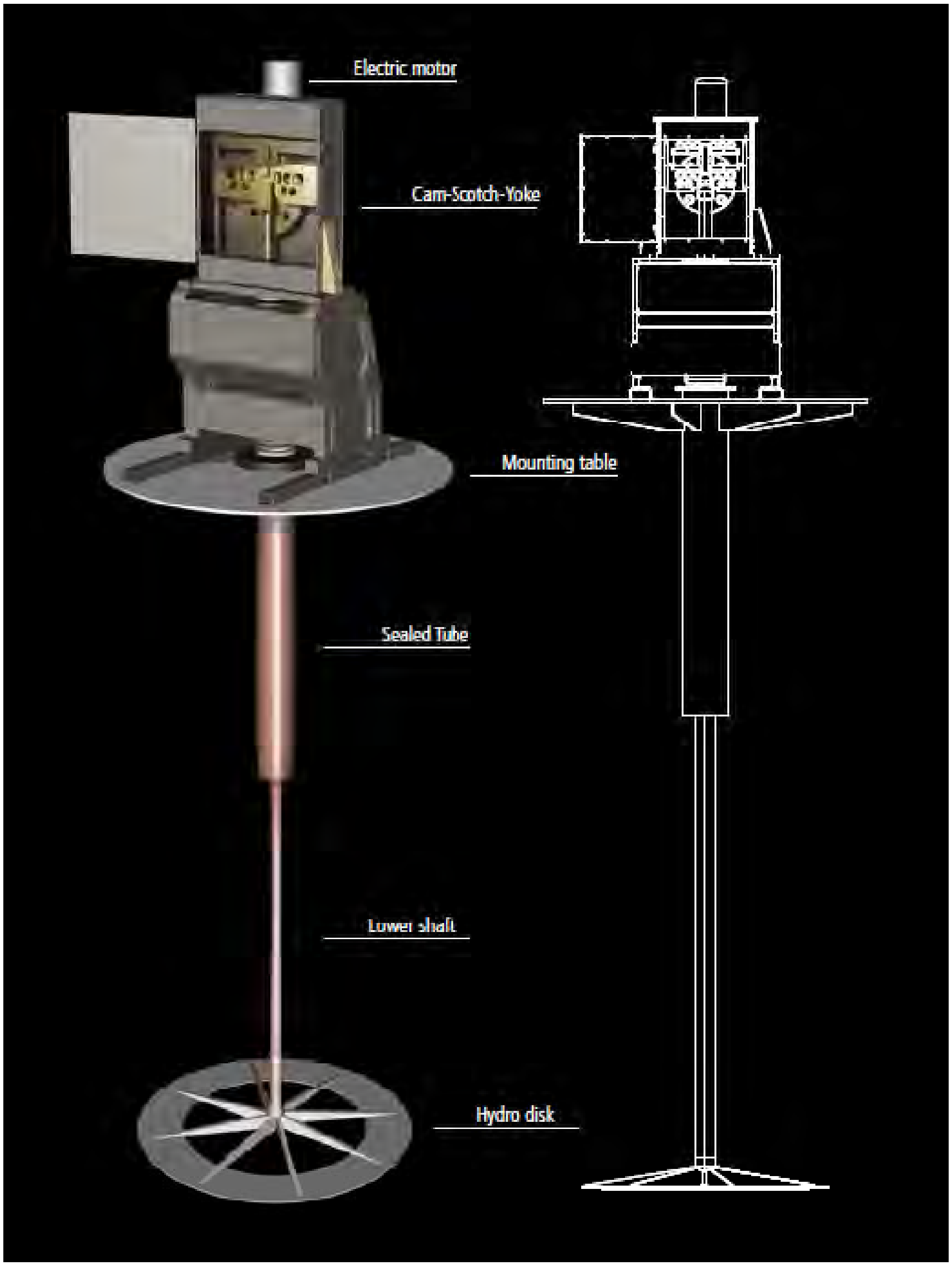

Figure 7-1 Vertical Linear Motion Mixer by Enersave Fluid Mixers, Inc.
Source: http://www.enersavemixers.com/. Used with permission

Massart et al. (2008) presents results of side-by-side testing of the vertical linear motion mixer and conventional mixing at the Ina Road Wastewater Reclamation Facility (WRF) in Tuscon, Arizona. The Ina Road WRF, treating approximately 25 million gallons per day (mgd), operates four anaerobic digesters to stabilize combined waste solids from primary clarifiers, a high-purity oxygen activated sludge system, and waste activated sludge from a biological nutrient removal process. Each digester is approximately 90 feet in diameter and 40 feet deep. The digesters were originally each equipped with four peripheral 20 hp (15 kW) rotary draft tube impellers and one 10 hp rotary draft tube impeller in the center of the basin. A new vertical linear motion mixer was installed in Digester 4 in December 2003. The single 10 hp mixer consisted of a 7-foot diameter disk located approximately 18 feet below the digester surface. Based on manufacturer's experience at similar installations, only one central mixing unit was installed to fully mix the basin contents. The motor operates the disk up and down at approximately 0.5 cycles per second.

A tracer test was conducted to analyze the performance of the new system and compare its operation to that of a mechanically mixed basin (Digester 2). Results, presented in Massart et al. (2008), show that both the mechanically mixed basin and the basin with the linear motion mixer achieved a similar degree of mixing with neither showing an advantage over the other. Solids and temperature measurements showed homogeneity of the basin contents, confirming good mixing. The authors' review of historical data from January 2004 through April 2007 revealed good performance of the vertical linear motion mixer, although they noted that the digesters were not highly loaded or operated at a high solids concentration during the analysis period.

Massart et al. (2008) identified a unit power rating of 1.315 kW per 1,000 cubic meters (kW/1000m^3) for the vertical linear motion mixer compared to a unit power rating of 12.113 kW/1000m^3 for the existing draft tube mixers[2]. This example is consistent with the manufacturer's claims that the linear motion mixer operates at a fraction (approximately 10 percent) of the energy needed for a conventional mixer. In addition to energy savings, the authors predicted reduced maintenance requirements since there is only one disk compared to five mechanical impeller units for the conventional system.

7.3 Incineration

Incineration is the process of sludge combustion to produce an inert ash with a significantly reduced volume (90 percent or more reduction) compared to the influent solids loading. The two most common sewage sludge incineration technologies are the multiple hearth furnace (MHF) and the fluidized-bed furnace (FBF). The multiple hearth furnace was the most common type of incinerator used at WWTPs; however WEF (2009) reports that nearly all installations in the past 20 years have been FBFs.

The energy required for incineration depends on many factors, including the moisture and organic content of the sewage sludge, air pollution requirements, and operating practices. In recent years, advances in flue gas recirculation and exhaust heat recovery/reuse have made incineration more economical and less energy intensive (WEF 2009). Many of the incinerators being installed today are equipped with flue gas recirculation and waste heat recovery systems integral to the design of the furnace. Flue gas recirculation allows the furnace to be operated at a lower temperature while controlling air emissions, minimizing fuel consumption and reducing maintenance (through reduced ash slagging). Recovered heat energy from the furnace exhaust can be utilized to pre-heat the combustion air fed to the furnace. Since combustion air represents a significant heat load (fuel consumption requirement) to the furnace, pre-heating combustion air with waste heat reduces the amount of fuel required by the furnace to effect sewage sludge incineration.

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[2] Revised numbers provided in email communications from Neil Massart, Process Engineer, Black & Veatch. August 5, 2010.

Older MHFs without these energy saving features can be modified and upgraded to incorporate waste heat recovery/combustion air pre-heating, not only resulting in fuel savings but also increasing furnace capacity and reducing maintenance. The following describes how the Washington Suburban Sanitary Commission (WSSC) was able to save approximately 320,000 therms (equivalent to 32,000,000 cubic feet) of natural gas per year (a 76% reduction), saving approximately $400,000 per year in energy costs while at the same time increasing incinerator capacity.

The WSSC Western Branch WWTP is a 30 mgd plant that includes a denitrification activated sludge (DNAS) biological nitrogen removal process utilizing methanol addition for biological denitrification and chemical precipitation for enhanced biological phosphorus removal. Biosolids are thickened and dewatered using dissolved air flotation and centrifuges, respectively, and are subsequently incinerated in two natural gas fired MHFs. The furnaces were commissioned in 1974 and in 1977 (as part of the Phase I and Phase II plant modifications, respectively) and were originally designed to process 26 dry tons per day (dtpd) of heat treated biosolids. WSSC decommissioned the biosolids heat treating process at the Western Branch WWTP soon after commissioning the second MHF in 1977. In 2001, to comply with the promulgation of Title V and “zero visible emissions” requirements of the Clean Air Act, the capacity of the MHFs was reduced to 12 dtpd and external afterburners were installed, which increased natural gas consumption.

The MHFs were retrofitted in 2009 and 2010 with Flue Gas Recirculation (FGR) systems that take the exhaust flow from the top hearth of the furnace and re-injects it into the one of the lower hearths. The recirculated flue gas mixes with the higher temperature combustion gases, providing ample time and heat to completely oxidize volatile hydrocarbons released from the sludge feed entering the top hearth of the MHF. This allows the furnace to be run at a lower temperature (or without an exhaust gas afterburner), optimizing fuel consumption and eliminating ash slagging (i.e., melting of ash inside the furnace when operated at high temperature to reduce smoky and odorous emissions). The MHFs were also retrofitted with air-to-air waste heat recovery heat exchangers that recover and utilize the heat contained in the furnace exhaust streams (exhaust combustion air and center shaft cooling air) to preheat the furnace combustion air, reducing both the heat load to and fuel consumption of the furnace. Circle Slot Jets were added to the furnaces to convey the preheated combustion air into the hearths to increase turbulence and air-fuel mixing. The improved convection and turbulence increased drying and combustion rates of the furnaces and subsequently increased their capacity from 12 to 17 dtpd (a 42% to 58% capacity increase). Figure 7-2 is a schematic representation of the ECM modifications to the Western Branch WWTP MHFs.

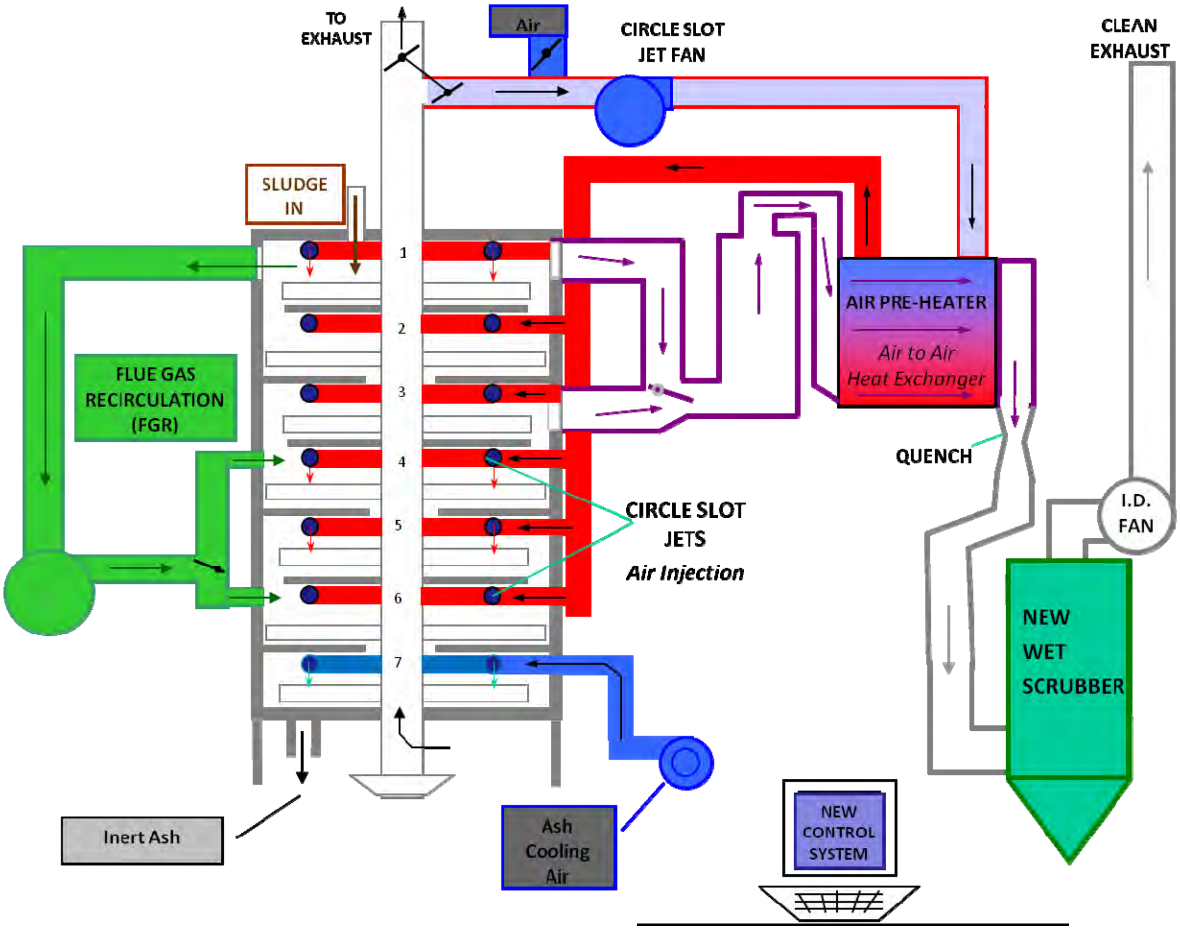

Figure 7-2 Schematic Representation of Multiple Hearth Incinerator Energy Efficiency Improvements at WSSC Western Branch WWTP
Source: Provided courtesy of WSSC. Circle Slot Jet copyright held by American Heat and Power.

The total cost of the retrofits was $4.5 million. With annual natural gas cost savings of approximately $400,000, the simple payback of the project was approximately 11 years. For more information, see the case study summary in Chapter 8 and the full case study description including schematics and detailed operating information in Appendix A.

7.4 Thermal Drying

Thermal drying is the use of heat to evaporate residual water from sludge. It typically follows dewatering and can increase the dry solids content from between 18 and 30 percent to more than 90 percent (WEF 2009). The thermal drying process reduces the mass and volume of dewatered solids and results in a product with a high nutrient and organic content that can be used as a low-grade fertilizer. A major advantage of heat drying compared to other techniques is that it is ideal for producing Class A biosolids.[3] (USEPA 2006)

Methods for thermal drying are direct or indirect depending on the way that thermal energy is transferred to the sludge. Direct, also called "convection," dryers move hot air through a vessel where it comes into contact with the wet solids. Types of convection dryers include rotary drum, flash, and fluidized bed (WEF and ASCE 2010). Indirect, also called "conduction," dryers separate wet solids from the heat transfer medium typically with a solid metal wall. Types of dryers include the paddle, hollow-flight, and rotary chamber dryer. Simpler materials handling and emissions control have made conduction dryers more popular with medium and small systems.

The energy required for thermal drying includes fuel/thermal energy and electricity to operate equipment. USEPA (2006) cites a typical efficiency rate of 1,400 to 1,700 Btu per pound of water evaporated. Conventional thermal dryers use a large amount of fuel compared to other processes (e.g., composting and land application); however, they generally produce a higher quality product on a more consistent basis. External fuel requirements for thermal drying can be reduced by using an onsite energy source such as anaerobic digester gas or wood chips. Recycling of heated gas can also reduce fuel requirements (USEPA 2006).

WEF and ASCE (2010) report on growing use in Europe and the United States of an emerging ECM for thermal drying called solar drying. First developed by researchers in Germany, solar drying uses solar energy and convective air drying methods to produce solids containing no more than 10 percent moisture. Solar dryers consist of a wide concrete pad with low walls enclosed in a "greenhouse" type structure. Sludge is pumped onto the pad and arranged in a relatively thin layer or in windrows. A microprocessor monitors temperature and humidity and adjusts fans and louvers to provide sufficient ventilation for drying. Auxiliary heat may be used to enhance drying performance.

Figure 7-3 shows an example of a solar dryer manufactured by the Parkson Corporation. As of 2008, WEF and ASCE (2010) report that 10 solar drying facilities are being built or operated in the U.S., mainly at small plants.

The Parkson Corporation reports that approximately 95 percent of energy used for drying is provided by solar panels. They cite 100 installations in a variety of climates and for WWTP sizes ranging from 0.2 to 40 mgd. Solar drying is considered an emerging ECM because of its capacity to significantly reduce fuel requirements compared to conventional dryers. Disadvantages of the technology are its large footprint, the need for sufficient days with adequate solar heating, and potential for odor problems. If odors are present, appropriate control technologies is available and can be provided.

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[3] Class A biosolids are defined in 40 CFR Part 503 as biosolids that have met "the highest quality" pathogen reduction requirements confirmed by analytical testing and/or the use of a Process to Further Reduce Pathogens (PFRP) as defined in 40 CFR Part 257.

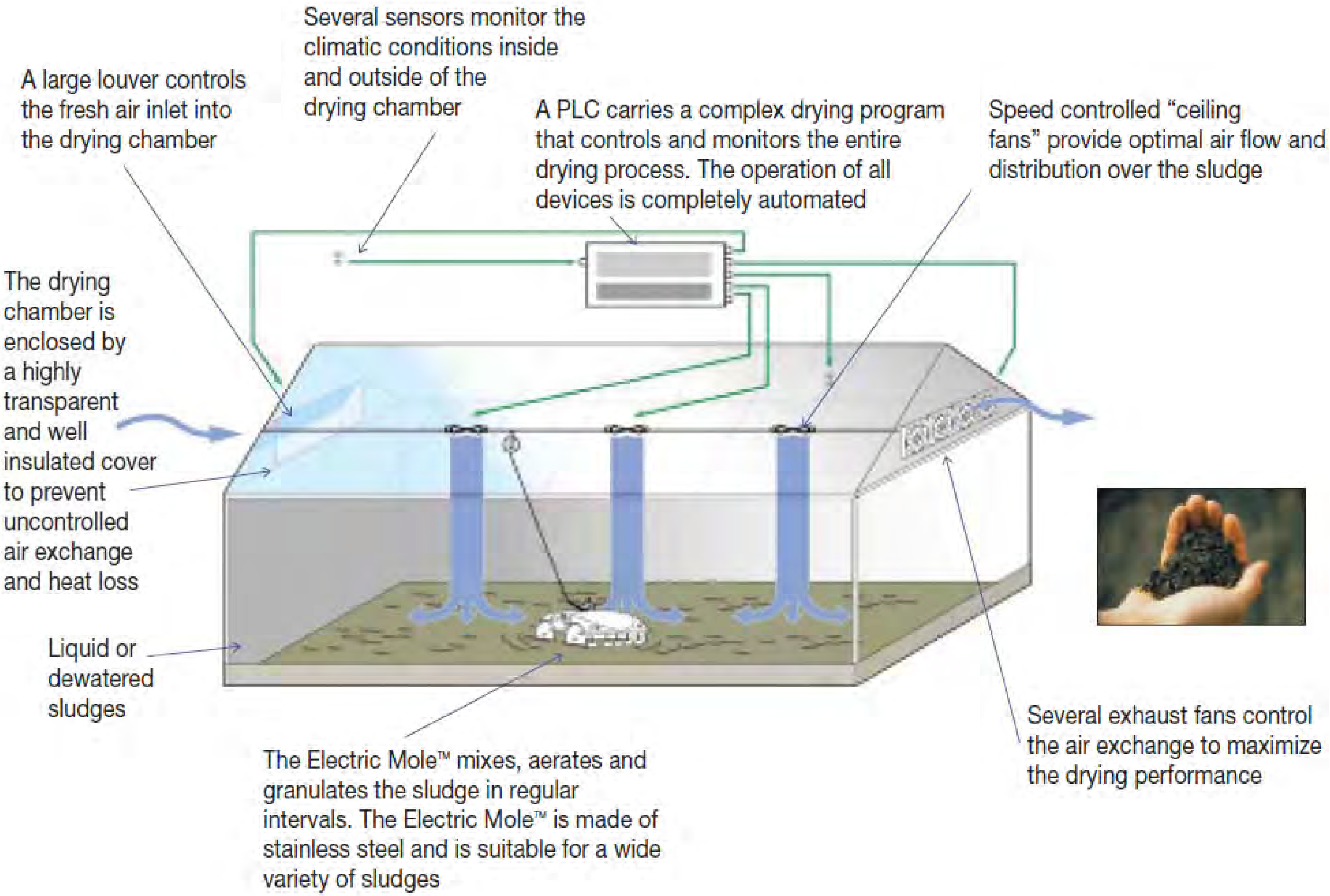

Figure 7-3. Example of Solar Dryer by Parkson . Used with permission.

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8. Summary of Facility Case Studies

Chapter 8 covers:

8.1 Introduction

This chapter supplements technical information presented in this report on innovative energy conservation measures (ECMs) for municipal wastewater treatment plants (WWTPs) with real-world experience and data analyses of ECM implementation at nine plants. The approach for selecting the case study facilities is presented in Section 8.2. Section 8.3 summarizes the facility case study results. Detailed information including process flow diagrams, wastewater quality information, detailed ECM specifications, and energy consumption and cost data are provided in Appendix A.

8.2 Approach

The following three-step selection process was used to select the nine facilities:

1. An in depth literature review was used to identify more than 30 candidate facilities.

2. The project team conducted screening calls to the candidate facilities to –
    - Verify the ECMs;
    - Determine the availability of cost and energy savings data;
    - Determine utilization of submetering, and;
    - Determine if the utility would be willing to participate in the project and provide the required information.

3. The results of the screening calls were presented to a technical expert panel. The panel was comprised of experts from the USEPA, private wastewater consulting companies, wastewater utilities, state environmental programs, and nonprofit organizations. (See the acknowledgement section of this report for a list of expert panel members.)

The final facilities were selected using the criteria presented in the text box on the following page.

Criteria for Selecting Final Nine Case Studies

- The case studies should include innovative blower technologies (air bearing and mechanical).
- The case studies should include one or more innovative dissolved oxygen (DO) control systems (e.g., BIOS, DO control using respirometry, solids retention time (SRT) and DO control using biological process modeling based control algorithms).
- Each should show significant savings and reasonable payback period. Savings should not be based on poor operations/malfunctioning equipment in place prior to ECM.
- Particularly innovative uses of new equipment should be prioritized.
- To the extent possible, the case studies should be distributed geographically and represent a range of facility sizes.
- At least one facility should include cost and energy savings data for one or more conventional ECM (e.g., variable frequency drive (VFD) motor controls, fine bubble diffusers).
- Where possible, the case study should have at least one year of full-scale operating data.

The case studies were prepared in accordance with written quality assurance protocols (the Quality Assurance Project Plan). Data and information from the nine selected case study facilities were collected, analyzed and documented in the case study presentations in accordance with the Plan. The project team began the data/information collection process by sending a detailed questionnaire to each wastewater utility's contact person. The questionnaire asked for general information on the facility (e.g., process description, plant history) and the following information on each ECM installed:

- Description
- Year installed
- Capital and operating costs
- Energy use, costs and savings
- Factors that led to the selection of the ECM and contributed to its success
- Impact(s) on other operations
- Lessons learned

The utilities' responses were reviewed and analyzed based on the project technical team's experience with similar types of wastewater treatment facilities and energy conservation measures implemented at similar facilities (i.e., size and process type) and compared across respondents for consistency. The project team conducted follow-up telephone interviews and used e-mail communications to ask questions, clarify perceived discrepancies and confirm written information and data provided by the utilities. All calculations were documented in excel spreadsheets and independently checked for errors. Draft case studies were sent to the utilities' contacts for review and comment. Final draft case study presentations were subsequently reviewed by USEPA and then peer reviewed.

8.3 Summary of Results

Table 8-1 summarizes the results of the facility assessments, including a brief description of the ECMs installed at the facility, capital cost, energy savings, and payback period. A short description of each case study follows the table. See Appendix A for additional information.

Table 8-1. Summary of Facility Case Studies

Case Study No.	Facility	Avg Daily Flow (MGD)	ECM(s)	Project Cost	Energy Savings	Payback Period (Yrs)^1
1 Green	Bay Metropolitan Sewerage District De Pere, WI	8.0	Aeration system upgrade: • Replaced 5 positive displacement blowers with 6 HST® ABS magnetic bearing turbo blowers	$850,000 ($2004)	$63,758/yr 2,143,975 kWh/yr (50% reduction)	13.3
2 Sheb	oygan Regional WWTP Sheboygan, MI	11.8	Aeration system upgrade: • Replaced 4 positive displacement blowers with 2 Turblex ® blowers with upgraded DO control and SCADA • Installed air control valves on headers, upgraded PCL	$790,000 ($2005) ($773,000 with $17,000 utility incentive) for blowers, $128,000 ($2009) for air control valves	$25,644/yr associated with blower replacement (358,000 kWh/yr – 13% reduction) $38,245/yr associated with air control valves (459,000 kWh/yr – 17% reduction)	14
3 Big	Gulch Wastewater Treatment Plant, Mukilteo, WA	1.5	• Replaced mechanical aeration with Sanitare fine bubble diffusers and air bearing KTurbo blowers. • Upgraded to automated DO control • Installed automated ORP-based control for nitrification (dNOx Anoxic Control System)	For Oxidation Ditch A: $487,066 ($2007) - ($447,875 with $39,191 incentive), For Oxidation Ditch B: $1,045,023 ($2007) - ($998,429 with $46,594 incentive),	$10,721 per year (based on Y2010 savings following Ditch A and Ditch B commissioning) $43,756 (for 2010) based on $0.037 per pound CBOD removed)	135 33 years

Table 8-1. Summary of Facility Case Studies (Continued)

Case Study No.	Facility	Avg Daily Flow (MGD)	ECM(s)	Project Cost	Energy Savings	Payback Period (Yrs)[1]
4	City of Bartlett, TN Wastewater Treatment Facility	1.0	Added VFD Control of oxidation ditch rotors using 4-20mA signal from optical DO probes	$13,500 total ($2007)	$9,176/yr 71,905 kWh/yr (13% reduction)	1.5
5	Oxnard, CA Plant #32	22.4	Optimization and control of SRT and DO using proprietary process modeling based control algorithms	$135,000 $26,9	80/yr 306,600 kWh/yr (20% reduction)	5
6	Bucklin Point – Narragansett Bay Commission (RI)	23.7	DO Optimization Using Floating Pressure Blower Control and a Most Open Valve Strategy	$200,000 ($2007)	Average of approx $135,786/yr for first 3 years Average of 1,247,033 kWh/yr (11.6% reduction) for first 3 years	1.5
7 W	ashington Suburban Sanitary Commission (MD) Western Brach WWTP	21.6	Solids processing system upgrade: • Waste Heat Recovery • Flue Gas Recirculation (FGR) • Circle Slot Jets (CSJs) Air injection System	$4,500,000 $40	0,000 / yr estimated natural gas 320,000 therms/yr (76% reduction)	11.3

Table 8-1. Summary of Facility Case Studies (Continued)

Case Study No.	Facility	Avg Daily Flow (MGD)	ECM(s)	Project Cost	Energy Savings	Payback Period (Yrs)[1]
8	San Jose/Santa Clara (CA) Water Pollution Control Plant	107	Plant pumping systems optimization, BNR pulsed aeration and DAF Solids Thickening Process optimization using proprietary process control algorithms	$269,569 $1,17	8,811/yr for electricity and natural gas 18.3 kW/mg – average (20% reduction) associated with pumping systems optimization 1.2 X 10^{11} BTU/yr (38% reduction) and 4.8 X 10^{6} kWh/yr (23% reduction) associated with pulsed air mixing 1,603,030 kWh/yr (64% reduction) associated with DAF optimization	3 months
9	Waco Metropolitan Area Regional Sewer System (Waco, TX)	22.8	Aeration system upgrade: • Increased number of diffusers • Installed DO probes and automatic blower and aeration system control	$397,708 ($2002)	$331,272 total energy savings for first two years after ECM installed 4,642,741 kWh/yr average (33% reduction)	2.4

1. Represents simple payback for entire project. In some cases, includes multiple improvements and considers savings from electric utility rebates.

Case Study No. 1, Magnetic Bearing Turbo Blowers at the Green Bay Metropolitan Sewerage District De Pere Wastewater Treatment Facility

The Green Bay (Wisconsin) Metropolitan Sewerage District's (GBMSD) De Pere Wastewater Treatment Plant is a 8.0 mgd (average daily flow) two-stage activated sludge plant with biological phosphorus removal and tertiary effluent filtration. The plant had been running five 450 HP Roots multi-stage centrifugal blowers for the first stage aeration process. The blowers were approaching the end of their service life and required either extensive rebuild or replacement. An evaluation conducted by the plant operations manager and their engineer determined that replacement of the multi-stage centrifugal blowers with magnetic bearing turbo blowers would reduce the aeration system's energy consumption and associated cost and reduce the level of maintenance required for the aeration system.

Six ABS, Inc. HST 330 HP magnetic bearing turbo blowers were installed as replacements for the five 450 HP multi-stage centrifugal blowers in first stage aeration for a capital cost of $850,000. The turbo blower project reduced the electrical energy consumption by approximately 2,144,000 kWh/yr (a 50% reduction) compared to the costs to operate the multi-stage centrifugal blowers ($170,000 per year), representing an estimated $63,758 per year (a 38 percent savings) reduction in electrical energy costs and resulting in a payback estimated at 13.3 years. The blower project also contributed to the facility's objective of reducing the wastewater treatment plant's electrical energy consumption to enable a maximum percentage of the required electrical energy being provided by on-site generation using digester gas fueled microturbines.

Case Study No. 2, Turblex Blowers and Air Flow Control Valves at the Sheboygan Regional Wastewater Treatment Plant

The Sheboygan Regional Wastewater Treatment Plant in Sheboygan, MI is an 11.8 (average daily flow) mgd activated sludge plant with biological phosphorus removal. The plant had been running four 250 hp Gardner Denver positive displacement blowers for the aeration basins. Typically, two blowers were required in the summer to provide sufficient aeration, with the remaining two blowers used as standby units. In 2005, one of the blowers failed and inspection of the remaining three indicated they would all require complete rebuilds. Instead of rebuilding existing blowers, plant managers decided to replace the four positive displacement blowers with two 300 hp, high efficiency motor Turblex centrifugal blowers equipped with inlet guide vanes and variable diffuser vanes. One of the centrifugal blowers was sufficient to provide the necessary aeration year-round with the second unit operated as standby unit.

Following commissioning of the Turblex blowers, the plant operators experienced difficulty controlling dissolved oxygen (DO) in the individual aeration basins. DO levels were reaching as high as 6 mg/L during evening hours and during the winter months, wasting blower output and energy. To correct this problem, air flow control valves were installed on the headers to each aeration basin. PLC programming was also upgraded to provide improved control of the DO levels through automatic operation of the air flow valves and blowers.

The capital cost of the Turblex blowers was $504,000 with a total project cost (capital plus installation) of $790,000 ($2005). The plant received a $17,000 energy efficiency grant reducing the project costs to $773,000. The control valves had an installed cost of $128,000 ($2009).

The centrifugal blowers saved the plant an estimated 6.2 percent in annual electricity bills, amounting to an average yearly energy savings of $25,644 for the first three years of operation from 2005 to 2008. The addition of the control valves more than doubled the energy savings, resulting in a total savings of $63,889 in 2009 and a payback period for both projects of 14 years. The reduction in energy consumption averaged approximately 358,000 kWh/yr for the blower replacement project. The installation of the air control valves resulted in an additional reduction in electrical energy consumption of 459,000 kWh/yr. Although the plant had delayed installing the air control valves because of cost issues, they found that poor air control limited their ability to realize the full potential energy savings of the new blowers.

Case Study No. 3, Upgrade from Mechanical Aeration to Air-bearing Turbo blowers and Fine Bubble Diffusers at the Big Gulch Wastewater Treatment Plant

The Big Gulch WWTP, owned and operated by the Mukilteo Water and Wastewater District (Washington), is a 1.5 mgd (average daily flow) oxidation ditch plant operating two parallel oxidation ditches. Ditch A treats approximately 40 percent of the plant flow and Ditch B treats approximately 60 percent of the flow. To address increases in biochemical oxygen demand (BOD) and total suspended solids (TSS) loadings, the oxidation ditch aeration system has been upgraded as follows:

- The existing mechanical brush (rotor) aeration system in the oxidation ditches were replaced with Sanitaire fine bubble diffusers and 3 turbo blowers (K-Turbo, TB 50-0.6S).
- DO probes with a PLC based control system were installed to automate blower operation.
- A dNOx Anoxic control system was installed to detect the nitrate knee (the point in the nitrogen conversion process where complete denitrification has occurred, i.e., NO_3^- has been converted to N_2). With the dNOx control system, the blowers are allowed to go idle as loading increases and automatically switch on when the nitrate knee is detected.

The aeration systems were replaced sequentially with Ditch A upgraded in 2008 and Ditch B upgraded in 2009. The total cost of the Ditch A upgrade (including the removal of one aeration rotor and the installation of one turbo blower, diffusers, probes, and controls) was $487,066. The Big Gulch WWTP received a $39,191 grant from its electric utility to offset the cost of the project making the total costs $447,875. The total cost of the Ditch B upgrade (including the removal of four aeration rotors and the installation of two turbo blower, diffusers, probes, and controls) was $1,045,023. An additional utility company grant of $46,594 reduced the Ditch B project costs to $998,449.

Observed energy savings following the aeration system upgrade was 148,900 kWH for 2010 (average energy use of 1,405,540 kWH for 2005 through 2008 minus energy use of 1,256,640 kWH in 2010). At a current electricity rate of $0.072/kWH, this translates to an electricity cost savings of $10,721. Based solely on energy cost savings, this project shows a 135 year payback. While the Big Gulch project does not meet the case study selection criteria for reasonable payback (as discussed in Chapter 1), it does serve as an example of energy savings derived as a collateral benefit from a major plant upgrade and expansion. Although a greater reduction in energy consumption would be expected from this type of aeration system upgrade, it should be noted that the plant experienced a 40 percent increase in the influent organic loading during the construction and commissioning period, compared to the period prior to the aeration system upgrade.

If an alternative payback analysis is considered that accounts for the 40 percent increase in the plant's organic loading during the construction and commissioning of the Ditch A and Ditch B upgrades, the project shows a significantly lower payback of 33 years. In the year following commissioning of the total project (2010), the plant removed approximately 34 percent more Carbonaceous Biological Oxygen Demand (CBOD) compared to the period 2004 through 2008 (prior to the implementation of the oxidation ditch upgrades) while consuming less electrical power (an average of 1.59 kWh/lb CBOD during the period 2004 through 2008 compared to an estimated 1.06kWh/lb CBOD in 2010). This translates to a savings in electricity cost of $0.037 per pound of CBOD removed and an estimated $43,756 for 2010 (a 33 year payback for the total project cost of $1,446,304).

In addition to improved treatment at lower electric consumption, the Big Gulch WWTP experienced other benefits from the aeration system improvements. The plant experienced a reduction in labor and maintenance costs as the turbo blowers do not require the level of maintenance required for the mechanical brush system. Chlorine use (for bulking sludge control) decreased due to improved settling.

Case Study No.4, Optical DO Sensor technology and Aerator Rotor VFD Control at the City of Bartlett Wastewater Treatment Plant

The City of Bartlett, TN, WWTP is a 1.0 mgd (average daily flow) secondary facility utilizing two mechanically aerated oxidation ditches to provide secondary treatment. Each of the aeration basins is equipped with three rotor aerators. Prior to implementing their aeration system modification ECM project, each basin was operated using one (each) aeration rotor running continuously and a second rotor activated daily (and run at full speed) during periods of peak flow.

Under the Demonstration of Energy Efficiency Development Research Program funded by the Tennessee Valley Authority (TVA) and the American Public Power Association (APPA), the City of Bartlett Wastewater Division implemented optical DO sensor technology integrated with VFD speed control of the oxidation ditch rotor aerator. The objective of the TVA/APPA research/demonstration project was to advance the use of optical DO sensor technology integrated with VFD motor speed control to achieve energy savings at small to medium sized wastewater treatment facilities (i.e., < 10 MGD) within the TVA service area.

Under the demonstration program, the DO control setpoint was established in each basin at 1.2 mg/l, and the rotor speed controlled based on the DO readings in the oxidation ditches, relative to setpoint. During the demonstration program, one rotor in each basin reached full speed for only 20 to 30 minutes each day during the peak flow period. The second rotor was not, and has not ever been, required to maintain the oxidation ditch DO setpoint concentration.

The optical DO sensor technology and aeration rotor VFD controls were installed and commissioned for $13,500 ($2007). Following implementation of the aeration system modifications, first year (2008) energy consumption was reduced by nearly 72,000 kWh (13 % reduction) and peak demand was reduced by 51 kW (a 39 % reduction). The resulting energy cost savings was $9,176/year (a 22 % savings). The project resulted in a payback of 1.5 years.

Case Study No.5, Advanced Aeration Control for the Oxnard, CA Wastewater Treatment Plant

The Oxnard, CA Wastewater Treatment Plant serves a population of approximately 200,000 people and treats an average daily flow of 22.4 mgd. The trickling filter-activated sludge treatment facility uses Turblex blowers and associated proprietary pressure based control software to automate the activated sludge aeration process. To address aeration basin foaming and clarifier sludge bulking problems, the facility implemented activated sludge process optimization and automation utilizing the following integrated components:

- Replaced the aeration blowers' pressure based control software with DOmaster™ control software. DOmaster™ (an Ekster and Associates, Inc. proprietary biological process control software) utilizes biological treatment process modeling based algorithms and process data mining algorithms to effect DO control.
- Installed InsiteIG optical DO sensor technology replacing outdated membrane probes.
- Installed two total suspended solids (TSS) monitors, one in the mixed liquor channel and one in the Return Activated Sludge wet well.
- Installed SRTmaster™, Ekster and Associates, Inc. proprietary software providing real time control of the activated sludge process SRT. The software utilizes a biological process modeling based control algorithm which maintains minimum variability of wasted solids (over the course of a day) resulting in significant improvements in solids settling/thickening.
- Installed OPTImaster™, Ekster and Associates, Inc. proprietary software which optimizes the process control setpoints for SRT and DO in each of the facility's aeration basins.

The effect of these modifications was improved biological process stability and discharge permit compliance and reduced Sludge Volume Index [SVI] (20% for average SVI and 50% for maximum SVI). Since the implementation of this ECM, foaming in the aeration basin has not occurred.

In addition to improving the stability of the biological treatment process, improved solids settling/thickening and elimination of foaming, blower energy consumption was reduced by 306,600 kWh/yr (a 20 % reduction). This reduction in energy consumption represented a nearly $27,000/year savings in electrical energy costs. Polymer dosage for thickening was reduced as a result of the improved settleability of the biological solids, resulting in a reduction in chemical costs of $7,500/year. Additionally, the improved automation of the aeration process reduced labor costs by $18,500/year.

The total project implementation cost was approximately $135,000. The payback, considering only energy savings was approximately 5 years. Including the chemical cost savings and labor savings in the payback analysis reduces the payback period to approximately 2.5 years.

Case Study No. 6, DO Optimization Using Floating Pressure Blower Control in a Most Open Valve Strategy at the Narragansett Bay Commission Bucklin Point WTF, RI

The Narragansett Bay Commission's (NBC) Bucklin Point Wastewater Treatment Facility (WWTF) in East Providence, Rhode Island is a 23.7 mgd (average daily flow) activated sludge nitrification/denitrification facility employing the Modified Ludzak-Ettinger (MLE) process. Commissioned in 2006, the MLE process aeration system utilized a conventional aeration/blower control system consisting of individual Proportional-Integral-Derivative (PID) loops to control DO in and air flow to each of the MLE process aerobic zones. This control system was based on Most Open Valve (MOV) logic. The control system modulated blower air flow based on discharge pressure. Each of the air distribution system's 16 drop legs were modulated independently based on DO measurements in the aeration basins. The MOV logic was programmed to use the positions of the 16 valves to increase or decrease the pressure setpoint.

Following commissioning of the MLE process, the plant experienced difficulty attaining consistent nitrogen removal because the constant pressure based PID aeration control system was unable to adjust to changing process conditions and maintain proper DO concentration in the MLE process aerobic zones, resulting in insufficient conversion of ammonia nitrogen to nitrate and inhibition of denitrification due to high DO concentration in the Return Activated Sludge (RAS) flow to the MLE process anoxic zones. During normal influent loading conditions, the system was unable to maintain DO levels in the aeration process closer than 1.0 ppm from setpoint. The DO control problem was exacerbated during wet weather events. An analysis of the process concluded that the interaction between the PID control loops was causing instability in the control of aeration process DO.

The following modifications to the aeration process control system were implemented:

- A specialized/proprietary DO/blower control algorithm (Dresser Roots) replaced the PID control loops.
- Direct air flow control was substituted for the pressure control logic, basing the MOV strategy on air flow vs. pressure.

The results of these modifications were:

- The RAS flow DO control is consistent and no longer inhibits biological denitrification.
- Aeration system energy consumption and costs are below projections.
- DO excursions are less than 0.5 ppm from setpoint.
- MOV logic is effective in minimizing blower energy consumption.
- Operator intervention (manual control of blowers and drop leg valves) is no longer required to effect discharge compliance.

The annual electrical energy consumption reductions achieved through the implementation of this ECM project were 1,068,700 kWh for 2007 (a 10.3% reduction), 1,464,800 kWh for 2008 (a 14% reduction) and 1,207,600 kWh for 2009 (an 11.6 % reduction). The electrical energy savings for the first three year following implementation of the aeration control system were $115,881 (Y2007), $155,457 (Y2008) and $136,022 (Y2009). The cost of implementing the aeration control system modification was $200,000. The payback for this project was achieved in 1.5 years.

Case Study No. 7, Multiple Hearth Biosolids Incinerator Upgrade – Capacity and Fuel Efficiency Improvements at the Washington Suburban Sanitary Commission Western Branch WWTP, Prince Georges County, MD

The Washington Suburban Sanitary Commission's (WSSC) Western Branch WWTP is a 21.6 mgd (average daily flow) denitrification activated sludge (DNAS) biological nutrient removal facility utilizing methanol supplementation for biological denitrification and chemical precipitation for supplementing biological phosphorus removal. Biosolids are thickened and dewatered using dissolved air flotation and centrifuges, respectively, and are subsequently incinerated in two natural gas fired Multiple Hearth Furnaces (MHF)s prior to landfill disposal. The furnaces were commissioned in 1974 and 1977 and were originally designed to process 26 dry tons per day (dtpd) of heat treated biosolids. WSSC decommissioned the biosolids heat treating process at the Western Branch WWTP soon after commissioning the second MHF in 1977.

MHF fuel consumption, in many cases, is high due to the design of the furnace. "Cold" sludge is fed to the top (hearth) of the furnace which is also the exhaust point for the furnace combustion gases. The cold sludge, contacting the hot furnace, releases volatile hydrocarbons that do not have adequate residence time in the furnace or exposure to adequately high temperature to be completely burned. The result is a high hydrocarbon, smoky and odorous emission which is usually addressed by increasing the operating temperature of the upper hearth(s) of the furnace or adding an afterburner section to increase the final temperature of the furnace's exhaust gas stream. Both of these options increase furnace fuel consumption. Additionally, operating the furnace at a higher temperature may also cause slagging (melting) of the residual ash inside the furnace, resulting in higher maintenance costs. In 2001, to comply with the promulgation of Title V and "zero visiobe emissions" requirements of the Clean Air Act, the capacity of the MHFs at WSSC was reduced to 12 dtpd and external afterburners were installed, which increased natural gas consumption.

Many furnaces that are now employed to incinerate biosolids are equipped with flue gas recirculation and waste heat recovery systems integral to the design of the furnace. Flue gas recirculation controls air emissions while allowing the furnace to be operated at a lower temperature. Recovered heat energy from the furnace exhaust can be utilized to pre-heat the combustion air fed to the furnace. Since combustion air represents a significant heat load (fuel consumption requirement) to the furnace. pre-heating combustion air with waste heat reduces the amount of fuel required by the furnace to effect sludge incineration. Older MHFs that are not equipped with such energy saving features can be modified and upgraded to incorporate waste heat recovery/combustion air pre-heating, not only resulting in fuel savings but also increasing furnace capacity and reducing maintenance.

The Western Branch MHFs were retrofitted in 2009 and 2010 with Flue Gas Recirculation (FGR) systems that take exhaust flow from the top hearth of the furnace and re-injects it into the one of the lower hearths. The recirculated flue gas mixes with the higher temperature combustion gases, providing ample time and temperature to completely oxidize the volatile hydrocarbons released from the sludge feed entering the top hearth of the NHF. This allows the furnace to run at a lower temperature (or without exhaust gas afterburner), optimizing fuel consumption and eliminating ash slagging. The MHFs were also retrofitted with air-to-air waste heat recovery heat exchangers that recover and utilize the heat contained in the furnace exhaust streams (exhaust combustion air and center shaft cooling air) to preheat the furnace combustion air, reducing the heat load to and fuel consumption of the furnace. Circle Slot Jets were added to convey the preheated combustion air into the hearths to increase turbulence and air-fuel mixing. The improved convection and turbulence increases drying and combustion rates of the furnaces, resulting in an increase in their capacity.

The modifications to the Western Branch WWTP MHFs have resulted in the following benefits:

- Increased the throughput capacity of the furnace to 17 to 19 dptd from 12 dtpd (a 42% to 58% increase), postponing the need to build new furnaces to meet growing demand.

- Reduced NOx emissions from the MHFs to meet Best Available Control technology

- Reduced natural gas consumption and cost by 320,000 therms per year (a 76% reduction) and $400,000 per year, respectively.

Energy and maintenance savings will achieve a payback on the $4.5 million in approximately 11 years.

Case Study No. 8, Permit Safe and Energy Smart Greening of Wastewater Treatment Plant Operations at the San Jose / Santa Clara (CA) Water Pollution Control Plant

The San Jose/Santa Clara Water Pollution Control Plant (SJ/SC WPCP), one of the largest advanced wastewater treatment facilities in California, serves a population of 1,500,000 people in a 300 square mile area encompassing San Jose, Santa Clara, Milpitas, Campbell, Cupertino, Los Gatos, Saratoga and Monte Sereno. The Plant, treating an average daily flow of 107 mgd, was last upgraded from a two-stage nitrification process to a step-feed Biological Nutrient Removal (BNR) process in 1995.

In 2008, the SJ/SC WPCP implemented the following Energy Conservation Measures (ECMs) projects with financial assistance from the California Wastewater Process Optimization Program (CalPOP):

- Optimization of three Plant pumping systems (Post Screening, Post Primary Settling and Post Clarification).

- Implementation of pulsed air mixing of the WPCP's BNR process anaerobic and anoxic reactors.

- Optimization of the sludge thickening Dissolved Air Flotation (DAF) pressurization pumps.

All three ECM projects involved the development and implementation of proprietary control system algorithms.

The Post Screening, Post Primary Settling and Post Clarification pumping systems' optimization project resulted in electrical energy use reductions of 13.33 kW/million gallons (MG) (a 22% reduction), 19.9 kW/MG (a 23.5% reduction) and 21.6 kW/MG (a 17% reduction), respectively. Pulsed air mixing of the BNR process anaerobic and anoxic reactors reduced natural gas consumption by 1.2×10^{11} BTU/yr (a 38% reduction) and electrical energy consumption by 4.8×10^{6} kWh/yr ,a 23% reduction (aeration for one of the two BNR trains at SJ/SC WPCP is provided by internal combustion engine driven blowers; the blowers for the second BNR train are electric motor driven). Optimization of the operation of the DAF pressurization pumps reduced electrical energy consumption by 1,603,030 kWh/yr (a 64% reduction).

Testing and verification of these ECM projects by the SJ/SC WPCP's energy utility (Pacific Gas & Electric) reported a total energy savings of $1,178,811 per year. With a total implementation cost for these three ECM projects of $269,569, the payback for the combined ECM projects was less than 3 months.

Case Study No. 9, Diffuser Upgrades and DO Controlled Blowers at the Waco, TX Metropolitan Area Regional Sewer System Wastewater Treatment Facility

The Waco Metropolitan Area Regional Sewer System (WMARSS) Treatment facility is a 22.8 mgd (average daily flow) single-stage nitrification plant with multi-stage centrifugal blowers. The facility was experiencing difficulty achieving single stage nitrification because the existing aeration system was unable to deliver the required oxygen to complete the nitrification reaction. As a result, the air flow rate for the diffusers was set at a rate that exceeded the design rate of the diffusers causing them to produce coarse bubble vs. fine bubbles, further exacerbating the inadequate transfer of oxygen into the wastewater.

The WMARSS facility staff analyzed the problem and concluded that an upgrade to the aeration system was necessary. Under the upgrade, the number of fine bubble diffusers in each basin was increased from 2,800 to 3,500. In addition, a DO probe was added into each of the aeration basins' three aeration zones (mid-way in the first and second aeration zones and at the end of the third aeration zone). The control system was upgraded to provide automatic control based on the readings of the DO monitoring system.

The upgrades to the aeration system cost $397,708 (total installed cost). The installation was done by plant personnel so no outside installation costs were incurred by WMARSS. Electrical energy savings of $331,272 were realized in the first two years and $335,907 in year 3 following the installation/commissioning of the ECM project, resulting in a payback of 2.4 years. Between 2003 and 2008, the system reduced electrical energy consumption by an average of 4,642,741 kWh/yr (33% reduction) representing over 2.5 million dollars in energy cost savings over this period (an average annual energy cost savings of $423,226/yr). In addition to energy savings, labor costs have been reduced as operators no longer are required to perform routine DO readings and associated manual blower adjustments. Since the nitrification process is now working as designed, nitrate levels are lower in the effluent, reducing chlorine demand in the disinfection process, and thus resulting in reduced chemical costs for chlorine.

Appendix A

Facility Case Studies

Case Study No. 1, Magnetic Bearing Turbo Blowers at the Green Bay Metropolitan Sewerage District De Pere Wastewater Treatment Facility

Case Study No. 2, Turblex Blowers and Air Flow Control Valves at the Sheboygan Regional Wastewater Treatment Plant

Case Study No. 3, Upgrade from Mechanical Aeration to Air-bearing Turbo blowers and Fine Bubble Diffusers at the Big Gulch Wastewater Treatment Plant

Case Study No.4, Optical DO Sensor technology and Aerator Rotor VFD Control at the City of Bartlett Wastewater Treatment Plant

Case Study No.5, Advanced Aeration Control for the Oxnard, CA Wastewater Treatment Plant

Case Study No. 6, DO Optimization Using Floating Pressure Blower Control in a Most Open Valve Strategy at the Narragansett Bay Commission Bucklin Point WTF

Case Study No. 7, Multiple Hearth Biosolids Incinerator Upgrade – Capacity and Fuel Efficiency Improvements at the Washington Suburban Sanitary Commission Western Branch WWTP

Case Study No. 8, Permit Safe and Energy Smart Greening of Wastewater Treatment Plant Operations at the San Jose / Santa Clara (CA) Water Pollution Control Plant

Case Study No. 9, Diffuser Upgrades and DO Controlled Blowers at the Waco Metropolitan Area Regional Sewer System Wastewater Treatment Facility

EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 1

Magnetic Bearing High Speed Turbo Blowers
Green Bay Metropolitan Sewerage District – De Pere Facility
De Pere, Wisconsin
Facility Size: 14.2 mgd design, 8 mgd average daily flow

Figure 1: Aerial View of the GBMSD - De Pere Wastewater Treatment Facility
(*Photo provided courtesy of the Green Bay Metropolitan Sewerage District*)

Facility/Process Description:

The Green Bay (WI) Metropolitan Sewerage District's (GBMSD) De Pere Wastewater Treatment Facility (WWTF) serves the City of De Pere, portions of the Village of Ashwaubenon and portions of the Towns of Lawrence, Belleview, and Hobart. GBMSD acquired ownership of the De Pere WWTF from the City of De Pere on January 1, 2008.

The original circa mid-1930's plant (a primary treatment facility with sludge digestion) was upgraded in 1964 to an activated sludge process, with chlorination for disinfection. In the late 1970s, there was a major upgrade to the facility (which represents the current operational scheme), including a two stage activated sludge process with biological phosphorus removal, tertiary filtration (gravity sand filters), solids dewatering with incineration, and liquid chlorine disinfection.

Influent data for the De Pere WWTF are presented in Table 1.

Table 1: Profile of De Pere WWTF Influent Data (Y2009)

Parameter	Daily Average
Flow (mgd)	8
BOD (lbs/day)	29,070
TSS (lbs/day)	18,587
Ammonia-N (lbs/day)	Not Monitored
Phosphorus (lbs/day)	307.5

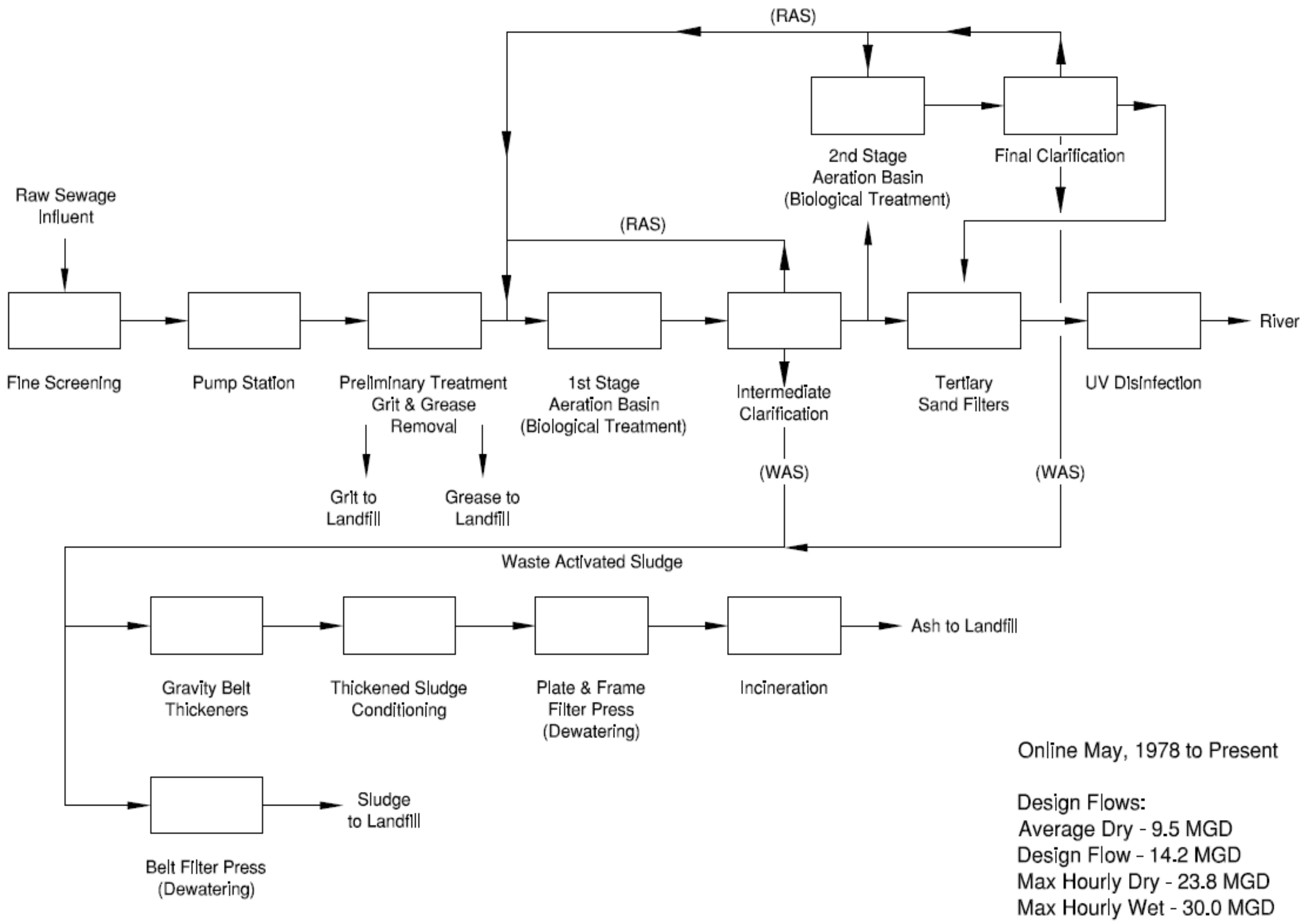
In 1997, additional upgrades to the facility were initiated, beginning with UV disinfection replacing the liquid chlorine system. The chlorine disinfection system is currently maintained as a back-up system. Several other major upgrades included: replacement of the coarse influent screens with fine screens (1998-1999), renovation of the multi-media tertiary filtration system to a single media U.S. Filter Multiwash air scour system (1999-2000), and a solids handling upgrade which included installation of two gravity belt thickeners (replacing dissolved air flotation) and the addition of two filter presses (2001-2002).

Figure 2 presents the process flow diagram for the GBMSD - DePere WWTF, a two-stage activated sludge treatment plant with tertiary filtration.

Influent to the plant undergoes fine screening and is subsequently pumped to preliminary treatment (grit removal followed by grease removal, utilizing two 50 ft X 50 ft clarifiers with grease/scum collection). The influent pump station consists of four 150 hp, 10 mgd pumps. Screenings are disposed in a landfill. Grit, oil and grease removed in preliminary treatment units are also disposed in a landfill.

Biological treatment is conducted in two serial stages, each with a 1.1 mgd anaerobic zone (for phosphorus removal) followed by a 2.2 mgd aeration zone. Approximately 100% of the mixed liquor suspended solids from the aeration zone is recycled to the anoxic zone. Aeration is provided by six (each), 6000 scfm, 330 hp turbo blowers for the 1st stage aeration process and three (each), 4000 scfm, 250 hp multi-stage centrifugal blowers for the 2nd stage aeration process.

The first stage biological treatment is followed by clarification (two each, 100 ft diameter, 13.7 ft side water depth clarifiers (one on line for each aeration basin)). Clarifier effluent from the first stage biological treatment process can be further treated in the second stage treatment process. However, all wastewater is currently treated only in the first stage biological process. The second stage of biological treatment is not currently utilized since it is not required to achieve discharge compliance. Biological treatment is followed by three 125 foot diameter, 10.9 foot side water depth clarifiers. Clarifier effluent



Online May, 1978 to Present

Design Flows:
Average Dry - 9.5 MGD
Design Flow - 14.2 MGD
Max Hourly Dry - 23.8 MGD
Max Hourly Wet - 30.0 MGD

Figure 2: GBMSD - De Pere WWTF Process Flow Diagram (*graphic provided courtesy of Green Bay Metropolitan Sewerage District*)

is polished by tertiary sand filtration and disinfected using UV prior to discharge. During periods of high flow, UV disinfection is supplemented by disinfection with liquid chlorine.

Clarifier underflow (WAS – waste activated sludge) from biological treatment undergoes one of two dewatering processes. Approximately 75% of the WAS undergoes thickening (two each, 2 m gravity belt thickeners), chemical conditioning (lime and ferric chloride), dewatering (two each, 1.5 m X 2 m plate and frame filter press) and incineration (18.75 foot diameter, 7 hearth, 7,500 lb/hr multiple hearth incinerator). The incinerator ash is disposed in a landfill. The balance of the WAS is chemically conditioned with polymer and dewatered in two each, 2 m belt filter presses. The dewatered sludge is disposed in a landfill. Filtrate from sludge thickening and dewatering operations is returned to 1st stage biological treatment.

The most recent upgrade (2003-2004) replaced the facility's 1st stage treatment centrifugal blowers (See Figure 3) with high-speed, magnetic turbo blowers (See Figure 4), the first installation of this new, energy efficient technology in the country. Because the 2nd stage aeration process is currently not utilized, only the 1st stage process blowers were replaced under the ECM project.

Figure 3: Multi-stage Centrifugal Blowers - GBMSD - De Pere Wastewater Treatment Facility

(*Photo provided courtesy of the Green Bay Metropolitan Sewerage District*)

Figure 4: Magnetic Bearing Turbo Blowers - GBMSD - De Pere Wastewater Treatment Facility
(*Photo provided courtesy of the Green Bay Metropolitan Sewerage District*)

Description of Energy Conservation Measures (ECMs):

In October 2004, the City of De Pere commissioned six new high speed, magnetic bearing turbo blowers (330 hp HST Model S9000-1-H-5 manufactured by ABS, Inc.) for the facility's 1st stage aeration process. Prior to the blower replacement ECM project, the facility's existing blowers (five each, 450 hp multi-stage centrifugal blowers) had reached the end of their service life, requiring an extensive and expensive rebuild or replacement. An evaluation by the WWTP operations manager and their engineer determined that replacement of the existing multi-stage centrifugal blowers with magnetic bearing turbo blowers would meet the wastewater utility's mission of providing the highest quality of wastewater treatment for their service area customers at the lowest cost. The new blowers would help meet this goal by:

- Increasing the efficiency of the aeration system and reducing energy costs.
- Reducing/eliminating normal routine maintenance requirements of the aeration system.
- Reducing operating costs through better matching of blower capacity to aeration demand (operating two to three 330 hp turbo blowers versus two to three 450 hp centrifugal blowers).
- Maintaining high efficiency over a wide range of operation, while offering a high degree of turndown.

ECM Commissioning Date:

Six new 330 hp magnetic bearing turbo blowers were commissioned October 18, 2004 replacing five 450 hp centrifugal blowers.

Description of ECM Project Drivers and Issues:

Implementation of the blower replacement project was initiated by the City of De Pere in response to the need to address the situation in which the aeration system blowers had reached the end of their design operating life. Other drivers for the project included requirements for increasing the plant's capacity, reducing the amount of staff time for maintenance and control of the aeration system, maintaining high quality effluent, and effecting energy savings. The WWTF management and their engineer had determined that replacement of the blowers was necessary to continue providing their customers with high quality wastewater treatment services at the lowest price.

Plant Influent and Effluent Quality

Table 2 provides a comparison of the De Pere WWTF performance prior to the implementation of aeration system improvements (Y2003) and current (post-ECM implementation) performance.

Table 2: Monthly Average

Parameter		Y2003 Concentration Range, mg/L	Y2009 Concentration Range, mg/L
BOD	Influent	453.10 to 704.07	380.09 to 499.43
	Effluent	0.62 to 5.69	2.31 to 6.10
	Permit Limit	9	9
TSS	Influent	267.43	229.36 to 352.46
	Effluent	0.66 to 3.33	1.39 to 3.35
	Permit Limit	10	10
NH_3	Influent	Note 1	Note 1
	Effluent	0.14 to 2.44	0.16 to 4.14
	Permit Limit	24 (summer) 34 (winter)	24 (summer) 34 (winter)
P	Influent	5.43 to 8.24	4.05 to 6.12
	Effluent	0.15 to 0.33	0.1 to 0.24
	Permit Limit	1	1

Note 1: Influent concentration is not required to be monitored/reported as a permit condition

Results

ECM Implementation Cost

Table 3 summarizes the implementation cost for the De Pere turbo blower ECM project:

Table 3: ECM Implementation Cost

Capital Cost (Note 1)	$850,000
Installation Costs	Note 2
Total Cost	Note 2

Note 1: Capital cost included replacement of the plant's medium power supply voltage system (2400 volts) to a lower voltage system (480 volts) to provide compatibility with the new turbo blowers.
Note2: The blower replacement project was implemented as part of a larger ($2,000,000) plant infrastructure improvement project. Installation costs exclusively associated with the blower upgrade are not available. Installation costs for blowers are site specific and equipment specific. However. for estimating purposes, installation costs often run 10% to 15% of capital costs.

Energy

Table 4 summarizes the De Pere WWTF electrical energy consumption and savings for the aeration system improvement project.

Table 4: Electricity Use and Estimated Savings

Year	Annual Electrical Energy Use	Electrical Energy Cost	
		Rate	Annual Cost
Prior to ECM Implementation			
2003	4,325,700 kWh	$0.0393/kWh	$170,000
Following ECM Implementation			
2005	2,181,725 kWh	$0.0487/kWh	$106,250
Savings	2,143,975 kWh (50% reduction)		$63,758 (38% reduction)

Payback Analysis/Benefits

The blower replacement project did not focus solely on investment payback, but weighed heavily on energy conservation, full automation of the aeration process while maintaining high-quality effluent, ensuring protection of the environment, and gaining equipment dependability for the plant operation. The old aeration system experienced frequent blower surging when multiple blowers were in operation, requiring that the aeration system be operated in the manual mode. A simple payback analysis is determined by dividing the available blower project cost ($850,000 from Table 3) by the projected annual electricity cost savings following the project implementation. The electrical energy costs savings provided by the turbo blower implementation resulted in a project payback in 13.3 years.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

This project was unique in that the blower equipment to be installed was the first of its kind in this country. This retrofit was intriguing and vitally important to the De Pere WWTP operation, creating an ownership stake in the project. All stakeholders involved in this project (City officials, management, operations staff, and the utility's engineering firm) worked as a team.

Impact on Other Operating Costs Resulting from ECM Implementation

Energy conservation (as shown in Table 4) was the most important factor, along with the importance of the replacement of outdated and failing equipment.

In addition to energy saving resulting from this project, the following benefits were also realized.

Labor: Maintaining the old blower equipment was labor-intensive. Maintenance needs for the old system included greasing the centrifugal blower motors, monitoring and filling oil levels in the blower bearing lubrication reservoirs, changing out the inlet filters, seal replacement, and vibration analysis on a weekly basis.

Operationally, the old system was designed for coarse air bubble aeration. Therefore, when fine bubble diffusers were installed for energy conservation, blower surging, (especially when multiple blowers were in operation), became a major problem when trying to operate in the automatic mode. As a result, operation of the aeration system required manual control of the blowers. System demand variations required staff to make changes to blower output many times throughout the day.

The new High Speed Turbo Blower system is SCADA controlled, making the operation fully automatic, reducing staff surveillance of the aeration process.

Maintenance: Routine maintenance to the turbo blowers is minimal. Changing of the inlet filters is done on an as needed basis, normally once per year, unless outside conditions become very dusty. The location of the new blowers (away from other plant process areas) contributed to reducing air inlet filter maintenance. Additionally, without the presence of any wear parts (bearings, gears, etc.), maintenance on the turbo blowers is virtually eliminated and vibration analysis is not required for the turbo blowers.

Lessons Learned

As a result of this project and facility upgrade projects implemented subsequent to the blower replacement, the GBMSD-De Pere WWTF management learned that developing and executing a carefully planned program for replacing outdated and failing equipment can be accomplished without increasing treatment costs and customer user fees.

Additionally, the blower replacement project provided other benefits and lessons that included:

- The magnetic bearing turbo blowers operate at significantly lower noise levels (75 dBA compared to 100 dBA) and are vibration-free compared to the multi-stage centrifugal blowers, providing a comfort benefit to wastewater treatment staff working in the blower room. With the multi-stage centrifugal blowers, spending any extended time in the blower room was difficult to tolerate and unsafe without hearing protection.
- Heat from the turbo blower's cooling air exhaust is recirculated to plant buildings, reducing the demand for auxiliary heat.
- The GBMSD-De Pere WWTF was the first facility in the United States to install magnetic bearing turbo blowers. Following a thorough investigation of the magnetic bearing turbo blower technology, the stakeholder/project team concluded that the benefits offered by this new cutting–edge technology far outweighed the risk.

Acknowledgements

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Michael Kersten, Operations Manager, Green Bay Metropolitan Sewerage District De Pere (WI) Wastewater Treatment Plant.

Dean P. Zannon, P.E., Project Engineer – Robert E. Lee & Associates, Inc., Oneida, WI

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References and Bibliography

Shumaker, Gerald; *High Speed Technology Brings Low Costs*, Water and Wastes Digest, August 2007.

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 2

Aeration System Blower Replacement and Control Valves
Sheboygan Regional WWTP – City of Sheboygan
Sheboygan, Wisconsin
Facility Size: 18.4 MGD design, 11.8 MGD average daily flow

Figure 1: Aerial View of the Sheboygan Wastewater Treatment Plant
(Photo provided courtesy of Sheboygan Regional WWTP)

Facility/Process Description:

The Sheboygan Regional Wastewater Treatment Plant (WWTP) serves approximately 68,000 residential customers in the cities of Sheboygan and Sheboygan Falls, the Village of Kohler, and the Town(s) of Sheboygan, Sheboygan Falls, and Wilson. The plant was originally constructed in 1982 as a conventional activated sludge plant using turbine aerators with sparger rings. In 1990, the plant was upgraded to include a fine bubble diffused air system with positive displacement blowers. From 1997 through 1999, additional improvements were made to the facility to implement biological nutrient removal and to the bar screens, grit removal facilities, bio-solids storage tanks, and the primary and secondary clarifiers. The plant currently operates as an 18.4 MGD biological nutrient removal plant with fine screens, grit removal, primary clarification, biological nutrient removal, activated sludge aeration, secondary clarification, disinfection, anaerobic sludge digestion, gravity belt sludge thickening, and liquid (6% solids) bio-solids storage. Table 1 provides average daily influent data for the plant. Figure 2 provides a process flow diagram of the plant treatment scheme.

Table 1: Profile of Sheboygan WWTP Influent Data (Y2009)

Parameter	Daily Average
Flow (MGD)	11.78
BOD (mg/L)	175
TSS (mg/L)	203
Ammonia-N (mg/L)	Not Monitored
Phosphorus (mg/L)	5.7

Influent to the plant goes through two automatic self cleaning fine screens. A 20 feet diameter cyclone separator removes grit before the wastewater enters primary clarification. Primary clarification is provided by four primary clarifiers. Secondary biological treatment is conducted in six basins. The first two basins are anaerobic to provide phosphorus removal. They are configured with baffles in an “N” pattern. The remaining 4 basins are currently aerated using two Turblex blowers. Following aeration, secondary clarification is provided by 4 clarifiers. Return activated sludge (RAS) from the clarifiers is sent to the anaerobic zone. A portion of the RAS is conveyed upstream of the primary clarifier. Plant effluent is disinfected with chlorine and is then dechlorinated before discharge to Lake Michigan.

The combined primary and secondary sludge underflow from the primary clarifier (waste sludge) is sent to 3 primary anaerobic digesters. From the primary digesters the sludge flows to a single secondary anaerobic digester. Methane from the digesters is used to provide heat to the digesters as well as fuel for ten 30 kW microturbines that provide electricity to the plant. Two belt thickeners, (one at 2 meter. and one at 3 meter) increase the solids content of the digested sludge from 2.5 percent to 6 percent solids. Digested, thickened sludge is held in two storage tanks before being land applied.

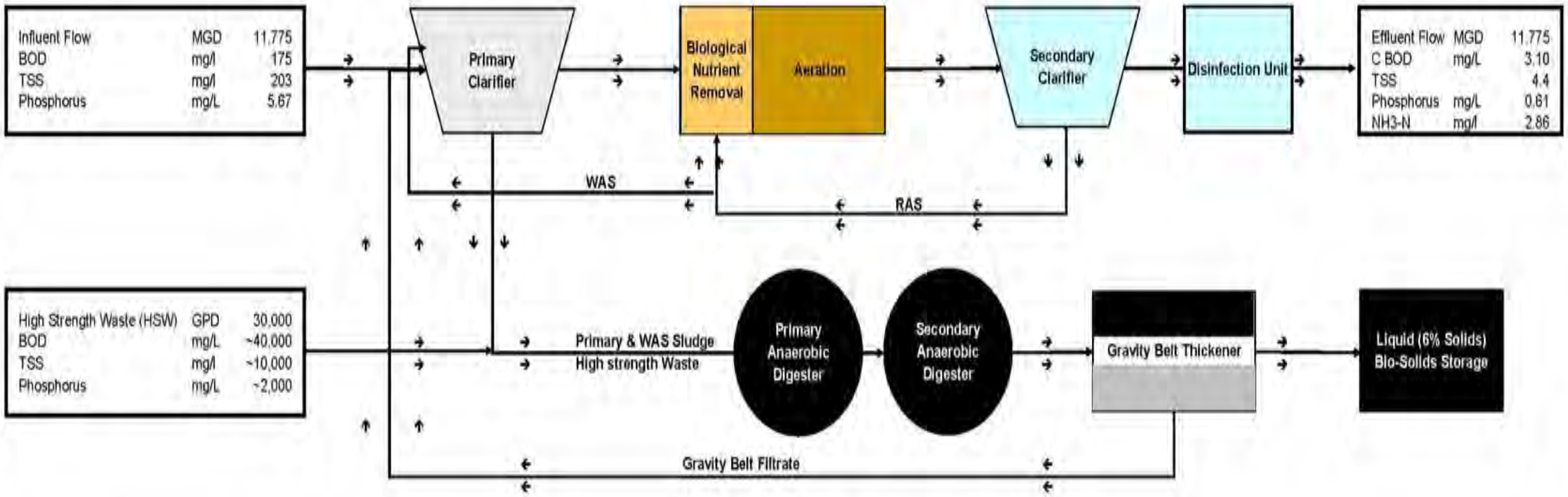

Figure 2: Sheboygan Wastewater Treatment Plant Process Flow Diagram

(graphic *provided courtesy of Sheboygan Regional WWTP*

Description of Energy Conservation Measures (ECMs):

The Sheboygan plant implemented improvements to its aeration system in order to provide better dissolved oxygen (DO) control and to replace failing blower equipment. The upgrade consisted of:

- Replacing the four 250 HP positive displacement blowers with two single-stage centrifugal blowers with inlet guide vanes and variable outlet vanes. Specifically the blowers were Turblex® model KA5 SV-GL210 blowers equipped with 350 HP Premium Efficiency Motors.
- Replacing the DO blower controls
- Upgrading the SCADA system
- Installing air control valves on the headers to the individual aeration basin (AUMA valve actuators and DEZURIK butterfly valves were used on the headers of the 6 aeration basins).
- Upgrading the PLC programming for the blowers.

ECM Commissioning Date:

The Turblex® blowers were installed in the summer of 2005, and the aeration basin header control valves were installed in the spring of 2009.

Description of ECM Project Drivers and Issues:

Prior to 2005, the Sheboygan plant was operating its aeration system using four 250 HP (each) Gardner Denver positive displacement blowers (installed in 1990). During the summer months, two blowers were required to provide sufficient aeration, with the remaining two as standby. In 2005, one of the blowers failed. This prompted an investigation of the remaining blowers, the results of which were that all three of the remaining operational blowers would require total rebuild. The plant managers determined that two new Turblex blowers with larger, energy efficient motors would allow a single blower to meet year round aeration needs while saving energy and allow the second blower to be used for standby (i.e., the four 250 HP positive displacement blowers could be replaced with two 350 HP (each) centrifugal blowers).

Following commissioning of the Turblex blowers, the plant operators experienced difficulty controlling DO in the individual aeration basins. DO levels could reach as high as 6 mg/L during evening hours and during the winter months, wasting blower output and energy. In the spring of 2009 the plant installed air flow control valves on the headers to each aeration basin to control DO levels in the basins to match aeration requirements and to decrease wasted blower output and energy consumption. PLC programming was also upgraded to provide improved control of the DO levels through automatic operation of the air flow valves and blowers.

Plant Influent and Effluent Quality

Tables 2a and 2b show the influent and effluent qualities both before and after the implementation of the ECMs.

Table 2a: Monthly Average

Parameter		Y2003 Monthly Average Concentration, mg/l	Y2009 Average Concentration, mg/l
BOD / CBOD[1]	Influent	246	175[1]
	Effluent	12	3.1[1]
	Permit Limit[1]	30	25[1]
TSS	Influent	244	203
	Effluent	6.1	4.4
	Permit Limit	30	30
NH_3[2]	Influent	Not measured	Not measured
	Effluent	2.4[3]	2.86[2,4]
	Permit Limit	N/A	23[2]
P	Influent	5.96	4.7
	Effluent	0.75	0.6
	Permit Limit	1.0	1.0

Notes:

1. Effluent BOD limit changed to CBOD limit on October 1, 2005.
2. NH_3 limit effective April 1, 2009
3. NH_3 monitored weekly
4. NH_3 monitored weekly

Table 2b: Daily Maximum

Parameter		Y2003 Daily Maximum Concentration, mg/l	Y 2009 Daily Maximum Concentration, mg/l
BOD/ CBOD[1]	Influent	420	397[1]
	Effluent	64	12[1]
TSS	Influent	1650	872
	Effluent	63	12
NH_3	Influent	Not measured	Not measured
	Effluent	19[2]	16.4[3]
P	Influent	11.8	9.8
	Effluent	4.5	2.2

Notes:

1. Effluent BOD limit changed to CBOD limit on October 1, 2005.
2. NH_3 monitored weekly
3. NH_3 monitored daily

Results

ECM Implementation Cost

Table 3 summarizes the implementation costs for the new blowers and motors. Table 4 summarizes the costs for the air control valves. The system received a Focus on Energy Grant that offset a portion of the costs of the blowers. Focus on Energy is a quasi-governmental agency in Wisconsin which distributes grants for electricity conservation. The source of this funding is a tax levied on electric utility bills.

Table 3: Blower ECM Implementation Cost

Cost Category	Cost (in Y2005 $)
Capital Cost	504,000
Installation Costs (Note 1)	286,000
Focus on Energy Grant	-17,000
Total Cost	773,000

Table 4: Control Valve ECM Implementation Cost

Cost Category	Cost (in Y2009 $)
Capital Cost	60,000
Installation Costs (Note 1)	68,000
Total Cost	128,000

Note 1: The installation costs for the blower and control valve ECM projects included modifications to the existing blower building to pull in outside air, installing new electrical conduit and larger diameter wire to accommodate the increased blower motor horsepower, installing new soft start controls and cabinets, installing valve actuators on the discharge valves required for the blower start-up sequence and modifications done to the aeration basin air piping to install individual basin air flow control valves and the air blow-off channel air.

Energy

Table 5 summarizes the electricity savings from the two components of the aeration system upgrade ECM project. The utility estimated an average reduction in annual energy costs of $25,644 following commissioning of the Turblex blowers (for the years 2006 through 2008), representing an average reduction in annual electrical energy consumption of 358,000 kWh over this period. Based on the three previous years' average annual energy cost savings, the implementation of the air control valves resulted in an additional energy cost savings of $38,245 for 2009, representing an additional reduction in annual energy consumption of 459,000 kWh.

Table 5: ECM Implementation Electrical Energy Savings

Year	Energy Consumption and Savings		Energy Costs and Savings	
	kWh Used	kWh Annual Reduction	Rate ($0.00/kWh)	Annual Savings
Pre ECM Implementation				
2004	2,760,000	Baseline Year	$0.0538	Baseline Year Cost = $148,888
Post ECM Implementation				
2006[1]	2,402,000	358,000 (13%)	$0.0665	$23,807
2007[1]	2,402,000	358,000 (13%)	$0.0720	$25,776
2008[1]	2,402,000	358,000 (13%)	$0.0764	$27,350
2009[2]	1,943,000	817,000 (30%)	$0.0782	$63,889

Note 1: Electrical energy savings, from blower upgrade only, estimated by utility – blower electrical energy consumption is not sub-metered.
Note 2: Electrical energy savings from blower upgrade and air control valve combined. , estimated by utility – blower electrical energy consumption is not sub-metered.
Source: Estimated annual energy cost savings provided by Sheboygan WWTP Superintendent

Payback Analysis/Benefits

The ECMs presented in this case study were part of a larger plan implemented by the Sheboygan WWTP management to become energy self sufficient. The facility installed 30 kW microturbines in 2006 that allow it to burn biogas from the anaerobic digesters to provide electricity and heat to the plant. In conjunction with the microturbine implementation, the plant has undertaken various energy conservation measures to reduce energy consumption and increase the percentage of the plant's electrical power that can be supplied by the microturbines.

The plant superintendent estimates that the Turblex blowers have a payback period of 14 years including the avoided cost of rebuilding the positive displacement blowers in the payback analysis. Installing the control valves result in a shorter payback period compared to the blowers. Although there is less than a year's worth of operating data for the air flow control valves, the initial Y2009 data show an additional $38,245 decrease in electricity costs (from the average savings of the previous three years from the blower replacement). Extrapolating this figure gives a payback period of less than 4 years for the air control valves. If the costs and energy savings of both the air control valves and blowers are taken together and the 2009 energy cost savings are taken as typical, the payback period is 14 years.

Although the payback period for this ECM project is longer than 10 years, the project was a significant component in the utility's objective of reducing the facility's electrical power demand toward achieving the status of meeting total plant electrical demand by on-site generation using digester gas fueled microturbines.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

The facility staff took a proactive approach to saving energy and reducing its dependence on electric utility purchased power. Staff evaluated and continues to evaluate the energy efficiency of all projects instead of implementing the least capital cost fix for addressing failing equipment. The control valves significantly improved both the resultant energy cost savings and efficient operation of the new blowers. Controlling the air flow and eliminating wasted blower output was essential to realizing the full potential of the new blower equipment.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to the energy costs savings, the ECM project provided the following additional benefits:

Labor:

Using automatic air flow control, plant operators no longer need to make seasonal adjustments to the aeration system valves for the individual aeration basins to control DO concentration.

Plant operators were required to make manual adjustments to the aeration system drop leg valves as needed to maintain the appropriate dissolved oxygen (D.O.) level in the aeration basins. In addition, twice a year at the beginning of winter and the beginning of summer when influent water temperature changed, the plant operators spent additional time adjusting the drop leg air valves. When the operating blower was rotated once a year, the operators again adjusted the drop leg air valves to maintain the proper D.O. level in the aeration basins. The adjustments to the drop leg air valve required approximately 90 man-hours annually (~$2,250/year).

Maintenance:

Less maintenance is required on the air piping system with the new blowers. The former positive displacement blowers caused a “hammering” effect on the air piping system creating the need for frequent maintenance. The repairs to the leaking air header system resulting from the hammering effect required 30 man-hours annually (~$750/year).

Lessons Learned

The plant initially postponed the installation of the control valves because of cost. Without the control valves, DO concentrations in the individual aeration basins could not be properly controlled, leading to waste of both blower output and energy. Installation of the control valves not only improved process performance (by properly controlling DO concentrations in the aeration basins) but resulted in greater energy cost savings than achieved by the blower replacement alone.

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Dale Doerr, Wastewater Superintendent, City of Sheboygan

Ron Hicks, Maintenance Supervisor, City of Sheboygan

References and Bibliography

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 3

Upgrade from Mechanical Aeration to Air-Bearing Turbo Blowers and Fine Bubble Diffusers
Big Gulch Wastewater Treatment Plant
Mukilteo Water and Wastewater District
Mukilteo, Washington
Facility Size: 2.6 mgd design, 1.45 mgd average daily flow

Figure 1: Aerial View of Big Gulch WWTP
(Photo courtesy of MapQuest – www.mapquest.com)

Facility/Process Description:

The Big Gulch WWTP provides wastewater treatment service for 22,455 people residing in portions of the City of Mukilteo and Snohomish County (Washington). Originally constructed in 1970, the WWTP consisted of a coarse bar screen and single oxidation ditch using brush rotor aerators, followed by a secondary clarifier and chlorine disinfection. Between 1989 and 1991, the Big Gulch WWTP underwent significant upgrades including the following:

- New headworks with a grit removal channel
- Influent screw pumps

- Selector tank
- Second oxidation ditch
- Third secondary clarifier
- Aerobic sludge holding tanks within a rotary drum thickener
- Sludge return piping.
- Scum and waste activated sludge pumps
- Sludge pumps
- Sludge dewatering belt filter press
- Chlorine contact chamber

Subsequent to the 1991 facility upgrade, the following upgrades to the treatment plant were implemented:

- Influent screening (perforated-plate fine screens)
- Submersible mixers (in the oxidation ditches)
- UV disinfection (replacing chlorine disinfection)

To address a need for additional oxidation ditch aeration capacity to handle intermittent increases in BOD loading, the aeration system in both ditches was upgraded with fine bubble diffusers and automatically controlled turbo blowers. As a result of upgrading the aeration system from mechanical rotors to automatically controlled turbo blowers and installing the diffused air system, the Big Gulch WWTP realized an incremental savings in energy cost, as detailed in Table 5 of this case study.

Influent data for the Big Gulch WWTP are presented in Table 1.

Table 1: Profile of Big Gulch WWTP Influent Data

Parameter	Average	Minimum	Maximum
Flow (mgd)	1.68	1.21	2.40
CBOD (mg/L)	217	116	462
TSS (mg/L)	255	131	398

Source: Data provided by Big Gulch WWTP
Note: Influent data from January 2004 to August 2010

Figure 2 presents the process flow diagram for the Big Gulch WWTP, an activated sludge treatment plant with UV disinfection

Influent to the plant passes through a perforated-plate mechanical fine screen (rated capacity of 6.5 mgd) into a gravity grit channel. Effluent from the grit removal system is returned to the headworks and grit is sent to the dumpster.

Degritted influent, combined with return activated sludge (RAS) from the secondary clarifiers and filtrate from the sludge dewatering belt filter press, is lifted to the selector mixing basin using the two influent screw lift pumps (3.83 MGD capacity, each). Selector mixing basin effluent is conveyed to the oxidation ditches via overflow channels equipped with adjustable weir gates to distribute the flow to the ditches (40% to Oxidation Ditch A and 60% to Oxidation Ditch B). The two oxidation ditches, operating in parallel and providing a combined 18-hour hydraulic residence time, are followed by three secondary clarifiers.

Effluent from the secondary clarifiers is conveyed to the UV disinfection system. The UV system consists of 96 lamps and provides 35 mJ/cm^2 at a peak flow of 8.7 MGD (based on 60% UV transmittance). The UV disinfection system produces an effluent with fecal coliform counts below the facility's permit limit of 200 colonies/100 ml (monthly average).

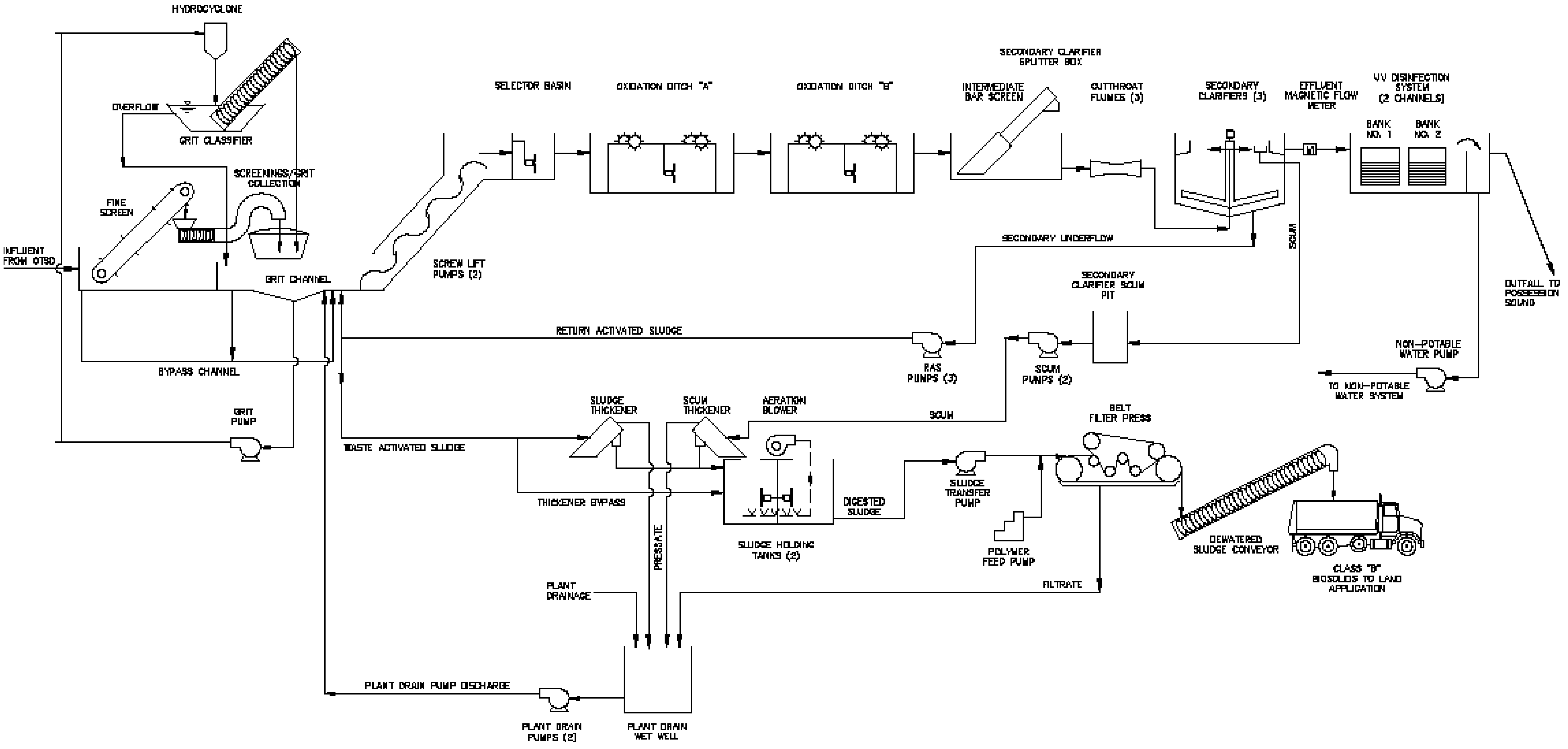
Waste activated sludge and scum from the secondary clarifiers are transferred via a rotary lobe pump to a pair of two-cell aerobic sludge holding tanks for aerobic digestion, producing Class B biosolids. In 2006 the aerobic sludge digestion system was upgraded with fine-bubble air diffusers and positive displacement blowers. Sludge is thickened through either settling in the aerobic sludge holding tanks or through rotary drum thickening. In 2007, the rotary drum sludge thickener was installed to increase digestion capacity. Digested sludge is dewatered using a gravity belt dewatering press and the dewatered sludge is transported for land application.

Table 2 provides additional detail on the activated sludge process.

Table 2: Big Gulch Activated Sludge System Overview

Activated Sludge System Component	Description
Oxidation Ditch A	• Constructed in 1970 • 640,000 gallons • Receives/treats approximately 40% of plant flow
Oxidation Ditch B	• Constructed in 1991 • 1,070,000 gallons • Receives/treats approximately 60% of plant flow
Fine Bubble Diffuser Aeration System (Note 1)	• Installed in 2008 (Ditch A) • Installed in 2009 (Ditch B) • Aeration provided by three, high-speed turbo blowers • Horizontal momentum maintained by submersible mixers
Monitoring and Control System (Note 1)	• Dissolved oxygen (DO) and Oxidation Reduction Potential (ORP) probes located in Ditch A and Ditch B • Controls blower air flow to oxidation ditches (DO/PLC) • Provides anoxic phase zone DO control for nitrate reduction (ORP/PLC)
Secondary Clarifier 1	• Constructed in 1970 • Diameter = 58 ft, Sidewater depth = 9 ft • Center feed, peripheral withdrawal (incorporated in 1990s)
Secondary Clarifier 2	• Constructed in 1980s • Diameter = 54 ft, Sidewater depth = 9 ft • Peripheral feed, center weir withdrawal
Secondary Clarifier 3	• Constructed in 1991 • Diameter = 54 ft, sidewater depth = 13 ft • Center feed, peripheral withdrawal

Note 1 – These components of the activated sludge system are part of the ECM described in detail in this case study.



OLYMPUS TERRACE SEWER DISTRICT
WASTEWATER TREATMENT PLANT
CAPACITY STUDY
FIGURE 2-2
EXISTING WWTP PROCESS FLOW DIAGRAM
Gray & Osborne, Inc.
CONSULTING ENGINEERS

Figure 2: Big Gulch WWTP Process Flow Diagram *(graphic provided courtesy of Mukilteo Water and Wastewater District)*

Description of Energy Conservation Measures (ECMs):

To address regulatory agency compliance notifications (and associated corrective action recommendations) regarding the operation of the treatment plant (the treatment plant was operating at design capacity and exceeding BOD_5 and TSS influent loading rate limitations contained in the permit), the Mukilteo Water and Wastewater District implemented improvements to the aeration system at the Big Gulch WWTP to increase the oxidation ditch aeration capacity and provide additional treatment for the intermittent peak BOD and TSS loadings. These improvements were based on recommendations provided by the Washington State Department of Ecology and a March 2008 Wastewater Treatment Plant Capacity Study and Engineering Report by the District's engineer, Gray & Osborne.

The aeration system improvements implemented by the Mukilteo Water and Wastewater District at the Big Gulch WWTP consisted of the following:

- Replacing the existing mechanical brush aeration systems in Oxidation Ditch A and Oxidation Ditch B with a Sanitaire fine bubble diffuser aeration system and turbo blowers. Each oxidation ditch has one 50-HP, high speed, turbo blower (K-Turbo, TB 50-0.6S) equipped with a variable frequency drive. A third 50-HP blower serves as a spare. A portion of the mechanical and electrical power infrastructure for Ditch B was included in the cost reported for the Ditch A project (although this work could not be defined as a separate line item by the utility).

- Installing DO probes and a PLC-based control system that provide automated monitoring of the Oxidation Ditch DO concentration and automatic response control of the aeration blowers.

- Implementing an automated ORP based control system (dNOx Anoxic Control System) to detect the occurrence of the nitrate knee in the anoxic zone (i.e., the ORP vs. time inflection point indicating when denitrification is complete). The dNOx Anoxic Control system uses ORP readings to detect nitrate levels during the anoxic phase. As loading to the activated sludge system increases, the blowers are allowed to go idle, and at the time of the nitrate knee, the blowers are automatically turned back on.

ECM Commissioning Date:

The aeration system upgrades (fine bubble diffusers, turbo blowers and controls, and blower building) were commissioned in Oxidation Ditch A and B in 2008 and 2010 (January), respectively.

Description of ECM Project Drivers and Issues:

Aeration system improvements at the Big Gulch WWTP were implemented to accommodate an increase in BOD and TSS loadings at the facility. Primary drivers for the project included the regulatory requirements for increasing the plant's capacity and improving effluent quality. Reducing energy consumption was a secondary consideration. Prior to the design phase of the aeration system improvements project, the local publicly owned electric utility (Snohomish County P.U.D.) was actively seeking ECM projects to grant funding assistance. The Mukilteo Water and Wastewater District had already received public and regulatory agency approval to implement the aeration system ECM project at the Big Gulch WWTP but the project had not yet been started. The aeration system improvements ECM project that was being planned for the Big Gulch WWTP satisfied the electric utility's project criteria and was provided a financial incentive of $39,191 (Oxidation Ditch A) and $46,594 (Oxidation Ditch B) to help offset project costs (see Tables 4a and 4b).

As a result of the aeration system improvements ECM project implementation, the Big Gulch WWTP has decreased their energy usage, benefited from reduced maintenance requirements, reduced noise levels, and decreased the amount of aerosols emitted from the oxidation ditches.

Plant Influent and Effluent Quality

Table 3 provides a comparison of the WWTP's performance prior to the implementation of aeration system improvements (Y2008) and current (post ECM implementation) performance. According to the 2008 capacity study conducted by Gray & Osborne, Inc., the intermittent spikes in the influent loading that led to the loading exceedances were probably caused by non-residential (commercial or industrial) loadings. Permit level exceedances are highlighted in Table 3 below.

Table 3: Big Gulch WWTP Influent and Effluent Data

Year	Average Flow (mgd)	CBOD NPDES Permit Limit: 3,953 lbs/day - influent, 544 lbs/day - effluent. Maximum capacity based on Capacity Analysis (5,813 lbs/day) Request for increase in loading limit (6,039 lbs/day)		TSS NPDES Permit Limit: 3,605 lbs/day - influent, 653 lbs/day - effluent. Maximum capacity based on Capacity Analysis (6,082 lbs/day) Request for increase in loading limit (6,082 lbs/day)	
		Influent Loading (lbs/day)	Effluent Loading (lbs/day)	Influent Loading (lbs/day)	Effluent Loading (lbs/day)
Prior to ECM Implementation					
2004	1.80	2,178	47	2,771	103
2005	1.74	2,052	45	2,603	102
2006	1.81	2,751	64	2,805	78
2007	1.82	2,611	53	4,340	118
2008	1.56	2,809	72	4,087	177
Following ECM Implementation					
2009 Ditch A	1.45	3,579	117	3,910	258
2010 Ditches A&B	1.48	3,327	87	4,063	194

Source: Data provided by Big Gulch WWTP

Note 1: Average CBOD$_5$:BOD$_5$ concentration ratio of 0.88 based on January 2004 – June 2007 data measurements (as reported in the March 2008 Wastewater Treatment Capacity Report by Grey & Osborne, Inc.). CBOD$_5$:BOD$_5$ ratio used to convert BOD$_5$ influent permit value and request for increase in loading limit permit value to CBOD$_5$.

Note 2: Based on average concentrations – In 2006, the BOD$_5$ loading limitation was exceeded for 3 months. In 2007, the TSS loading limitation was exceeded for 5 months.

Note 3 Since a full year of data for 2010 was not available at the time of the study report, 2010 data is based on January 2010 – August 2010 operating data.

🟨 = Permit Limit Exceeded

Results

ECM Implementation Costs

The Ditch A project involved removing 1 aeration rotor, installing 1 turbo blower, air piping and air diffusers. A portion of the mechanical and electrical power infrastructure for Ditch B was included in the cost reported for the Ditch A project (although this work could not be defined as a separate line item by the utility). The total cost of the Ditch A aeration system upgrade (including the turbo blowers, diffusers, probes, control; capital and installation) was $487,066. Construction costs were $389,653, and the remainder (or 25% of the total costs) were engineering and construction administration costs of $97,413. The Big Gulch WWTP received a $39,191 grant from its electric utility (Snohomish County P.U.D.), which was used to offset the construction costs incurred for the ECM implementation. Implementation costs for Oxidation Ditch A are presented in Table 4a.

Ditch B (whose treatment capacity is 1.5 times the capacity of Ditch A) involved removing 4 aeration rotors, installing 2 blowers, air piping and diffusers and the construction of a blower building to house all three blower. The total cost of the Ditch B aeration system upgrade (which included construction costs for building housing for the three blowers) was $1,045,022. Construction costs were $836,018, and the remainder (or 25% of the total costs) were engineering and construction administration costs of $209,005. The Big Gulch WWTP received a $46,594 grant from its electric utility (Snohomish County P.U.D.), which was used to offset the construction costs incurred for the ECM implementation. Implementation cost estimates for Oxidation Ditch B are presented in Table 4b.

Table 4a: Implementation Cost Estimates for Oxidation Ditch A

Cost Category	Cost ($2007)
Construction Cost	$ 389,653
Engineering and Construction Administration (25%)	$ 97,413
Subtotal	**$ 487,066**
Incentives (Note 1)	($ 39,191)
Total	**$ 447,875**

Note 1:Incentive offered by Snohomish County P.U.D. was used to offset Construction costs incurred for ECM implementation.

Table 4b: Implementation Cost Estimates for Oxidation Ditch B

Cost Category	Cost ($2007)
Construction Cost	$ 836,018
Engineering and Construction Administration (25%)	$ 209,005
Subtotal	**$1,045,023**
Incentives (Note 1)	($ 46,594)
Total	**$ 998,429**

Note 1:Incentive offered by Snohomish County P.U.D. was used to offset Construction costs incurred for ECM implementation.
Note 2: Oxidation Ditch B upgrades included construction of buildings to house the 3 blowers for Oxidation Ditches A and B.

Energy

Table 5 summarizes the Big Gulch WWTP electrical energy consumption and costs prior to and following the implementation of the aeration system improvements to Oxidation Ditch A (2009) and Oxidation Ditch A and B (2010). The last column presents an estimate of the electrical cost savings per year at the plant.

Observed energy savings following the Oxidation Ditch A and Ditch B aeration system upgrades was 148,900 kWh for 2010, a reduction of nearly 11% (compared to the average electricity consumption to the years 2005 through 2008 before the ECM project implementation). At a current electricity rate of $0.072/kWh, this translates to a total cost savings of $10,721 in 2010.

Payback Analysis/Benefits

Dividing the total project cost minus the incentive by the 2010 observed energy savings of 148,900 kWh and rate of $0.072/KWh, the simple payback for this ECM project is 135 years. From strictly an energy savings perspective, this project does not represent an economic benefit. The primary driver for this project was the utility's need to replace aging and undersized aeration equipment in Oxidation Ditch A and B as a means of addressing chronic wastewater discharge compliance issues. The utility took this opportunity to also consider incorporating energy efficient technologies into the treatment facility upgrade. Reducing energy consumption was not the primary motivation for implementing the aeration system upgrades, but rather a consideration that was prioritized by the utility when planning the required wastewater treatment facility upgrade.

While the Big Gulch ECM project does not meet the case study selection criteria for a reasonable payback period described in Chapter 1, the project case study is a good example of energy savings derived as a collateral benefit from a major plant upgrade and expansion. As noted earlier, the primary objective of this project was to increase the plant's capacity to accommodate increases in BOD and TSS loadings to improve effluent quality to comply with permit discharge limits and restore permit compliance. Reducing energy consumption was a secondary consideration. In fact, providing additional oxygen to satisfy the increased organic loading was expected to increase the total energy used by the facility (Note: the average CBOD influent loading following the upgrade of the oxidation ditches' aeration systems [2009 and 2010] was 3,453 lbs/day, an increase of 40% compared to the average CBOD loading of the five years prior to the aeration system upgrade project [2,480.2#/day for the period 2004 – 2008]). However, the replacement of the existing mechanical brush aerators in the oxidation basins with new fine bubble diffusers and turbo blowers did result in actually lowering the overall energy used by the Big Gulch facility. While this project resulted in a long payback period based solely on energy savings, the benefits of increased plant capacity and returning the plant to compliance should not be overlooked.

Using electricity consumption and cost per pound of CBOD removed, an alternative payback analysis was conducted. At the average annual electricity cost and pounds CBOD removed for the period 2005 through 2008 of $96,692 per year and 884,760 pounds CBOD removed per year (respectively), the electricity cost per pound of CBOD removed for this period is $0.109. For 2010, the annual cost of electricity (based on plant operating data for the period January 2010 through August 2010) and pounds CBOD removed are $90,478.08 and 1,182,600 pounds (resulting in a cost of $0.072 per pounds CBOD removed). Comparing the pre-ECM and post ECM electricity cost per pound of CBOD removed results in a cost savings $0.037 per pound of CBOD removed through implementation of the ECM project. The energy cost savings in 2010 associated with the ECM project implementation (to remove 1,182,600 pounds of CBOD) is $43,756. With a total project cost for the Ditch A and Ditch B modifications/upgrade of $1,446,304, the simple payback for the project using this alternative analysis is 33 years.

Table 5: Electricity Use and Estimated Savings based on ECM Implementation in Oxidation Ditch A and B

Year	Total Electricity Use (kWh)	Average Flow (mgd)	Electricity Use / Flow (kWh/mgd)	Average Electricity Rate ($/kWh)	Estimated Electricity Cost Savings ($)
A	**B**	**C**	**D = B/C**	**E**	$(B_{\text{pre-ECM implementation}} - B_{\text{post-ECM implementation}})*E$
Pre-ECM Implementation					
2005	1,358,720	1.74	779,380	0.068	
2006	1,355,440	1.81	750,590	0.068	
2007	1,353,200	1.82	743,857	0.069	
2008	1,554,800	1.56	997,199		
Post-ECM Implementation					
2009 Ditch A	1,261,600	1.45	867,576	0.070	$10,076
2010 Ditch A&B	1,256,640	1.48	849,081	0.072	$10,721

Source: data for columns B, C and E provided by Big Gulch WWTP

Note 1: A full year of data for 2010 was not available at the time of the study report, the average electricity use from January 2010 through August 2010 was used for a monthly projection of electricity use from September 2010 through December 2010.

Note 2: 2010 estimated electricity cost savings are based on average electricity usage prior to any ECM implementation (2005 through 2008, before upgrades were implemented in Oxidation ditch A)

Conclusions

Factors Leading to Successful ECM Implementation/Operation

The WWTP manager gained the support of the engineer and design group for replacing the surface aerators with a fine bubble diffuser system by presenting the benefits of reduced plant maintenance that would result from the implementation of the ECM project. Additionally, Big Gulch WWTP contacted equipment vendors and made site visits to learn how to best employ their ECM equipment. Lastly, the WWTP contacted their local publicly owned electric utility (Snohomish County P.U.D.) to obtain an energy audit of their existing equipment, and subsequently entered into an agreement with the electric utility that provided incentive payments of $39,191 to help offset project costs for Oxidation Ditch A and $46,594 for Oxidation Ditch B.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to energy saving resulting from this project, the following benefits were also realized.

Labor:	Big Gulch WWTP staff used to lubricate the bearings of the surface aerators two times per week, and change out the transmission oil twice per year. Additionally the drive belts for the surface aerators had to be regularly maintained or replaced. Since the turbo blowers do not require the same level of maintenance as the rotor aerators, the WWTP no longer has to expend staff resources for aeration system maintenance at the same level and does not have to purchase, store, or dispose of aerator lubrication oil (which needs to follow hazardous waste guidelines for disposal).
Chemicals:	With the aeration system automated, mixed liquor settling has improved, and chlorine usage to control filamentous bacteria has been reduced to an as needed basis.
Maintenance:	The surface aerators used to produce a mist of aerosols that would coat the steel columns, handrails, and grating in the area contiguous to the oxidation ditches. These areas required cleaning on a regular basis. As a result of replacing the surface aerators with fine bubble diffusers (which sit on the floor of the basin, and gently produce bubbles), the Big Gulch WWTP staff no longer has to clean up the aerosol deposits. This upgrade has resulted in a cleaner, quieter, and safer WWTP. Additionally, the turbo blowers in the oxidation ditches require minimal maintenance to replace the air filters when they become dirty.

Lessons Learned

The project and the operational issues that provided the drivers for the aeration system improvements have emphasized to Big Gulch WWTP management and operations staff the importance of “constantly investigating new and innovative technologies. It’s an exciting time for the wastewater industry, we’re able to make improvements to our wastewater treatment system and realize significant energy savings as a result.” (Source: Phone conversation with Thomas G. Bridges – Wastewater Treatment Plant Manager, Big Gulch WWTP. February 19, 2010).

Acknowledgements

EPA would like to acknowledge the following individuals for their generous contributions to this case study:

Thomas G. Bridges, Wastewater Treatment Plant Manager, Big Gulch Wastewater Treatment Facility.

Brianna Sheppard, Laboratory Analyst, Big Gulch Wastewater Treatment Facility.

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 4

Optical DO Sensor Technology and Aerator Rotor VFD Control
City of Bartlett Wastewater Treatment Plant
Bartlett, TN
Facility Size: 2.2 mgd design, 1.0 mgd average daily flow

Figure 1: Aerial View of the City of Bartlett Wastewater Treatment Plant #1
(Photo provided courtesy of the City of Bartlett Wastewater Division)

Facility/Process Description:

The City of Bartlett's Wastewater Treatment Plant (WWTP) #1, located in West Tennessee near Memphis, serves approximately 24,000 residential customers and one school. One hundred percent of the plant influent is domestic wastewater. The facility was originally commissioned in 1994 as a 0.5 mgd aerated lagoon and has undergone three major expansions (in 1999, 2003 and 2005) to meet the city's growing population. In 1993, the facility was upgraded to a secondary treatment facility (one oxidation ditch [see Figure 2] and secondary clarification). In 2003, the facility was upgraded with solids handling (aerobic digester and belt filter press). In 2005, a second oxidation ditch was added.

Figure 2: Oxidation Ditch/Aeration Rotor at the City of Bartlett WWTP #1
(Photo provided courtesy of the City of Bartlett Wastewater Division)

Influent data for the City of Bartlett WWTP #1 is presented in Table 1.

Table 1: Profile of the City of Bartlett WWTP #1 Influent Data (Y2009)

Parameter	Daily Average
Flow (mgd)	1.0
BOD (mg/L)	130
TSS (mg/L)	180
Ammonia-N (mg/L)	Not Monitored
TKN (mg/L)	41
Phosphorus (mg/L)	6

Figure 3 is a process flow diagram depicting the current configuration of the treatment plant.

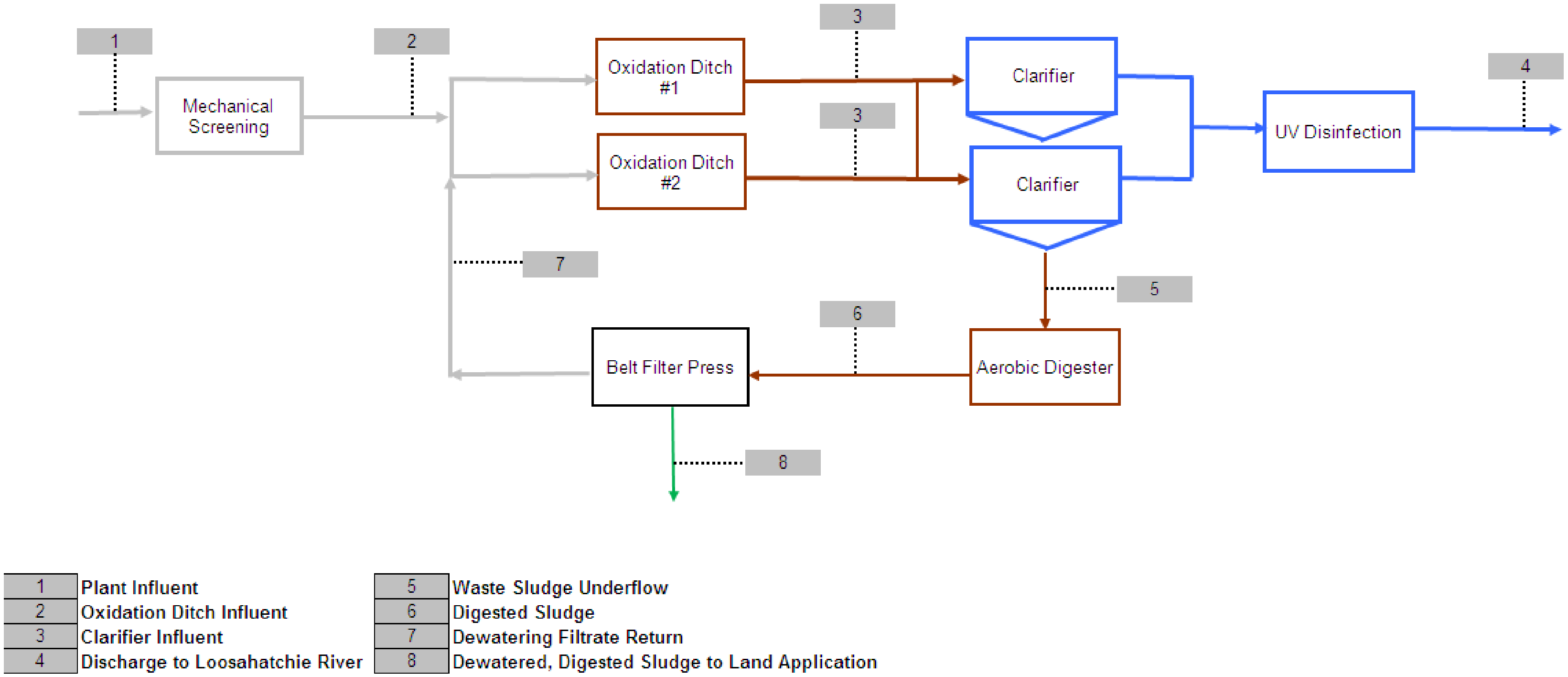

Figure 3: City of Bartlett WWTP #1 Process Flow Diagram

(graphic *provided courtesy of City of Bartlett Wastewater Division)*

Plant influent undergoes mechanical screening followed by biological treatment in two mechanically aerated oxidation ditches. Each oxidation ditch is equipped with three 60 HP rotor aerators. Oxidation ditch effluent undergoes secondary clarification followed by UV disinfection prior to discharge to the Loosahatchie River.

Waste sludge from the secondary clarifiers undergoes aerobic digestion. Digested sludge is dewatered in a belt filter press and is then land applied as an agricultural soil amendment and fertilizer.

Description of Energy Conservation Measures (ECMs):

The City of Bartlett Wastewater Division implemented energy efficiency improvements to its aeration system as a result of a successful demonstration project conducted at the WWTP #1 by the utility, Tennessee Valley Authority (TVA) and two technology vendors. The aeration system improvements consisted of the following:

- Installing InsiteIG optical DO sensor technology (Model 10) to provide reliable DO monitoring in the oxidation ditches.

- Integrating optical DO monitoring instrumentation output (4-20 mA signal) with VFD control (ABB variable speed motor drives) of the aeration rotor speed.

ECM Commissioning Date:

The VFD controls for the rotor aerators and optical DO sensor technology were installed in 2007.

Description of ECM Project Drivers and Issues:

Prior to implementing the aeration system's optical DO sensor technology with integrated VFD control of the oxidation ditch aeration rotor speed, the City of Bartlett WWTP #1 was operating each of the two oxidation ditches with two of the available three 60 hp aeration rotors (in each oxidation ditch). A single aerator was run (at full speed, 60 Hz) continuously and the second rotor was run (at full speed, 60 Hz) during periods of peak flow (activated by a timer/clock). The third rotor was installed, never operated in the original plant configuration, and is not currently required but is available as a backup spare.

The objective of the demonstration project was to advance the use of optical dissolved oxygen sensor technology coupled with variable speed drive motor controllers to achieve energy savings at small to medium sized (< 10 mgd) wastewater treatment facilities. Funding and/or technical support for the demonstration project was provided by the American Public Power Association's Demonstration of Energy-Efficient Development research program and the Tennessee Valley Authority. Additional in-kind support was provided by the technology manufacturers (InsiteIG and ABB) which consisted of personnel to assist in the installation and commissioning of the ECM equipment and providing DO instrumentation and VFD equipment (at no cost) during the initial demonstration trial period.

Currently and during the demonstration program (with a DO control setpoint of 1.2 mg/L in each of the oxidation ditches), one rotor in each of the plant's two oxidation ditches operates continuously at full speed and the second rotor's speed varies, depending upon the DO reading in the oxidation ditch.

The VFD controls the second rotor's input electrical power frequency between 60 Hz (at full speed) and 30 Hz (at minimum speed) and rotational speed depending on the input DO reading. The second rotor reaches full speed for only 30 to 45 minutes each day during the peak flow period. The frequency input to the second rotor from the VFD is 30 Hz for much of the day and occasionally the VFD controlled rotor is turned off when the setpoint DO concentration can be maintained exclusively by the primary single, full speed rotor.

Plant Influent and Effluent Quality

Tables 2a and 2b show the influent and effluent qualities both before and after the implementation of the ECMs.

Table 2a: Monthly Average

Parameter		Y2006 Monthly Average Concentration, mg/L	Y2009 Average Concentration, mg/L
CBOD	Influent	160	130
	Effluent	5	5
	Permit Limit	20	20
TSS	Influent	279	280
	Effluent	12	12
	Permit Limit	30	30
NH_3	Influent	not measured	not measured
	Effluent	0.11	0.15
	Permit Limit	5	5
TKN	Influent	not measured	41
	Effluent	not measured	10
	Permit Limit	not measured	monitor only
P	Influent	not measured	6
	Effluent	not measured	4
	Permit Limit	not measured	monitor only

Table 2b: Daily Maximum

Parameter		Y2006 Daily Maximum Concentration, mg/L	Y 2009 Daily Maximum Concentration, mg/L
BOD	Influent	212	200
	Effluent	5	5
	Permit Limit	30	30
TSS	Influent	500	580
	Effluent	27	35
	Permit Limit	45	45
NH_3	Influent	not measured	not measured
	Effluent	0.40	0.20
	Permit Limit	10	10
TKN	Influent	not measured	42
	Effluent	not measured	15
	Permit Limit	not measured	monitor only
P	Influent	not measured	6.5
	Effluent	not measured	7
	Permit Limit	not measured	monitor only

Results

ECM Implementation Cost

Table 3 summarizes the implementation costs for the optical DO sensor technology and the aeration rotor VFD motor speed controls.

Table 3: ECM Implementation Cost

Cost Category	Cost (in Y2007 $)
Capital and Installation Costs – Optical DO Sensor Technology	$ 3,500
Capital and Installation Costs – VFD	$10,000
Total Installed Cost	**$13,500**

Energy

Table 4 summarizes the electricity energy consumption and costs prior to and following implementation of the aeration system ECM and energy savings. Implementation of the aeration system control ECM realized reductions of 13% in KWh per year consumed, 39% in peak demand and 22% in annual electrical energy cost.

Table 4: Electrical Energy Cost and Savings

	Electrical Energy Consumption and Costs Y2006 (Rotor Controls w/Timers)	Electrical Energy Consumption and Costs Y2008 (Optical DO/VFD Rotor Controls)
Energy Consumption		
• KWh/day	1,553	1,356
• KWh/year	566,845	494940
• Peak Demand, kW	130	79
Total Annual Energy Savings		71,905 kWh/year (13%)
Energy Costs		
• (@ $0.05/kWh)	$28,342/year	$24,747/year
• Peak Demand Charge	$14,227/year	$ 8,646/year
Total Energy Cost	**$42,569/year**	**$33,393/year**
Energy Cost Savings		**$ 9,176/year (22%)**

Source: City of Bartlett Wastewater Division Manager

Payback Analysis/Benefits

At an annual energy savings of $9,176 per year and ECM implementation cost of $13,500, The ECM project at the Bartlett WWTP #1 realized a payback in less than 1.5 years.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

The collaborative effort by the project team and stakeholder interest in the demonstration of this technology/ECM resulted in a successful demonstration of energy savings leading to full scale operation with continuing energy savings results.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to the energy costs savings, the ECM project provided the following additional benefits:

Labor:

Prior to implementing the aeration system ECM, manual monitoring of the DO concentration in the oxidation ditches required an operator’s attention for approximately 1 hour/day (260 hours per year) at an associated labor cost of $4,680 per year. This requirement has been eliminated by automatic DO monitoring.

Maintenance:

The InsiteIG DO sensor requires no periodic maintenance other than monthly inspection and rinsing with a garden hose and annual calibration. The annual cost associated with this maintenance activity is approximately $200/year.

Lessons Learned

VFDs provide a soft start to the aeration rotor motors which should extend the operating life of the motors.

Additionally, plant personnel learned that small changes in process control can lead to large savings in energy costs to the City.

Acknowledgements

EPA would like to acknowledge the following individuals for their generous contributions to this case study:

Larry Gamblin, Wastewater Division Manager, City of Bartlett, TN

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO.5

Advanced Aeration Control
Oxnard Wastewater Treatment Plant
Oxnard, California
Facility Size: 31.7 mgd design, 22.4 mgd average daily flow

Figure 1: Aerial View of Oxnard Wastewater Treatment Plant
(Photo provided courtesy of Oxnard WWTP)

Facility/Process Description:

The Oxnard wastewater treatment plant (WWTP), serves approximately 200,000 people from the city of Oxnard (California). In the early 1970's, the WWTP was originally commissioned as an advanced primary plant. In 1977, trickling filters were installed and in 1989, the facility was upgraded to a trickling filter-activated sludge system with an increase in capacity from 24.5 mgd to 31.7 mgd. Current influent data for the Oxnard WWTP are presented in Table 1.

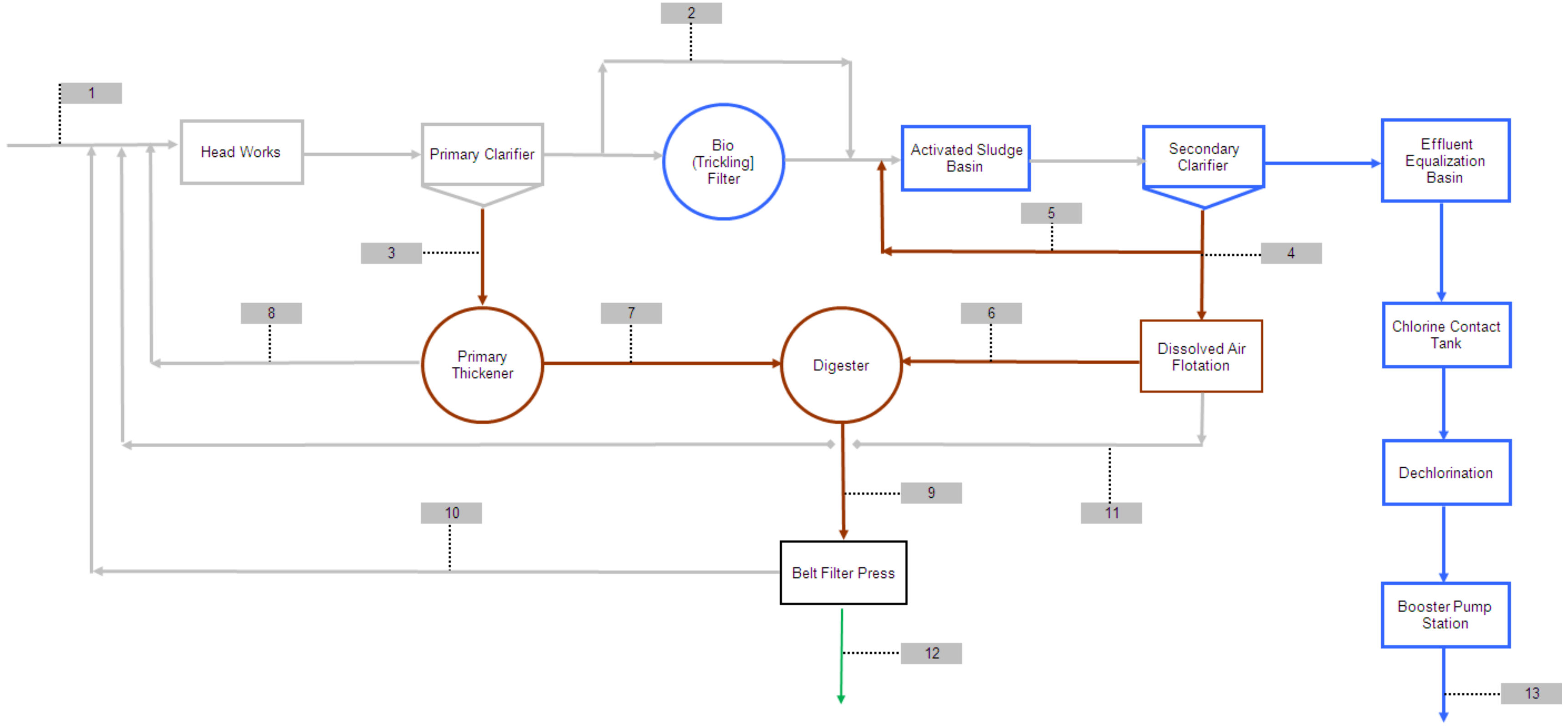
Table 1: Profile of Oxnard WWTP Influent Data

Oxnard WWTP Influent Quantity and Quality		
Parameter	**Average**	**Daily Maximum**
Flow (mgd)	22.4	26.9
BOD (mg/L)	328	369
TSS (mg/L)	265	788

Figure 2 presents the process flow diagram for the Oxnard WWTP.

Influent undergoes screening followed by primary clarification. Primary clarified effluent is distributed to two trickling filters filled with plastic media. One trickling filter is 40 ft in diameter and 26 ft deep, and the other is 100 ft in diameter and 26 ft deep. Under normal conditions, only the large trickling filter is used. From the tickling filter, flow enters the aeration process (two basins, each consisting of three compartments measuring 450 ft x 27 ft x 15 ft. The two aeration basins are of equal size but only one basin is used at one time. Each compartment in an aeration basin has three individually controlled aeration grids equipped with ceramic diffusers. In each aeration basin there are nine dissolved oxygen meters (one per each grid), nine air flow meters (FCI Inc.), and correspondingly nine valves that are automatically controlled using Rotork electrical actuators. In the original design, a proprietary (Turblex Inc.) automatic DO (dissolved oxygen) control system was installed in combination with five 350 hp Turblex blowers. Each blower is rated at maximum flow of 6950 acfm and 10 psig pressure. Aeration is followed by secondary clarification, flow equalization and chlorination/dechlorination. Treated effluent is discharged to the Pacific Ocean.

Primary sludge is thickened in a gravity thickener to 4.8% solids, while secondary sludge is thickened in the dissolved air floatation units to 6.2% solids. Both primary and secondary sludge are mixed prior to entering two digesters. Anaerobic digesters operate under methophilic conditions. Gas from the digesters is used for electrical energy production by three gas-driven generators (500 kW each). Typically, only two generators are used simultaneously. Digested sludge is dewatered in a belt filter press (to 20% solids concentration) and disposed in a landfill.



1	Plant Influent
2	Excess Bypass
3	Primary Sludge
4	Waste Activated Sludge
5	Return Activated Sludge
6	Thickened Secondary Sludge
7	Thickened Primary Sludge
8	Thickener Supernatant
9	Digester Sludge
10	Filtrate
11	DAF Underflow
12	Dewatered Sludge to Landfill
13	Ocean Outfall

Figure 2: Oxnard WWTP Process Flow Diagram

(graphic provided courtesy of OWWTP)

Description of Energy Conservation Measures (ECMs):

The optimization and automation of the activated sludge system included the following measures:

- Installing two on-line TSS (total suspended solids) meters (InsiteIG, Inc). One meter was installed in the mixed liquor channel, another in the RAS wet well. The TSS instrumentation provides suspended solids concentrations of the aeration process mixed liquor and of the Return Activated Sludge (RAS) which is a required input to the process control and optimization algorithms implemented as part of the subject ECM.

- Replacing outdated GLI dissolved oxygen meters with optical sensor technology (InsiteIG Inc).

- Installing SRTmaster^{TM} (Ekster and Associates, Inc) software providing real-time control of solids retention time (SRT). The software utilizes a biological process model based control algorithm and employs multilayer data filtration that guarantees that malfunctions of TSS or flow meters will not lead to erroneous control actions and process upset. The software alerts operators about both meter problems as well as changes in the patterns of process BOD loading or migration of solids to the clarifiers. Finally, the software maintains minimum variability of wasted solids over a day resulting in significant improvements in sludge thickening. SRTmaster^{TM} receives instrumentation readings from the plant SCADA system and sends an optimized waste sludge flow set point to the SCADA system electronically using industry standard OPC drivers.

- Replacing the Turblex blower pressure based control software with DOmaster^{TM}(Ekster and Associates Inc). DOmaster^{TM} uses biological process model based algorithms instead of traditional PID algorithms for DO control. The software also uses a data mining algorithm, instead of pressure data as a DO control criterion, guaranteeing the lowest blower energy consumption. Utilization of these algorithms allows precise control of DO in each of the aeration basin compartments, minimizing energy used by blowers without aeration system oscillations. DOmaster^{TM} uses multilayer data filtration to guarantee reliability of automatic control even if one of the control elements (meters or actuators) fails. The software communicates with the plant SCADA system in the same manner as SRTmaster^{TM}, receiving instrumentation readings and returning airflow set points to the SCADA system for each aeration diffuser grid control valve opening and blower vane positioning.

- Using OPTImaster^{TM} (Ekster and Associates Inc) software to optimize set points for SRT and DO for each aeration compartment diffuser grid.

ECM Commissioning Date:

SRTmaster^{TM} (in addition to the associated TSS and DO instrumentation) was implemented at the Oxnard WWTP in 2003. DOmaster^{TM} for control of the blowers was implemented in 2004 and OPTImaster^{TM} was implemented in 2005.

Description of ECM Project Drivers and Issues:

Activated sludge automation and optimization ECMs were initiated to address foaming and intermittent bulking problems, and to reduce operator workload, and reduce energy and chemicals usage.

Plant Influent and Effluent Quality

The data in Tables 2a-2c (provided by the Oxnard WWTP Operations manager) compares the OWWTP performance prior to the implementation of aeration system improvements (Y2002) and current (Y2009, post-ECM implementation) performance.

Table 2a: Monthly Average

Parameter		Y2002 Monthly Average Concentration, mg/L	Y2009 Average Concentration, mg/L
BOD	Influent	262	328[1]
	Effluent	17	17
	Monthly Limit	30	30
TSS	Influent	221	265[1]
	Effluent	5	5
	Monthly Limit	30	30

Note 1. In 2009 Influent samples includes recycled flow.

Table 2b: Daily Maximum

Parameter		Y2002 Daily Maximum Concentration, mg/L	Y 2009 Daily Maximum Concentration, mg/L
BOD	Influent	480	369[1]
	Effluent	74	35
	Weekly Limit	45	45
TSS	Influent	370	788[1]
	Effluent	31	11
	Weekly Limit	45	45

Note 1. In 2009 Influent samples includes recycled flow.

Table 2c: Sludge Volume Index (SVI)

Parameter	Y2002, mL/g	Y 2009, mL/g
Average	165	130
Maximum	385	170

Results

ECM Implementation Cost

Table 3 summarizes the implementation cost for the Oxnard WWTP ECM project.

Table 3: ECM Implementation Cost

Cost Category	Cost (in Y2002 $)
Software cost [1]	$ 100,000
Instrumentation costs	$30,000
Installation Costs [2]	$5,000
Total Cost	$ 135,000

Note 1 Due to pilot nature of the project, City contribution was $25,000 toward software purchase.
Note 2 – Most of ECM installation was done by plant personnel. Implementation of the control algorithms and associated instrumentation required approximately 2 to 3 days, while the design of the user interface required an additional 2 weeks.

Energy

Following implementation of the ECM project, the average energy usage by blowers was reduced from 175 kW in 2002 to 140 kW in 2009. This resulted in a 306,600 kWh per year reduction or a 20% energy savings. The average electricity cost in 2009 was $0.088/kWh. The annual energy savings attributed to the ECM implementation is $26,980 (35kW*24hr*365days*$0.088/kWh). Relatively small cost savings can be attributed to significant additional removal of BOD by the trickling filter.

Chemicals

Based on WWTP records: by reducing polymer dosage used for sludge thickening (a benefit of improved sludge settleability), chemical costs were reduced by approximately $7,500 a year.

Labor

Improved process monitoring and automation reduced the number of operator hours by at least 1 hour per day by eliminating sampling, frequent field measurements and manual adjustments. The average labor cost savings resulting from this ECM are approximately $18,250 per year (1hr/day*$50/hour*365 days per year).

The total energy savings for this ECM are $26,980 per year. Including chemical cost savings and reduced manpower requirements, the total savings resulting from this ECM are $52,730 per year.

Payback Analysis/Benefits

For this analysis, simple payback is determined by dividing the total project cost ($135,000 from Table 3) by the resultant savings ($26,980 per year for energy only, $52,730 per year total). Based on these data, the project payback period is five years considering only the electrical energy savings. Including the chemical cost savings and labor savings in the payback analysis reduces the payback period to approximately 2.5 years.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

The Oxnard WWTP operations manager was a champion of the innovations implemented under this ECM project and was also personally involved in integration of the Ekster's software packages with the plant wide control system. Under his supervision, the operation staff embraced innovative ideas and worked directly with the vendors to speed up the implementation and commissioning of new optimization and automatic control methods. The fact that automatic control reduced operators' workload and improved NPDES compliance has helped adaptation of new technology at OWTP.

Additional benefits from ECM Implementation

In addition to cost saving resulting from this project, the major benefit resulting from this ECM project was improved process stability, reducing Sludge Volume Index (SVI) on average by 20% and maximum SVI by 50% (see Table 2c). As a result, in 2009 effluent water quality never exceeded NPDES limits (see Table 2b). In addition, foam observed periodically before this ECM implementation has not been seen since the project was implemented.

Lessons Learned

- Operation management leadership was a key factor in the project's success.

- ECMs need to provide multiple benefits to reduce payback period and to speed up adaptation of new technology. Benefits related to improving reliability of operation are especially valuable.

- Reliable operation of ECMs provides the necessary confidence of operating staff in new technology.

- When it comes to automation, the control algorithms need to take into account potential failures of control elements and ensure that these failures will not have negative impacts on operation.

- Third party specialized automatic control software packages can be easily integrated with SCADA control systems using modern communication protocols. Ready to use automation software reduces algorithm design and programming costs and provides better reliability of automated control.

Acknowledgements

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 6

DO Optimization Using Floating Pressure Blower Control in a Most Open Valve (MOV) Strategy

Narragansett Bay Commission Bucklin Point WWTF
East Providence, RI
Facility Size: 46 mgd (dry weather)/116 mgd (dry plus wet weather) - design
23.7 mgd - average daily flow

Figure 1: Narragansett Bay Commission Bucklin Point WWTF
(*Photo provided courtesy of the Narragansett Bay Commission and United Water*)

Facility/Process Description:

The Narragansett Bay Commission's (NBC) Bucklin Point Wastewater Treatment Facility (WWTF) serves a population of approximately 130,000 residing in the cities of Central Falls, Cumberland, East Providence, Lincoln, Pawtucket and Smithfield in the Blackstone River Valley and East Providence, Rhode Island area. The WWTF is operated for NBC under a management contract with United Water.

The Bucklin Point WWTF was originally commissioned in 1950 and has since undergone four major upgrades. The last comprehensive upgrade of the Bucklin Point WWTF was completed in 2006, a reconfiguration of the conventional activated sludge aeration process to a Modified Ludzak-Ettinger

(MLE) process to effect nitrogen removal. The MLE biological treatment process is configured in four parallel trains each consisting of three anoxic zones followed by four aerobic zones in each train. Aeration for the aerobic stage of the MLE process is provided by three 600 hp (each) Dresser Roots single stage centrifugal blowers, each capable of delivering 12,100 cubic feet per minute (cfm).

Prior to the Y2006 upgrade, conventional biological treatment was accomplished in the same aeration tanks (and tank volumes) currently being used in the modified MLE process. At that time, the four aeration trains consisted of four aerobic zones only (each train) for a total of sixteen aerobic zones. The modified MLE process utilized the same configuration but provided for twelve anoxic zones (three sequential tanks at the head end of the aeration train) followed by sixteen aerobic zones (four in each train following the three sequential anoxic zones). The Y2006 upgrade provided for a fine bubble diffusion system in place of the mechanical aerators. The additional equipment at the aeration basin included optical DO probes and sixteen electric motor-operated butterfly valves for modulating air flow. Each of the 16 control zones also had a flow tube and flow transmitter to provide measurement of ACFM (Actual Cubic Feet per Minute) to each zone.

The Y2006 plant upgrade was designed with conventional aeration/blower control utilizing individual Proportional-Integral-Derivative (PID) loops for controlling dissolved oxygen (DO) and air flow in each of the MLE process aerobic zones. The DO/blower control system was based on constant discharge pressure using Most Open Valve (MOV) logic to minimize blower energy consumption by manipulating the air delivery system's pressure setpoint (through opening and closing the air distribution system's drop leg valves to each of the aeration system's 16 aerobic zones) in response to DO readings in the aerobic zones

Influent data for the NBC Bucklin Point WWTF is presented in Table 1.

Table 1: Profile of the NBC Bucklin Point Influent Data (Y2009)

Parameter	Daily Average
Flow (mgd)	23.7
BOD (mg/L)	155
TSS (mg/L)	147
Ammonia-N (mg/L)	15.37
TKN (mg/L)	25.70
Phosphorus (mg/L)	4.17

Figure 2 is a process flow diagram depicting the current configuration of the treatment plant.

Influent (dry and wet weather flow) from the facility's two main sewer interceptors (the Blackstone Valley Interceptor and the East Providence Interceptor) are collected in the facility's influent pump station and are conveyed (using three each 100 hp, 38.7 mgd screw pumps) to preliminary treatment for screening and grit removal (four, 40 mgd each screens with 0.75 in openings followed by four, 40 mgd each 19 ft diameter grit vortex units). Grit and screenings are disposed in a landfill. Primary treatment for "dry weather" flow (up to 46 mgd) follows using three circular clarifiers (102 feet in diameter and 14 feet deep, each). Wet weather flow (i.e., influent exceeding 46 mgd) is collected, following preliminary treatment, in two 2.5 million gallon (total volume) holding tanks. The contents of the wet weather holding tanks are returned to the treatment plant to undergo primary and secondary treatment once the wet weather event flow ceases. During a wet weather event, any flow that exceeds the capacity of the holding tanks undergoes chlorination followed by dechlorination and is discharged to the Seekonk River.

Primary effluent undergoes biological treatment in a four train MLE process. Each train consists of three sequential anoxic zones (0.59 million gallons each) followed by four sequential aerobic zones (2.28 million gallons each). Anoxic/aerobic treatment is followed by six secondary clarifiers (four at 111 feet in diameter and 11 feet deep each and two at 110 feet diameter and 12 feet deep each). An internal mixed liquor recycle carries nitrates from the aerobic zone to the anaerobic zone for denitrification. A portion of the settled sludge from the secondary clarifiers is returned and mixed with the influent to the anoxic zones. Secondary clarifier effluent is disinfected using ultraviolet radiation prior to discharge to the Seekonk River.

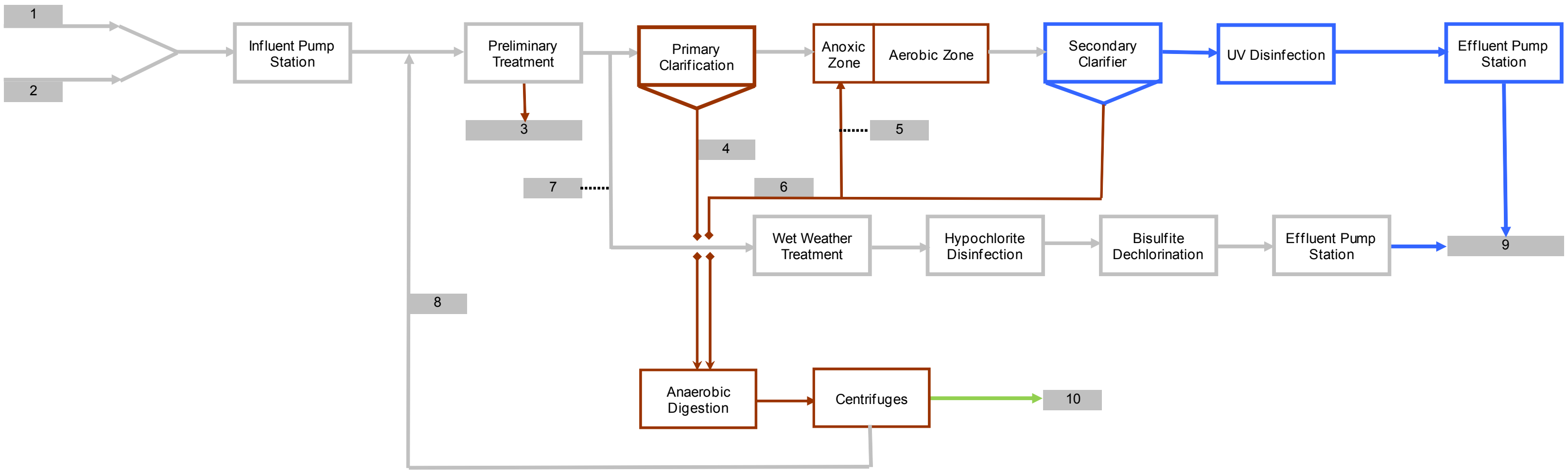
Primary sludge underflow from the primary clarification process and Waste Activated Sludge (WAS) underflow from the secondary clarifiers are anaerobically digested and then are dewatered in centrifuges to produce biosolids that are recycled as compost for use in non-agricultural land application.

Description of Energy Conservation Measures (ECMs):

The ECM implemented at the Bucklin Point WWTF is a DO/blower control system utilizing proprietary control algorithms (developed by ESCOR, Inc. a subsidiary to Dresser Roots]) in lieu of PID loop control allowing DO/blower control based on air flow versus pressure. Unlike the original pressure based system, the Dresser Roots (ESCOR) system employs direct flow control of the blowers. As the DO varies from setpoint, the required incremental changes in air flow are used to modify both aeration drop leg air flow and blower flow. The most open valve logic directly manipulates basin air flow control valve positions to insure that at least one valve is always at maximum position, thereby minimizing system pressure without using a pressure setpoint. The reduced complexity makes the control more robust and more accurate. Elimination of the pressure control loop also minimizes tuning.

ECM Commissioning Date:

In August 2006, an integrated air flow control system was implemented to provide stable control of the aeration system blowers. This air flow control based technology replaced the facility's pressure based aeration control system.



1	**Blackstone Valley Interceptor**	5	**Return Activated Sludge**	9	**Discharge to Seekonk River**		
2	**East Providence Interceptor**	6	**Waste Activated Sludge**	10	**Sludge to Beneficial Reuse**		
3	**Grit and Screenings to Landfill**	7	**Wet Weather Flow**				
4	**Primary Sludge and Scum**	8	**Centrate Return**				

Figure 2: NBC Bucklin Point WWTF Process Flow Diagram

(graphic provided courtesy of Narragansett Bay Commission and United Water)

Description of ECM Project Drivers and Issues:

Following commissioning of the Bucklin Point WWTF’s conversion of the activated sludge process to an MLE process in 2006, the plant experienced difficulty attaining consistent nitrogen removal because the constant pressure based aeration/blower control system was unable to adjust to changing process conditions and maintain proper DO concentration in the aeration basins, resulting in insufficient conversion of ammonia nitrogen to nitrate.

The constant pressure based control system was unable to maintain DO levels in the aeration tanks closer than 1.0 ppm compared to setpoint. This problem was exacerbated during wet weather events. The MOV control was unable to consistently minimize the system discharge pressure resulting in wasted energy. An analysis conducted by ESCOR determined that the interaction between the PID control loops was causing instability in the control of aeration basin DO. The DO/blower system control instability in turn caused the following problems:

- Biological nitrogen removal (denitrification) was being inhibited by high DO in the internal mixed liquor recycle (IMLR) flow to the MLE process anoxic zones.
- Energy consumption and costs exceeded expectations.
- A utility rebate was being jeopardized because the constant pressure MOV logic was ineffective.
- Plant operations staff were forced to manually intervene in the operation of the blowers/aeration system to maintain performance and compliance.

The drivers for implementing an improved DO/blower control system were primarily to enable the WWTF to maintain effluent Total Nitrogen levels below 8.5 mg/L (monthly average) during the permitted seasonal compliance period (May through October) and to provide consistent nitrification and denitrification during varying flows from wet weather events.

The ECM significantly revised the aeration system control strategy while maintaining existing control devices by:

- Substituting specialized/proprietary DO/blower control algorithms for PID control loops.
- Eliminating pressure control in lieu of direct air flow control.
- Basing MOV logic on zone air flow control.

The results of the ECM implementation were:

- The IMLR flow DO control is consistent and no longer inhibits denitrification in the anoxic zone.
- Aeration system energy consumption and costs are below original projections (and the utility rebate was secured).

- DO excursions are less than 0.50 ppm from setpoint.

- MOV logic is effective in minimizing blower discharge pressure (and associated energy consumption).

- Operator intervention (manual control) with the aeration system is no longer required to effect discharge compliance.

Plant Influent and Effluent Quality

Table 2 presents the monthly average influent and effluent qualities both before and after the implementation of the ECMs.

Table 2: Monthly Average

Parameter		Y2004 Monthly Average Concentration, mg/L	Y2009 Average Concentration, mg/L
BOD	Influent	232	155
	Effluent	14	4
	Permit Limit	30	30
TSS	Influent	143	147
	Effluent	15	7
	Permit Limit	30	30
NH_3	Influent	14.819	15.37
	Effluent	11.526	0.69
	Permit Limit	Not Applicable Limit	(May – October) 15
TKN	Influent	23.647	25.7
	Effluent	14.375	2.1
	Permit Limit	Not Applicable Limit	Not Applicable Limit
Total N	Effluent	15.614	7.95
	Permit Limit	Not Applicable Limit	(May – October) 8.5
P	Influent	4.995	4.17
	Effluent	1.884	2.01
	Permit Limit	Not Applicable Limit	Not Applicable Limit

Results

ECM Implementation Cost

Table 3 provides the installed cost (as estimated by the utility and operations management contractor) for the implementation of the proprietary DO/blower control system.

Table 3: ECM Implementation Cost

Cost Category	Cost (in Y200 $)[1]
Proprietary DO control / blower supply management system	$170,000
Installation/Commissioning	$30,000
Total Installed Cost	**$200,000**

Note1: The ECM/implementation cost is estimated by NBC and United Water

Energy

Table 4 summarizes the electricity energy consumption and costs prior to and following implementation of the aeration system ECM and resultant energy savings.

Table 4: Electrical Energy Cost and Savings

Year	Monthly Electricity Use (kWh)[1]	Average Daily Flow (mgd)	Annual Energy Use Reduction (kWh)	Average Electricity Rate ($/kWh)[3]	Annual Electricity Cost Savings
A	B			C	$E = (B_{\text{evaluation year}} - B_{2006})*C*12$
Prior to ECM Implementation					
2006	864,612			0.099	
After ECM Implementation[2]					
2007	775,553	20.33	1,068,700 (10.3%)	0.10843	$115,880 (11%)
2008	742,547	21.95	1,464,800 (14%)	0.10613	$155,457 (15%)
2009	763,980	21.66	1,207,600 (11.6%)	0.11264	$136,022 (13%)

1. Total facility monthly electrical energy use less UV disinfection system.
2. ECM implementation commissioned at end of 2006
3. Rate total for supply, delivery and demand

Source: NBC and United Water

Payback Analysis/Benefits

For this analysis, simple payback is determined by dividing the ECM project cost ($200,000) from Table 3 by the electricity cost savings following project implementation. The reduced electrical energy consumption and electricity cost savings provided by the aeration system control ECM resulted in a payback in the seventh month (July) of the second year following commissioning of the ECM (2008), a 1.5 year payback.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

Careful evaluation and documentation of operating conditions led to an identified need to address dissolved oxygen control after eliminating other possible sources.

Collaboration by all stakeholders (internal and external to the NBC and Bucklin Point WWTF) resulted in a successful resolution to the problem.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to the energy costs savings, the ECM project provided the following additional benefits:

Labor:	Implementation of the blower control system ECM eliminated field sampling/testing for aeration basin DO readings and manual manipulation of the aeration basins' drop leg valves.
Chemicals:	The more stabilized operation resulting from the implementation of the ECM reduced sodium bicarbonate addition, as a more consistent alkalinity in the effluent is achieved.

Lessons Learned

In larger facilities, every component has a significant impact when it is not operating efficiently.

Constant diligence to review and improve operational procedures is critical in a biological nutrient removal process, especially during wet weather events when the process is adversely impacted.

Biological nutrient removal processes must operate within narrow parameters (those controllable by operations staff) to achieve the best possible steady state conditions under significant variable conditions as compared to conventional wastewater treatment facilities. Monitoring data for the operating parameters must be timely, accurate and repeatable to ensure operational integrity during each shift.

Professionals involved in the design and operation of wastewater treatment facilities should be aware of the need to operate biological systems closely and respond to changes in process conditions within short periods of time. DO control systems and strategies must be properly designed and integrated to maintain reliability under frequent operational changes (e.g., for blowers, inlet and outlet guide vanes and drop leg valves which are designed for frequent changes of varying nature).

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 7

Multiple Hearth Biosolids Incinerator Upgrade – Capacity and Fuel Efficiency Improvements

Washington Suburban Sanitary Commission
Western Branch WWTP
Upper Marlboro, MD
Facility Size: 30 mgd design, 21.6 mgd - average daily flow

Figure 1: Washington Suburban Sanitary Commission Western Branch WWTP
(*Photo provided courtesy of the Washington Suburban Sanitary Commission*)

Facility/Process Description:

The Washington Suburban Sanitary Commission's Western Branch Wastewater Treatment Plant (WWTP) is located in Upper Marlboro, Maryland on the Western Branch of the Patuxent River. The facility was originally commissioned in 1966 as a five mgd primary/secondary plant utilizing anaerobic digestion and vacuum filters to process biosolids for land application. The current 30 mgd facility serves residential, commercial and industrial users in the east-central portion of Maryland's Prince George's County.

Since its original commissioning in 1966, the Western Branch WWTP has undergone several significant upgrades to accommodate the service area's growing population and to implement treatment process enhancements required to meet increasingly stringent effluent quality requirements promulgated by the State of Maryland and USEPA. In 1974, a 15 mgd nitrification plant (Phase I) was constructed as well as sludge incineration facilities. In 1977, a mirror image 15 mgd nitrification plant (Phase II) was commissioned. The Phase I and Phase II nitrification plants utilized a two sludge process with final filtration. In 1989, a denitrification activated sludge (DNAS) process was implemented to comply with seasonal (summer) permitted nitrogen removal effluent limits (1.5 ppm NH_3 and 3.0 ppm TKN). The DNAS process uses methanol as a carbon source for denitrification. Figure 2 provides a process flow diagram of the Western Branch WWTP.

Additional enhancements to the Western Branch WWTP are currently being designed to optimize the facility's nitrogen removal performance (to achieve an annual average effluent nitrogen concentration of 3 mg/L). These enhancements are scheduled to be commissioned in 2013 and include the following:

- High Rate Activated Sludge (HRAS) Process Upgrades
    - Centralized HRAS Return Activated Sludge (RAS)/Waste Activated Sludge (WAS) Pumping System
    - Scrubber Blow-Down Recycle isolation to HRAS process
    - Anaerobic Zone Baffle Walls and Mixers or Plug Flow Reactor Staging
    - HRAS Surface Wasting
    - HRAS Enhanced Nitrogen Removal (ENR) Monitoring and Control Systems

- Nitrification Activated Sludge (NAS) Process Upgrades
    - Centralized NAS RAS/WAS Pumping System
    - Anoxic Zone Baffles Walls and Mixers
    - NAS Plug Flow Baffle Walls
    - NAS ENR Monitoring and Control Systems

- Denitrification Activated Sludge (DNAS) Process Upgrades
    - DNAS ENR Monitoring and Control Systems

- Solids Handling Process Upgrades
    - Dissolved Air Flotation Thickening Improvements
    - Increased Thickened Sludge Storage Capacity
    - Dual Centrifuge Operation Capability

- HRAS Bypass with Grit Removal

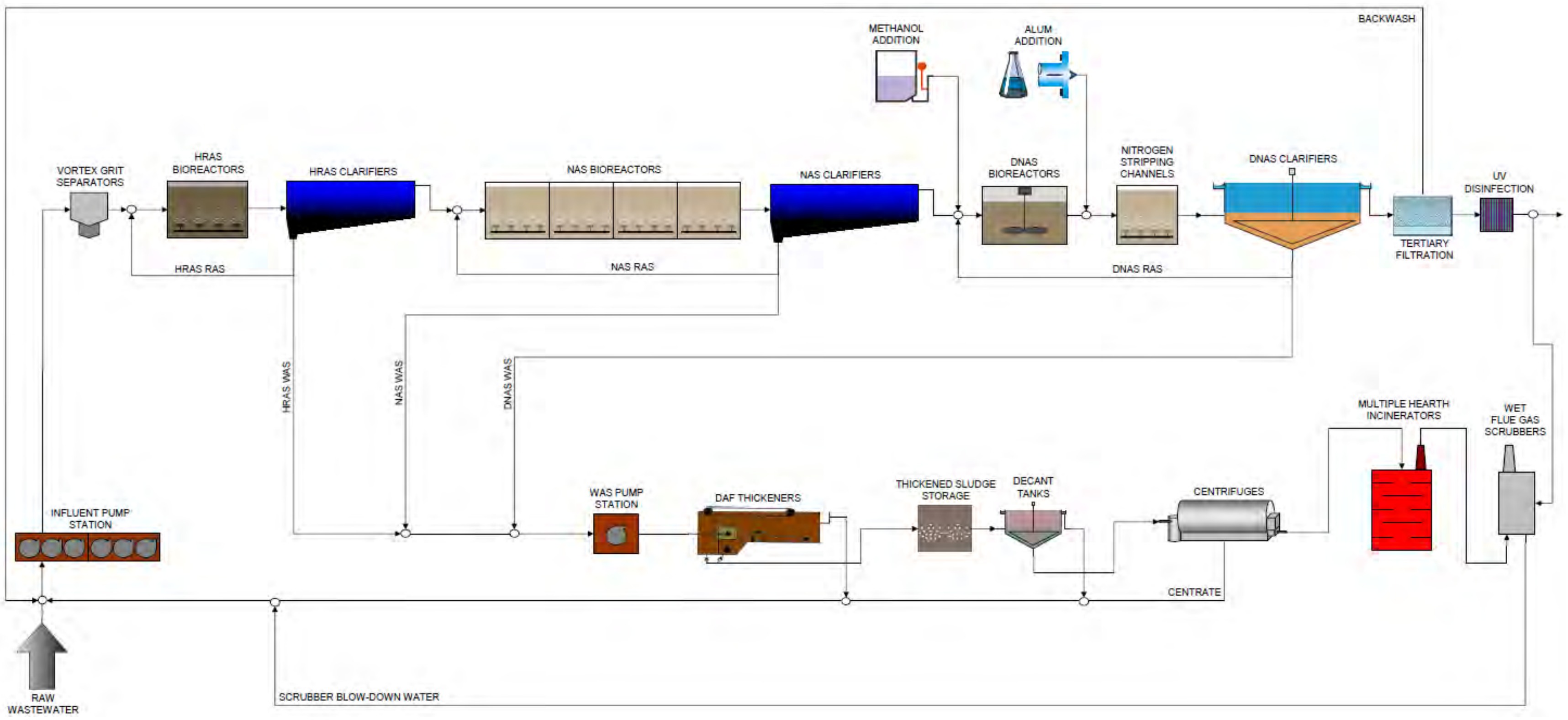

Figure 2: WSSC Western Branch WWTP Process Flow Diagram

(Graphic provided courtesy of WSCC and AECOM)

Description of Energy Conservation Measures (ECMs):

The ECM implemented at the Western Branch WWTP involved upgrades to the facility's biosolids incineration Multiple Hearth Furnaces (MHFs). Commissioned in 1974, the MHFs were designed to process (burn) 26 dry tons per day (DTPD) of heat treated biosolids. WSSC decommissioned the sludge heat treating process soon after commissioning the MHFs. In 1996, WSSC replaced the centrifuges to increase the capacity of the MHFs, but in 2001 the enactment of Title V and "zero visible emissions" required reducing the capacity of the MHFs to 12 DTPD. To mitigate visible emissions, WSSC installed external after-burners which increased the consumption of natural gas.

Pre ECM Operation

In the MHF process, the sludge was introduced into the top of the furnace. The top hearth was also the exhaust point for the combustion gases. The "cold" sludge feed, coming into contact with the hot furnace, released volatile hydrocarbons that did not have sufficient residence time in the furnace nor adequately high temperature to be oxidized (burned) completely before being emitted. The result was a high hydrocarbon content, smoky and odorous emission. This emission exhaust stream was controlled by increasing the operating temperature of the top of the furnace and/or utilizing the external afterburner to increase the exhaust temperature and residence time. This operating mode resulted in high natural gas consumption. The higher operating temperature of the furnace, in turn, created slagging (i.e., melting) of the ash inside the furnace, increasing maintenance and associated costs (to remove slag).

Exacerbating the increase in fuel consumption, the incoming furnace combustion air entered the furnace at room temperature. This cooled the furnace and added significant heat load (and increased fuel consumption) to maintain furnace temperature. The hot MHF exhaust stream was cooled and cleaned in a wet scrubber before being discharged to the atmosphere, and the heat in the exhaust stream was lost (i.e., waste heat was not utilized).

Energy Saving Improvements

The following energy savings modifications to the MHFs were implemented by WSSC at the Western Branch WWTP. Figure 3 is a schematic representation of the Western Branch MHF modifications described below.

Flue Gas Recirculation

A Flue Gas Recirculation (FGR) system was installed which collects exhaust flow from the top hearth of the furnace and re-injects it into the lower hearths. This recirculated flue gas accomplishes the following:

- Unburned vapors and gases from hearth 1 are redirected through the burn zone in the furnace, providing sufficient contact time and temperature to complete the hydrocarbon oxidation process before exhausting.
- The additional air flow through the furnace tends to cool the hot hearths (reducing slagging) and helps to heat the cooler drying hearths –stabilizing the furnace operations.

- The high water vapor content of the recirculated gas stream (entrained from the drying zones), reduces the production of nitrogen oxides (NOx) in the burning hearths. Stable temperatures in an MHF due to the addition of an FGR system are also known to reduce the production of thermal NOx.

Exhaust Waste Heat Recovery

An air-to-air heat exchanger was installed in the exhaust stream of the furnace, upstream of the quench and wet scrubber, allowing recovery of the waste heat from the furnace exhaust. The recovered heat is utilized to preheat the combustion air entering the furnace, reducing the consumption of natural gas. Additionally, the center shaft cooling air exhaust (heated air) is returned to the furnace as pre-heated combustion air.

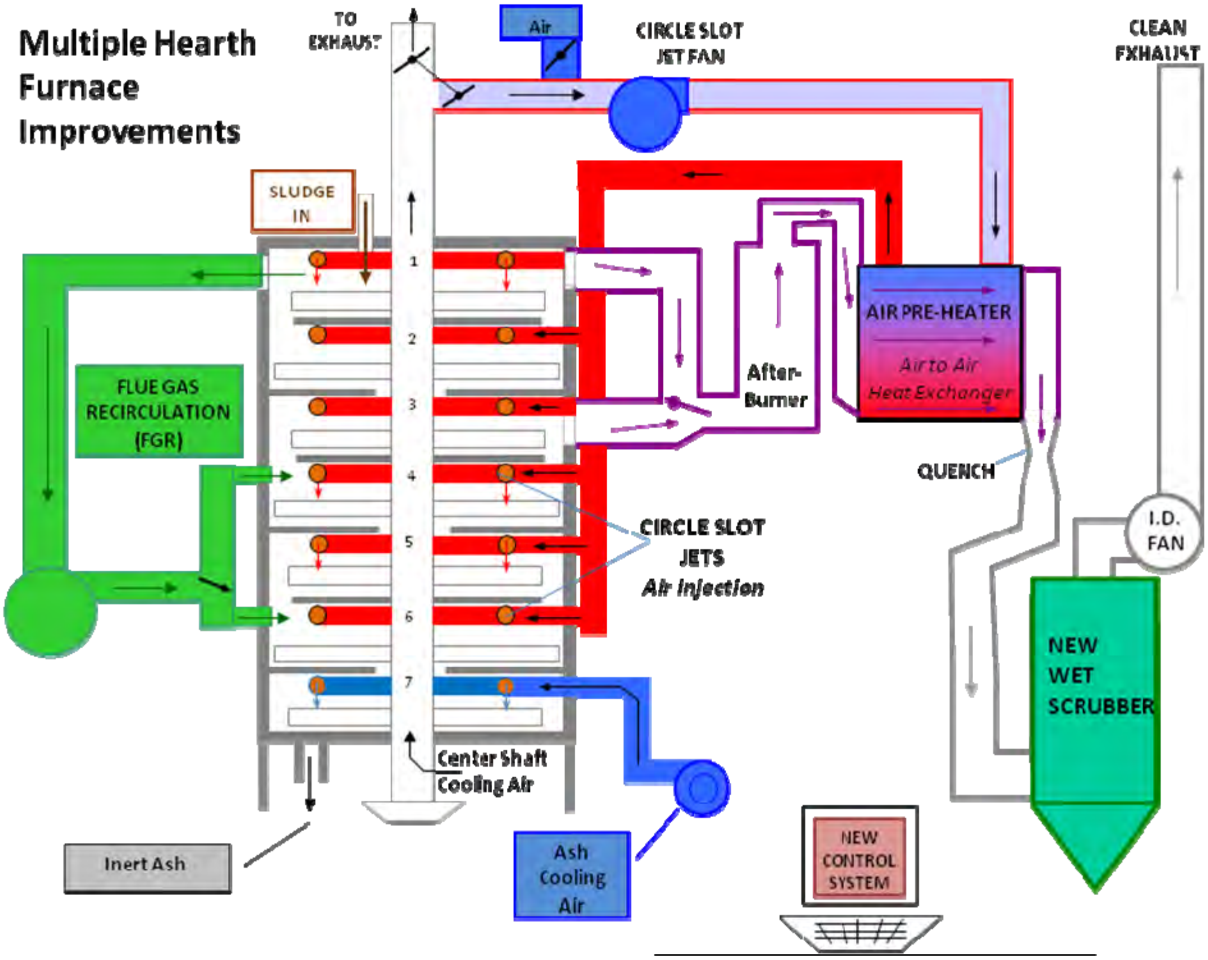

Figure 3: Schematic of MHF Improvements at the Western Branch WWTP
(graphic provided courtesy of WSCC and AHP)

Circle Slot Jets

Circle Slot Jets, a ring of small air jets located near the top of each hearth, concentric with the center shaft of the furnace and about one-half the diameter of the furnace, were installed in the MHFs. Pre-heated combustion air is injected downward into the hearths through the Circle Slot Jets creating an impingement region and dual set of donut shaped vortices in each hearth. This increases turbulence and air-fuel mixing. Simultaneously, a small portion of the required supply air is introduced (at room temperature) into the bottom hearth to cool the ash as it exits the furnace. The result of this modification is improved convection and turbulence which increases drying rates in the drying zone and combustion rates in the burn zones.

ECM Commissioning Date:

In 2009, one of the facility's multiple hearth furnaces was retrofitted with flue gas recirculation, exhaust waste heat recovery and circle slot jets to improve fuel efficiency and capacity. In 2010, the facility's second multiple hearth furnace was similarly modified. Sub-metering of the fuel to the furnaces (single meter) was implemented as part of the ECM project.

Description of ECM Project Drivers and Issues:

The drivers for this ECM were:

- To significantly reduce the amount of natural gas required to burn the sludge produced from the Western Branch WWTP.
- To meet air emission requirements.
- To pay 100% of the capital cost of upgrade through energy savings.
- To increase the throughput capacity of the furnaces.
- To reduce NOx emissions to meet Best Available Control Technology regulatory requirements.

Results

ECM Implementation Cost

Table 1 provides the installed cost (for the implementation of the MHF modifications.

Table 1: ECM Implementation Cost

Cost Category	Cost (in Y2008$)
Total Installed Cost	**$4,500,000**

Energy Consumption and Costs

Table 2 summarizes the energy consumption and costs (natural gas fuel) prior to and following implementation of the aeration system ECM and the resultant energy savings provided by the MHF modifications.

Table 2: Natural Gas Cost and Savings

Year	Natural Gas Consumption (therms/Year)	Gas Rate ($/therm)	Energy Cost ($/Year)
Prior to ECM Implementation			
2005	420,000	1.25	$525,000
Following ECM Implementation			
2009	100,000	1.25	$125,000
Savings	320,000 (76%)		$400,000

Based on the first six months of operation of the first of two MHFs to be modified, an annual reduction of 320,000 therms of natural gas are projected for the sludge incineration operation at the Western Branch WWTP (a 76% reduction), resulting in an annual fuel expenditure savings of $400,000 per year.

Payback Analysis/Benefits

For this analysis, simple payback is determined by dividing the total project cost ($4,500,000 from Table 1) by the natural gas fuel cost savings projection for year following the project implementation ($400,000 per year – Table 2). The fuel costs savings provided by the MHF modifications resulted in a project payback period of 11.3 years following commissioning (2009). This payback period does not include the avoided cost benefit (of delaying the construction of additional incineration capacity) provided by the increased capacity of the existing MHFs resulting from the ECM modifications. The new upgraded MHF operates at a continual throughput of 17-19 DTPD (a 42% to 58% capacity increase).

Conclusions

Factors Leading to Successful ECM Implementation/Operation

1. Project planning should include the condition of existing equipment and future process, O&M impacts, as well as energy.
2. Hands-on training of multiple operators is vital to the success of newly installed equipment.
3. To obtain commitment to a new system, plant staff must be shown that upgraded equipment improves operations and reliability.

Impact on Other Operating Costs Resulting from ECM Implementation

Emergency Sludge Hauling: MHF modifications increase the MHF capacity, reducing the need for emergency hauling of un-incinerated sludge. The resulting savings are estimated at $100,000 -

$200,000/yr. These savings, if included in the analysis of payback, result in a payback period of between 7.5 and 9 years.

Lessons Learned

1. As seasons change, the characteristics of the biosolids change, and can range anywhere from 21% solids to 29% solids. At high solids content, the MHF is almost autogenous and in this mode the furnace operation would be better if there was an ability to add ambient air separately from hot air on different hearths. The Circle Slot Jets, as installed currently, do not allow this operational mode.
2. The existing condition of the MHF should be closely evaluated when considering an ECM implementation, as repair costs can increase the overall capital cost of the project by 10-15%. If the existing furnace needs rehabilitation, it should take place before or during an ECM implementation. Rehabilitation becomes more difficult once Circle Slot Jets and heat exchanger ductwork is installed.

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO. 8

Permit Safe and Energy Smart Greening of Wastewater Treatment Plant Operations
San Jose/Santa Clara Water Pollution Control Plant
San Jose, California
Facility Size: 167 mgd design, 107 mgd average daily flow

Figure 1: Aerial View of SJ/SC WPCP
(*Photo provided courtesy of SJ/SC WPCP*)

Facility/Process Description

The San Jose/Santa Clara Water Pollution Control Plant (Plant) first began operations in 1956 as a primary treatment facility. The Plant was upgraded in 1964 to secondary treatment and again in 1979 with addition of a two-stage nitrification and filtration process. A step-feed Biological Nutrient Removal (BNR) was implemented in 1995 which led to reduction of the aeration energy consumption and costs, enhanced bulking control, and increased plant capacity. The single stage BNR process has the advantage of operating two activated sludge plants in parallel rather than in series (as was the case prior to the 1995 upgrade).

The Plant has capacity to treat 167 million gallons per day (mgd) and currently receives an average influent of 107 mgd. Approximately 10 percent of the Plant effluent is reused as recycled water for irrigation and makeup water for cooling towers. The Plant influent data are presented in Table 1.

Table 1: Profile of SJ/SC WPCP Influent Data (Y2009)

Parameter	Average	Daily Maximum
Flow (mgd)	107	167
BOD (mg/L)	298	512
TSS (mg/L)	241	797
Ammonia-N (mg/L)	31	54

Figure 2 presents the process flow diagram for SJ/SC WPCP.

Raw sewage entering the Plant undergoes several stages of treatment. First, the influent passes through screening, grit removal, and primary settling. The flow then splits into two parallel BNR plants (BNR1 and BNR2). The BNR plants consist of multiple treatment zones with multiple aerators and clarifiers. The first compartment in each aeration basin is operated under anaerobic conditions and the second and forth compartments are operated under aerobic conditions. The third compartment is operated under anoxic conditions. Approximately 60% of the influent flow and 100% of the Returned Activated Sludge (RAS) are fed to the first (anaerobic) compartment. Approximately 40% of the influent flow is fed to the third compartment that is operated under anoxic conditions. To maintain solids in suspension in the anoxic/anaerobic compartments, approximately 1000 scfm of air are pumped into each of these compartments. To minimize capital cost when the plant was upgraded from the two-stage nitrification configuration to the BNR plant, existing coarse bubble diffusers were utilized for mixing the anaerobic/anoxic zones versus installing new mechanical mixers.

A schematic of the BNR process is depicted in Figure 3.

Air is supplied to the BNR1 plant aeration process by internal combustion engine driven blowers that utilize a mixture of digester, landfill, and natural gas for fuel. A by-product of the operation of the internal combustion engines is hot water (spent cooling water) that is used for digester heating. Air is supplied to the BNR2 plant aeration process by electric motor driven blowers. BNR process effluent is filtered, disinfected with chlorine, and then dechlorinated prior to discharge to San Francisco Bay.

The solids wasted from the BNR processes are thickened in Dissolved Air Floatation (DAF) tanks. This thickened sludge is then fed to the Plant's mesophilic digesters where it blends with the sludge from the primary clarifiers. Digested solids are stored in sludge stabilization lagoons for up to three years and the dredged sludge from these lagoons is dried in solar drying beds. The dried solids are then hauled to a nearby landfill and used as landfill cover.

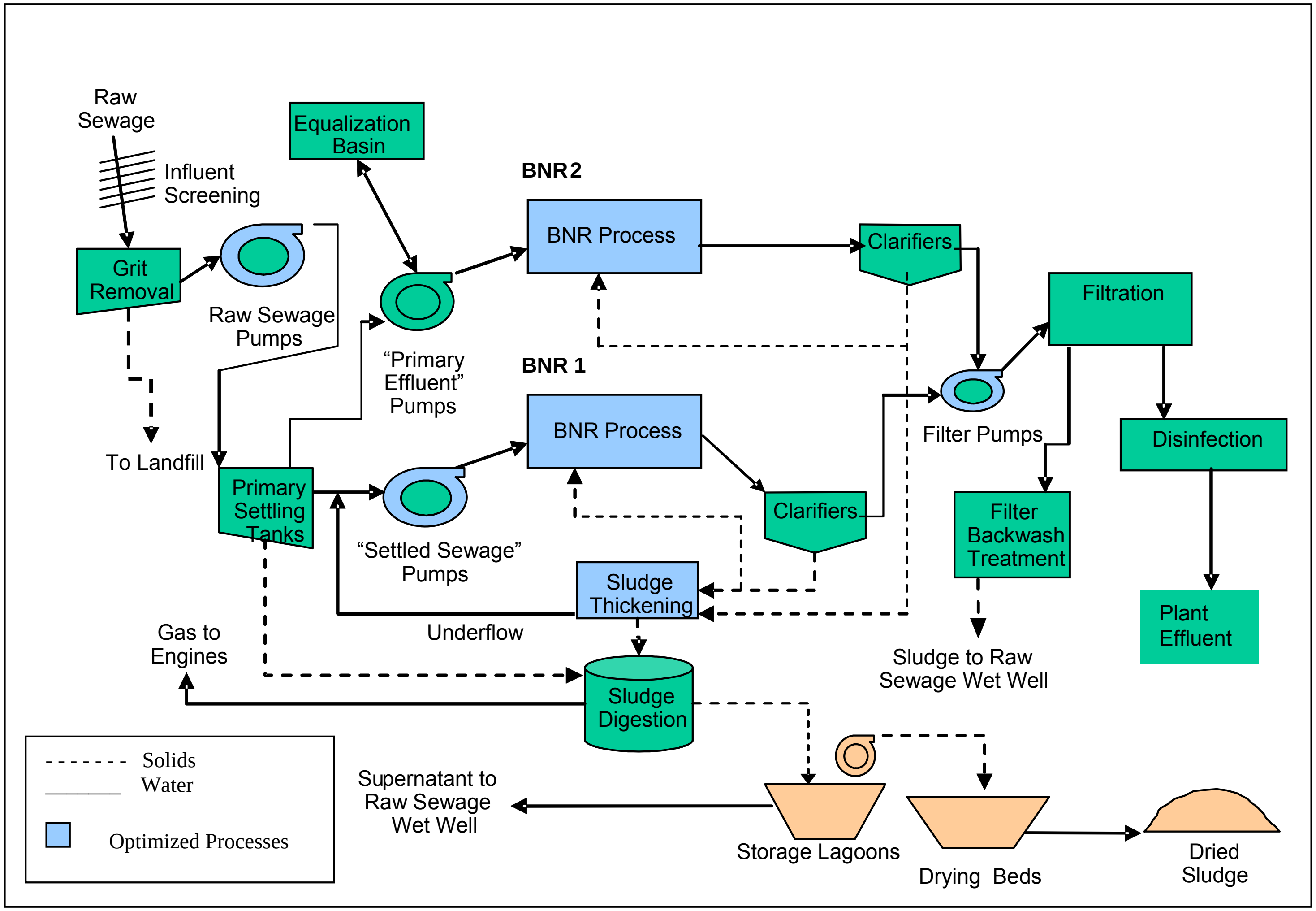

Figure 2: SJ/SC WPCP Treatment Process Flow Diagram

(graphic provided courtesy of SJ/SC WPCP)

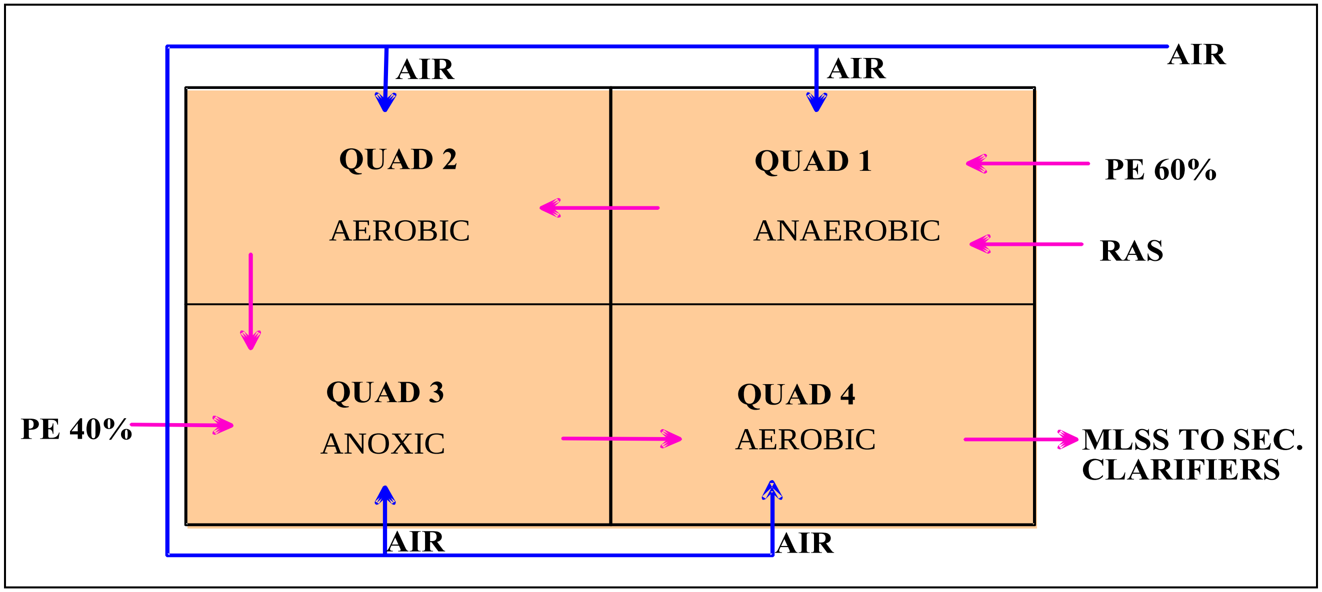

Figure 3: SJ/SC WPCP BNR Process Flow Diagram
(graphic provided courtesy of SJ/SC WPCP)

Description of ECM Project Drivers and Issues

During the past several years, the Plant has been quite active and successful in identifying and implementing energy saving projects without compromising effluent quality. The projects have produced significant sustained savings in operating costs. In addition to energy savings, financial incentives in the form of rebates from the local electric and natural gas utility, Pacific Gas & Electric Co. (PG&E; San Francisco), helped to incentivize these projects. In many cases, the utility rebates covered the entire cost of the projects resulting in a final implementation cost of zero.

This case study describes several energy conservation measures (ECM) projects completed in 2008 which were partially funded by the California Wastewater Process Optimization Program (CalPOP). The Program was administered by QuEST, Inc. (Berkeley,Ca). The ECM projects implemented at the SJ/SC Plant consisted of the following:

Pumping Systems Optimization

The first ECM project focused on reducing energy consumption by optimizing the operation of three of the Plant's major pump stations. The information on the optimized pump stations is provided in Table 2.

Table 2: Optimized Pump Stations

Pump Station	Average flow (mgd)	Total Number of Pumps[1]	VFD-Equipped Motors	Power Use (kWh/day)
Post Screening	113	7	3	282
Post Primary Settling	109	4	4	384
Post Clarification	108	5	5	570

Note 1: Not all pumps are operated simultaneously

The plant implemented an optimization algorithm developed by Ekster & Associates, Inc. (Fremont, Ca) to select the proper pump operating schedule and optimize energy consumption. This computer program utilizes field data such as pump station flows, pump discharge pressures, wet well levels, and the power usage associated with pumps. The pertinent data was collected using a specially designed pump testing routine. Thereafter, the software program selects the combination of pumps and speed (for the existing variable speed motors) at each flow rate. To assure that the global rather than local minimum power consumption is reached, the software program utilizes two optimization algorithms in tandem (genetic and gradient reduction algorithms) rather than a single algorithm. This methodology guarantees that the selected pumps and speed combination for each flow regime results in the consumption of less energy compared to any other possible combination.

Plant staff programmed the selected schedule and pump speed for each flow range into the Plant's Distributed Control System (DCS). In addition, discharge pressures and wet well levels were optimized by reassessing the minimum safety requirements.

During the implementation phase of this project, the plant compared field data to the pump manufacturers' data. This included a comparison of the manufacturers' pump performance curves with the experimental curves. The study revealed that some of the pumps had lost 5% - 7% of their efficiency, probably due to age and wear. These findings reinforced the idea that pump curves generated using field data — not manufacturer's pump curves — should be used to develop optimized operating sequences. In addition, this effort resulted in the identification and qualification of the pumping systems' information and data that will be used by the utility to plan for the refurbishing and replacement of underperforming pumping system components.

BNR Process Improvements Pulse Aeration of Anerobic/Anoxic Zones & Mixed Liquor Channels

A second ECM project implemented at the Plant involved switching the mode of air mixing in the anoxic/anaerobic compartments of BNR plants from continuous to pulse (On/Off). This aeration method was also applied to the Mixed Liquor Channels (MLC) of both BNR plants. Prior to switching to the pulse air mixing mode, solids were maintained in suspension in the anaerobic/anoxic compartments and MLCs by continuous air flow. By utilizing an Ekster and Associates' patent-pending method, continuous air mixing was replaced by pulsed air mixing.

The implementation of this ECM required significant modifications of the aeration system. These modifications included installation of new valves, actuators, pneumatic lines, electrical infrastructure, and special control system programming. These modifications were required to be completed within a six-month period due to deadlines associated with the CalPOP program. To meet this unusually stringent schedule requirement, the Plant staff performed the conceptual and detailed designs in-house and prepared all other pertinent documentations including the bid packages. Plant staff also specified control valves, flow meters, actuators, and auxiliary control elements, such as air piping for actuators, input–output units for the Plant's Distributed Control System (DCS), etc.

Establishing the timing sequence of the activation and deactivation (i.e., ON/OFF sequencing) of the pulsed air mixing control system is site-specific, depending on the settleability of the mixed liquor suspended solids and the geometry of the anaerobic/anoxic compartments. For the SJ/SC WPCP, an air flow rate and timing sequence were established by trial and error that maintained solids in suspension while keeping the dissolved oxygen concentration low enough (0.2 mg/L or less) so as not to significantly hinder the anaerobic/anoxic process. The adequacy of the mixing provided by the pulsed air system was verified by confirming equal concentrations of solids on the bottom and at the surface of the anaerobic/anoxic compartments (at the end of the air "ON" cycle). At the end of the "OFF" cycle, a bit of sludge settling occurs. At the end of the "ON" cycle, it is important to ensure that sludge resuspension has occurred.

During implementation of the pulse air mixing control, engineers discovered that providing simultaneous pulsed air for multiple tanks could lead to oscillation of the blower output. A special programming routine was subsequently developed to avoid this control system oscillation. The new routine sequences the tanks rather than simultaneously providing air to all the tanks to re-suspend solids.

Dissolved Air Floatation (DAF) Process Optimization

Optimization of the DAF process was achieved by reducing the energy used by the pressurization pumps. This was made possible by utilizing proprietary algorithms developed by Ekster and Associates that provided the means to optimize the DAF control systems.

Prior to optimization, each DAF tank was operating at a constant pressurized flow, which was significantly higher than required. The algorithm allowed automatic adjustment of the pressurized flow based on the number of DAF tanks in service and the incoming solids load to maintain the same Air to Solids ratio (A/S) under all operating and influent conditions. The new algorithm also provided a close approximation of equal solids loading throughout the day for each DAF unit. The minimum A/S was determined by trial and error. The criterion utilized to establish the minimum A/S was the equality of water and sludge concentrations before and after A/S reduction. The current A/S stands at 0.005 and is one of the lowest ever reported in the literature.

ECM Commissioning Date

The control system algorithms for the in-plant pumping systems, pulsed air mixing system, and DAF process were implemented and commissioned in 2008. Sub-metering of electrical power for the DAF process was also implemented as part of the ECM project. Electrical sub-metering for the in-plant pumping systems and BNR2 plant blowers were installed prior to the ECM project (with their original design) as was the gas metering (for the combined mixture of landfill gas, digester gas, and utility supplied natural gas) for the BNR1 plant internal combustion engine driven blowers.

Plant Influent and Effluent Quality

Tables 3a and 3b provide a comparison of the major water quality indicators associated with the SJ/SC WPCP influent and effluent in 2007 prior to the implementation of improvements and post ECM implementation performance.

Table 3a: Monthly Average

Parameter		2007 Daily Average Concentration, mg/L	Nov. 2009 – Feb. 2010 Daily Average Concentration, mg/L
BOD	Influent	332	363
	Effluent	3.1	3.7
	Monthly Permit Limit	10	10
TSS	Influent	291	293
	Effluent	1.5	1.5
	Monthly Permit Limit	10	10
NH_3	Influent	27.9	31
	Effluent	0.5	0.6
	Monthly Permit Limit	3	3

Table 3b: Daily Maximum

Parameter		2007 Daily Maximum Concentration, mg/L	Nov. 2009 – Feb. 2010 Daily Maximum Concentration, mg/L
BOD	Influent	438	516
	Effluent	5.0	6.0
	Permit Limit	20	20
TSS	Influent	534	546
	Effluent	3.5	2.1
	Permit Limit	20	20
NH_3	Influent	43.8	41.8
	Effluent	1.4	1.8
	Permit Limit	8	8

Table 3c provides comparison of DAF performance before and after optimization

Table 3c: DAF Performance Pre- and Post-ECM Implementation

Thickened Solids (%)		Underflow Total Suspended Solids (mg/L)	
Before Optimization	**After Optimization**	**Before Optimization**	**After Optimization**
3.8	3.8	92	87

Results

ECM Implementation Cost

Table 4 summarizes the cost associated with the implementation of the ECM projects.

Table 4: ECM Implementation Cost

Project	Capital Cost	Implementation Cost	Total Cost
Liquid Pumping Optimization	$4,545	$39,223 [1]	$43,768
Pulse Aeration	$62,822	$118,770	$181,592
DAF Process Optimization	$2,948	$41,261	$44,209
		Total Cost for All ECM	$269,569

[1] Implementation cost included data collection, data verification, installation of power meters and software costs.

Energy

Pump Station Optimization

Optimizing the pump stations led to energy reductions of between 17% and 23.5% (see Table 5).

Table 5: Energy Use Before and After Pump Station Optimization

Pump Station	Before Optimization (kW/million gal)	After Optimization (kW/million gal)	Energy Use Reduction (kW/MG)	% Reduction
Post Screening	59.58	46.25	–13.33	22%
Post Primary Settling	84.51	64.62	–19.89	23.5%
Post Clarification	126.51	104.88	–21.63	17.1%

BNR Process Improvements

Table 6 summarizes energy savings achieved by converting from continuous to pulsed aeration in the BNR process.

Table 6: Energy Savings Achieved by Switching to Pulsed Aeration

BNR[1]	Annual Energy Consumption		Energy Savings	
	Before Optimization	After Optimization	Net Annual Savings After Optimization	% Reduction
No. 1	3.1 X 10^{11} BTU	1.9 X 10^{11} BTU	1.2 X 10^{11} BTU	38%
No. 2[2]	6.2 X 10^{6} kWh	1.4 X 10^{6} kWh	4.8 X 10^{6} kWh	22.5%

Notes:
1. BNR = biological nutrient removal
2. Energy used only for mixed liquor channel aeration

DAF Process Optimization

Table 7 summarizes energy savings achieved through the DAF optimization ECM project.

Table 7: Dissolved Air Floatation (DAF) Process Optimization – Energy Use and Savings

Annual Energy Consumption		Energy Savings	
Before Optimization	After Optimization	Net Annual Savings After Optimization	% Reduction
2,496,600 kWh/yr	893,570 kWh/yr	1,603,030 kWh/yr	64%

Payback Analysis/Benefits

Table 8 summarizes the payback for the SJ/SC WPCP ECM projects.

Table 8: Payback Analysis For The Energy Saving Projects (verified by PG&E) – SJ/SC WPCP/Y2008

Project	Total Cost	Annual Savings (@$0.11/kWh)	Annual Savings ($1/Therm)	Payback Period (Months)
Liquid Pumping Optimization	$43,768	$244,858	N/A	2.1
BNR Process Improvements	$181,592	$176,339	$581,275	2.9
DAF Process Optimization	$44,209	$176,339	N/A	3.0

PG&E reimbursed the plant $269,569 for these three ECM projects.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

1. All ECMs were initially extensively tested on one unit before implementing the modification for the entire system. This provided the staff with the confidence that the ECMs will not have a negative effect on the performance of the treatment processes.

2. Measures are quickly reversible and adaptable to changing operational situations. One example is the suspension of pulsed aeration for a few brief period to accommodate operational corrective measures required to deal with foam observed from time to time on the surface of aeration basins.

3. Rebates from electrical utilities provided additional incentives for prioritizing the implementation of the ECMs.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to energy saving resulting from this project, it is expected that the service life of the pumps will increase as a result of operating the pumps closer to their best efficiency points (BEP).

Lessons Learned

Significant savings can be achieved with minimum capital investment by optimizing operating procedures and process control set points. However, changes in operating protocols and/or operating parameters require significant testing to ensure that these measures do not jeopardize plant reliability and water quality.

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Steve Colby, Control System Specialist, Environmental Services Department, City of San Jose, CA

Issayas Lemma, Sanitary Engineer, Environmental Services Department, City of San Jose, CA

Rong Liu, Sanitary Engineer, Environmental Services Department, City of San Jose, CA

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Issayas T. Lemma, Steve Colby, Tom Herrington *Pulse Aeration of Secondary Aeration Tanks Holds Energy Saving Potential without Compromising Effluent Quality* Proceedings of 82nd WEFTEC, Conference and Exposition, Orlando, 2009.

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EVALUATION OF ENERGY CONSERVATION MEASURES FOR WASTEWATER TREATMENT FACILITIES

CASE STUDY NO.9

Aeration System Improvements –DO Controlled Blowers and Fine Bubble Diffusers
Waco Metropolitan Area Regional Sewer System
Waco, Texas
Facility Size: 37.8 mgd design, 22.8 mgd average daily flow

Figure 1: Aerial View of the WMARSS WWTP
(*Photo provided courtesy of WMARSS*)

Facility/Process Description:

The Waco Metropolitan Area Regional Sewer System (WMARSS) treatment facility serves approximately 175,000 people from the cities of Bellmead, Hewitt, Lacy-Lakeview, Robinson, Waco and Woodway (Texas). In the early 1970's WMARSS was originally commissioned as a trickling filter plant and was upgraded to a 37.8 mgd activated sludge plant in 1983-1985. In 1995, the plant was upgraded to perform single stage nitrification. WMARSS facility influent data are presented in Table 1.

Table 1: Profile of WMARSS Influent Data

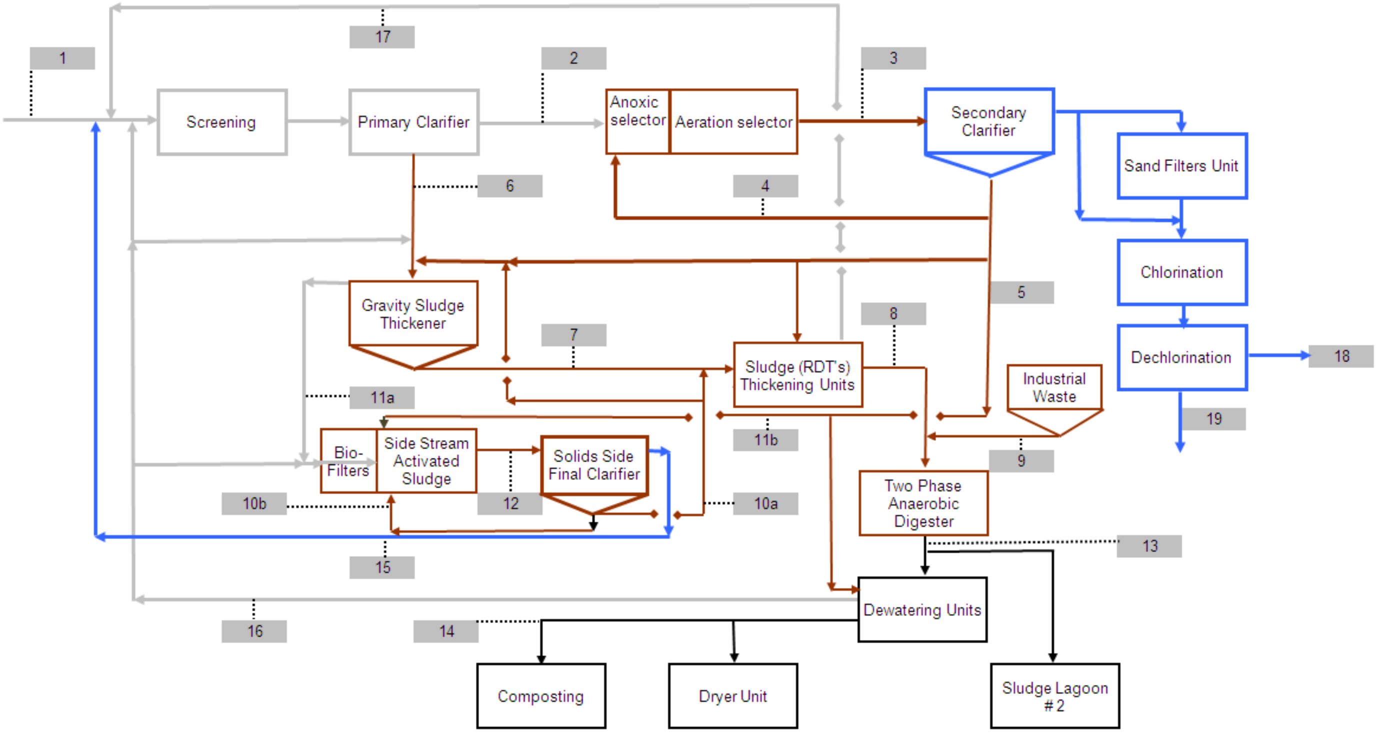
WMARSS Influent Quality 2009			
Parameter	**Average**	**Daily Maximum**	**Peak**
Flow (mgd)	22.8		83.2
BOD (mg/L)	251	608	
TSS (mg/L)	300	2671	
Ammonia-N (mg/L)	31.5	95.1	

Figure 2 presents the process flow diagram for the WMARSS WWTP, a single stage nitrifying activated sludge treatment plant.

Influent undergoes screening followed by primary clarification. Primary clarified effluent is distributed to five aeration basins, typically operated in a plug flow mode (in which primary settled wastewater and return activated sludge enter the head end of the aeration tanks and air is generally distributed uniformly throughout the length of the aeration tank). During high influent flow conditions, the aeration process is operated in a step feed mode (a modification of plug flow in which the primary clarifier effluent is introduced at several points in the aeration tank and the secondary return activated sludge (RAS) is introduced in the anoxic zone, resulting in a reduced MLSS loading entering the secondary clarifier). The first 50 feet (ft) of each aeration basin is maintained as an anoxic zone which receives RAS from the secondary clarifiers. Currently, RAS achieves oxygen savings in the aeration basins (as oxygen is stripped from the nitrate in the RAS stream in the anoxic zone). In the future, the anoxic zone and associated RAS will accommodate biological nutrient removal (phosphorus and nitrogen). Each aeration basin measures 50 ft wide by 251 ft long and has a sidewater depth of 18 ft (total basin volume = 8.45 million gallons). Seven Hoffman multi-stage centrifugal blowers (five 250 hp blowers at 6,000 standard cubic ft per minute (scfm) each and two 650 hp blowers at 12,500 scfm each) provide a total of 55,000 scfm through a fine bubble diffuser system.

Aeration is followed by secondary clarification in four clarifiers. Variable portions of the secondary clarifier effluent are pumped to sand filters. Unfiltered secondary clarifier effluent is blended with filtered effluent and the combined effluent stream undergoes chlorination and de-chlorination prior to reuse and/or discharge to the Brazos River.

Primary sludge undergoes two-stage thickening (gravity followed by rotary drum) prior to anaerobic digestion. Secondary waste activated sludge (WAS) is thickened in the Rotary Drum Thickener RDT) prior to digestion. The WAS is used as Mixed Liquor Suspended Solids (MLSS) seed for side stream treatment. Supernatant from the rotary drum thickener is combined with gravity thickener supernatant for sidestream treatment (existing trickling filters [and/or aeration currently under construction] followed by a final solids clarifier). Filtrate from sludge dewatering may also undergo sidestream treatment or be returned to the head of the plant. Sludge from the sidestream treatment final solids clarifier is thickened (by gravity and/or by rotary drum) prior to anaerobic digestion. A portion of the sidestream treatment final clarifier underflow is returned to the anoxic zone of the sidestream treatment process.



1	Plant Influent
2	Aeration Influent
3	Final Clarifier Influent
4	Return Activated Sludge Flow
5	Waste Activated Sludge Flow
6	Primary Sludge flow
7	Gravity Thickened Sludge Flow
8	RDT Thickend Sludge Flow
9	Industrial Waste Septage
10a	Solids Side Final Clarifier Under Flow
10b	Solids Side Return Sludge
11a	Gravity Thickener Supernatant
11b	WAS Seed to Side Stream Treatment
12	Solids Side Final Clarifier Influent Flow
13	Digested Sludge Flow
14	Dewatered Sludge to Disposal
15	Side Stream Final Effluent
16	Dewatering Filtrate Flow
17	RDT Supernatant
18	Plant Final Effluent To Reuse
19	Plant Final Effluent River

Figure 2: WMARSS Process Flow Diagram
(*graphic provided courtesy of WMARSS*)

Overflow from the sidestream treatment clarifier is returned to the head end of the plant. The plant has four mesophillic anaerobic digesters that can be operated in series, parallel, complete mix or as a combination of primary/secondary digesters. Industrial waste is received via tanker at the WMARSS facility in the form of blood, sludge and grease (animal source) from local food processing establishments (averaging 13,000 gallons per day). This industrial/commercial waste is treated with the primary and secondary sludge in the anaerobic digesters. Digested sludge is dewatered using a belt press or sent to surface disposal (sludge lagoons). Dewatered sludge is dried and pelletized (or composted, in the future).

Description of Energy Conservation Measures (ECMs):

The City of Waco, Texas Utility Services Department implemented improvements to the aeration system at their WMARSS treatment facility to address deficiencies in the plant's nitrification process. Single-stage nitrification was not possible using the existing diffuser system because insufficient oxygen was being supplied to the aeration process. The existing diffusers were being operated in excess of their design air flow rate, producing coarse bubbles instead of fine bubbles, and the number of diffusers was inadequate.

The aeration system improvements consisted of the following:

- Supplementing the existing Sanitaire fine bubble membrane and ceramic disc diffusers with additional diffusers. The number of diffusers in each basin was increased from 2,800 to 3,500.
- Installing Danfoss dissolved oxygen (DO) probes in each of the aeration basins' three aeration zones (mid-way in the first and second aeration zones and at the end of the third aeration zone).
- Implementing automatic blower and aeration system control through the plant's PLC system using aeration basin DO readings. The plant's control system software provided the following output based on aeration basin DO readings:
    - ON/OFF control of blowers.
    - Blower inlet valve throttling.
    - Aeration system drop leg throttling.

ECM Commissioning Date:

The aeration basins' diffuser system was supplemented with additional diffusers in February 2003. Additionally, DO probes were installed in the aeration basins and the aeration control system was programmed to utilize DO readings in the aeration basins to control the operation of the blower inlet and basin drop leg throttling valves.

Description of ECM Project Drivers and Issues:

Implementation of the aeration system improvements was initiated to address problems with completing the plant's nitrification cycle. Drivers for the project included requirements for increasing the plant's capacity, improving effluent quality and to effect energy savings.

Plant Influent and Effluent Quality

Tables 2a and 2b provide a comparison of the WMARSS facility performance prior to the implementation of aeration system improvements (Y2002) and current (post ECM implementation) performance.

Table 2a: Monthly Average

Parameter		Y2002 Monthly Average Concentration, mg/L	Y2009 Average Concentration, mg/L
BOD	Influent	322.58	251
	Effluent	2.81	2.31
	Permit Limit	10	10
TSS	Influent	419.56	300
	Effluent	3.06	1.2
	Permit Limit	15	15
NH_3	Influent	15.78	31.5
	Effluent	1.446	0.33
	Permit Limit	3	3

Table 2b: Daily Maximum

Parameter		Y2002 Daily Maximum Concentration, mg/L	Y 2009 Daily Maximum Concentration, mg/L
BOD	Influent	644	608
	Effluent	7.8	9.4
	Permit Limit	25	25
TSS	Influent	1600	2671
	Effluent	11.7	5.5
	Permit Limit	40	40
NH_3	Influent	26.7	95.5
	Effluent	13.8	4.96
	Permit Limit	10	10

Results

ECM Implementation Cost

Table 3 summarizes the implementation cost for the WMARSS aeration system ECM project:

Table 3: ECM Implementation Cost

Cost Category	Cost (in Y2002 $)
Capital Components	
• Additional diffusers	$239,200
• PLC automation	$ 24,906
• DO instrumentation	$ 18,420
• Air control valves	$66,692
Total Capital Cost	**$349,218**
Installation Costs[1]	
• Aeration Improvements	$18,390
• Aeration Improvements	$30,100
Total Installation Costs (Est.)	**$48,490**
Total Project Cost	**$ 397,708**

Note 1 – ECM installation was performed by plant personnel so no contractor installation costs were incurred.

Energy

Table 4 summarizes the WMARSS facility electrical energy consumption and costs prior to and following the implementation of the aeration system improvements. The last column presents the electrical cost savings per year at the facility.

Table 4: Electricity Use and Estimated Savings

Year	Total Annual Electricity Use (kWh)	Annual Energy Consumption Reduction (kWh)	Average Daily Flow (mgd)	Electricity Use per Average Daily Flow (kWh/mgd)	Average Electricity Rate ($/kWh)	Electricity Cost Savings ($)
A	B	C	D	E = B/C	F	$G = (B_{\text{evaluation year}} - B_{2002})*F$
Prior to ECM Implementation						
2002	14,076,530		26.4	532,431	$ 0.0430	
Following ECM Implementation						
2003	11,624,105	2,452,425 (17%)	24.3	477,996	$ 0.0537	$ 131,695.22
2004	11,006,112	3,070,418 (22%)	28.8	382,366	$ 0.0650	$ 199,577.17
2005	9,201,249	4,875,281 (35%)	24.6	373,701	$ 0.0689	$ 335,906.86
2006	7,969,924	6,106,606 (43%)	21.7	367,563	$ 0.0897	$ 547,762.56
2007	7,851,481	6,225,049 (44%)	27.6	284,400	$ 0.1150	$ 715,880.64
2008	8,949,861	5,126,669 (36%)	22.9	390,765	$ 0.1187	$ 608,535.61

Notes:
Column B – Data provided by WMARSS. Electricity use includes plant and sludge dryer combined. Sub metering is not conducted at WMARSS.
Column D - Data provided by WMARSS.
Column F – Rate data by WMARSS. If a rate change occurred during the year, a weighted average rate for the year was calculated based on electricity consumption.

Payback Analysis/Benefits

For this analysis, simple payback is determined by dividing the total project cost ($397,708 from Table 3) by the electricity cost savings for each year following the project implementation. The electrical energy costs savings provided by the aeration system improvements resulted in a project payback in the first quarter (March) of the third year following commissioning (2005), a 2.4 year payback.

Conclusions

Factors Leading to Successful ECM Implementation/Operation

Facility staff was directly involved in identifying the treatment plant's operational problems and the process equipment and operational modifications to address the plant's operational problems. The staff was also involved in the installation of the aeration system improvements.

The aeration system modifications resulted in improved plant performance, reduction in energy consumption, and reduction in direct operator involvement required to maintain blower and aeration system performance. Plant personnel reported that this ownership stake in the project was a critical factor in the successful implementation and the continued successful operation of treatment system.

Impact on Other Operating Costs Resulting from ECM Implementation

In addition to energy savings resulting from this project, the following benefits were also realized.

Labor:	The standard operating procedure before automating the aeration process was to manually check the DO concentration in each of the basins' zones on an hourly basis and adjust the drop leg valves and the blower demand in response to the DO readings. The utility estimates that automation of the aeration saves approximately three hours of operator labor per day (1095 hours per year) at a savings of $21,900 per year.
Chemicals:	With the ammonia cycle stabilized (less nitrite / chlorine demand in the effluent), chlorine demand has been reduced and stabilized. Prior to the implementation of the aeration system modifications, a daily maximum of approximately 6,000 pounds of chlorine was dosed per day (under normal flow conditions of approximately 25 mgd whenever the plant had high effluent nitrate level). Currently (under average daily flow conditions of 22.5 mgd and complete nitrification), the average chlorine dosage ranges between 800 and 1200 pounds per day. During the implementation of the aeration system ECM, the effluent chlorination monitoring and control system was also upgraded. It is not

possible to segregate the chlorine chemical consumption/cost reductions attributed exclusively to the ECM project since both the upgraded chlorination monitoring and control system and the ECM were commissioned during the same period in 2003/2004.

Maintenance: With the savings in energy cost and operator labor provided by automating the aeration process, WMARSS is able to maintain adequate staffing according to industry standards.

Lessons Learned

The project and the operational issues that provided the drivers for the aeration system improvements have impressed upon the WMARSS management and operations staff to maintain a "mindset of continually improving and re-evaluating operating practices because over time small, unnoticed system limitations add up to system failure." (Source: Personal communications from Mike Jupe – Plant Superintendent WMARSS January 18, 2010).

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Appendix B

Web Resources

B.1 Introduction

As interest in energy conservation for wastewater treatment plants has grown, so has the number of governmental, private, and non-profit organizations involved in evaluating and implementing energy conservation measures (ECMs). Table B-1 provides a description of and the web link to national and regional energy efficiency resources for wastewater treatment plants. Information is organized according to the name or the organization and its type (e.g., book, government resource, state, non-profit). The web links are current as of February 9, 2010.

Table B-1. Summary of Literature Sources

Type	Name/ Organization	Web link[1]	Description
EPA Resources	Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities (USEPA 2008)	http://www.epa.gov/waterinfrastructure/pdfs/guidebook_si_energymanagement.pdf	Provides water and wastewater utility managers with a step-by-step method based on a Plan-Do-Check-Act management system approach to improve energy efficiency at their utilities.
	Wastewater Management Fact Sheet: Energy Conservation (2006)	http://www.epa.gov/owm/mtb/energycon_fasht_final.pdf	Provides comprehensive approach to energy conservation along with case studies.
	Sustainable Infrastructure Web site	http://water.epa.gov/infrastructure/sustain/basicinformation.cfm	Provides basic information on energy required for water/wastewater and multiple links to EPA resources including benchmarking, management, full cost pricing, and on-site energy generation.
	ENERGY STAR for Wastewater Plants and Drinking Water Systems	http://www.energystar.gov/index.cfm?c=water.wastewater_drinking_water	Provides information on how a WWTP can become an ENERGY STAR partner, sign up for the ENERGY STAR Challenge, and benchmark its energy use with Portfolio Manager.
	Region 1 Energy and Water/ Wastewater Infrastructure Web site	http://www.epa.gov/region1/eco/energy/ew-infrastructure.html	Similar to the EPA Sustainable Infrastructure Web site with regional examples.
	Region 9 Sustainable Water Infrastructure Web site	http://www.epa.gov/region09/waterinfrastructure/	Provides detailed discussion and links for energy-efficient equipment and operations. Provides case studies for co-generation and renewable power.
Manuals and Guidance Documents (by organizations other than EPA)	Energy Conservation in Water and Wastewater Facilities, Manual of Practice No. 32 (WEF 2009)	Available for purchase at http://www.e-wef.org/timssnet/products/tnt_products.cfm?primary_id=W090037&Action=LONG&subsystem=ORD	Standard manual for the water and wastewater industry. In depth information including theory and practical information.
	Energy Audit Manual for Water/ Wastewater Facilities (EPRI 1994)	http://www.cee1.org/ind/mot-sys/ww/epri-audit.pdf	Includes step-by-step process for conducting an audit, process ECM ideas, and tips for creating an energy conservation program.

Type	Name/ Organization	Web link[1]	Description
	NEMA Standards Publication Condensed MG-1: Information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motors Standards	Available for purchase at http://www.techstreet.com/cgi-bin/detail?doc_no=NEMA%7CMG_1_2009&product_id=1680007	Provides information on performance, safety, test, construction and manufacture of ac and dc motors and generators. Helps readers in proper selection and application of motors and generators
DOE Resources	Alternative Wastewater Treatment: On-Site Biotreatment Wetlands at the Fernald Preserve Visitors Center	http://www.lm.doe.gov/Fernald/Documents.aspx	Case study of decentralized wastewater treatment (constructed wetlands).
	Process Optimization Saves Energy at Metropolitan Syracuse Wastewater Treatment Plant	http://www1.eere.energy.gov/industry/bestpractices/pdfs/onondaga_county.pdf	Case study of energy efficiency upgrades to WWTP in Syracuse, NY. Process improvements included retrofitting motors, changing impellers, and optimizing operations.
	City of Milford Pump Optimization Case Study	http://www1.eere.energy.gov/industry/bestpractices/pdfs/milford.pdf	Case study in which a WWTP changed out oversized pumps at lift station and reduced energy use by 15%.
	Town of Turnbull, Connecticut Case Study	http://www1.eere.energy.gov/industry/bestpractices/case_study_sewage_pump.html	Case study in which WWTP replaced an oversized pump at a lift station and changed operating strategy to reduce electricity consumption by almost 44%
	Best Practices Management Case Study in Fairfield, OH	http://www1.eere.energy.gov/industry/bestpractices/pdfs/fairf.pdf	Case study of WWTP that used systems approach to implement improvements identified by energy audit. Installed power monitoring device, installed fine bubble diffusers, and used *MotorMaster+* software.
	Best Practices: Motors, Pumps, and Fans	http://www1.eere.energy.gov/industry/bestpractices/motors.html	Web site with best practices resources specific to motor systems, including reports, tools, and training information
	Adjustable Speed Pumping Applications: Industrial Technology Program, Pumping system Tip Sheet # 11	http://www1.eere.energy.gov/industry/bestpractices/pdfs/38947.pdf	Tip sheet that provides overview information on adjustable speed pumping applications and recommendations for predicting performance at various operating points along a system curve

Type	Name/ Organization	Web link[1]	Description
	Improving Motor and Drive System Performance: A Sourcebook for Industry, second editiion	http://www1.eere.energy.gov/industry/bestpractices/pdfs/motor.pdf	Reference document published in 2008 that outlines opportunities for motor and drive system improvements. Includes guidance on how to find more information and assistance.
	Pumping System Assessment Tool (PSAT) User Manual.	http://www1.eere.energy.gov/industry/bestpractices/pdfs/psat_user_manual.pdf	Provides basic information about the the Pumping System Assessment Tool including data entry, calculated results, and various control button features.
	Improving Pump System Performance: A Sourcebook for Industry, second edition	https://www1.eere.energy.gov/industry/bestpractices/pdfs/pump.pdf	Reference document published in 2009 that outlines opportunities for pump system improvements. Includes guidance on how to find more information and assistance.
Nonprofits	American Council for an Energy Efficient Economy (ACEEE)	http://www.aceee.org/publications	Organization dedicated to advancing energy efficiency as a means of promoting economic prosperity, energy security, and environmental protection. Created a roadmap for water and energy efficiency in 2004. Web site provides links to CEE and NYSERDA.
	Consortium for Energy Efficiency (CEE), National Municipal Water and Wastewater Facility Initiative	http://www.cee1.org/ind/mot-sys/ww/ww.php3	Resource link has extensive links to reports, case studies, and other resources. Includes newly published energy efficiency RFP guidance.
	Flex Your Power — California's statewide energy efficiency marketing and outreach campaign	http://www.fypower.org/bpg/module.html?b=institutional&m=Water_Use	Best Practice Guide for Local Governments includes guidelines for wastewater utilities. Includes step-by-step plan and links to other resources.
	Electric Power Research Institute (EPRI)	http://my.epri.com/portal/server.pt?	Non-profit group representing electric utility industry. Conducts research and publish reports related to energy efficiency for wastewater utilities.

Type	Name/ Organization	Web link[1]	Description
	Hydraulic Institute Pump Systems Matter Initiative	www.PumpSystemsMatter.org	Goal is to provide tools and trainings for optimizing pump operation and improving energy efficiency. Provides pump system assessment guide and downloadable tool.
State Programs and Activities	Massachusetts — Energy Pilot for Wastewater and Water Treatment Plants	http://www.mass.gov/dep/water/wastewater/eerewwu.htm	Brings together state and federal agencies and electric and gas utilities to conduct facility energy audits, assess each plant for its renewable and clean energy possibilities, and offer support for the implementation of these energy-related projects.
	Wisconsin — Focus on Energy	http://www.focusonenergy.com/Business/Industrial-Business/Wastewater.aspx	Energy Advisors help water and wastewater plants conduct audits, develop an energy management plant, and identify ECMs.
	New York State Energy Research and Development Authority (NYSERDA) Focus on Water and Wastewater	http://www.nyserda.org/Programs/Environment/muniwaterwwt.asp	NYSERDA provides assistance to identify and install ECMs, as well as training and case studies. They have recently finalized a Water and Wastewater Energy Management Best Practices Handbook, available for download from this web site.
		http://www.nypa.gov/press/2009/090318.htm	Related press release from the New York Power Authority.
	California Energy Commission	http://www.energy.ca.gov/process/water/wastewater_treatment.html	Provides resources for reducing energy use at wastewater and water treatment plants. Extensive list and links to articles, fact sheets, reports, and technical papers on energy efficiency.
Water Research Foundation (WRF)[2]	Water and Wastewater Energy Efficiency: A Research Roadmap (2004)	http://www.energy.ca.gov/2004publications/CEC-500-2004-901/CEC-500-2004-901.PDF	The roadmap identifies and prioritizes research projects that will advance emerging technologies and best practices to improve energy efficiency and reliability for water and wastewater utilities.

Type	Name/ Organization	Web link[1]	Description
	Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Systems (2008)	Summary available at: http://www.hdrinc.com/Assets/documents/Publications/Waterscapes/summer2006/EvaluatingEnergy.pdf Full report available for purchase or free for subscribers at: http://www.waterresearchfoundation.org/research/TopicsAndProjects/projectSnapshot.aspx?pn=3056	Presents energy data for advanced water and wastewater treatment systems.
Water Environment Research Foundation (WERF)[3]	Knowledge Area: Operations Optimization	http://www.werf.org/AM/Template.cfm?Section=Operations_Optimization	Site with WERF products and Web links to support optimizing processes to improve performance, reduce energy costs and carbon footprint.
	An Assessment Tool for Managing Cost-Effective Energy Recovery from Anaerobically Digested Wastewater Solids (LCAMER, 2006)	http://www.werf.org/AM/CustomSource/Downloads/uGetExecutiveSummary.cfm?FILE=ES-01-CTS-18UR.pdf&ContentFileID=11402	Assessment tool that incorporates site-specific information such as energy costs, regulatory conditions, and wastewater plant capacity to help determine the most cost-effective alternative for recovering digester gas energy.
	An Economic Framework for Evaluating the Benefits and Costs of Biosolids Management Options (2007)	http://www.werf.org/AM/CustomSource/Downloads/uGetExecutiveSummary.cfm?File=ES-04-CTS-2.pdf&ContentFileID=9208	Framework that assists utilities with benefit-cost analysis; helps agencies select and justify biosolids management; and provides guidance, resources, and case study illustrations.
	Producing Class A Biosolids with Low-Cost, Low-Technology Treatment Processes (2004)	http://www.werf.org/AM/CustomSource/Downloads/uGetExecutiveSummary.cfm?FILE=ES-95-REM-2.pdf&ContentFileID=9017	Describes low-tech treatment processes for producing Class A biosolids under a variety of conditions. Also provides guidance to further reduce pathogens.
	State of Science Report: Energy and Resource Recovery from Sludge (2009).	http://www.werf.org/AM/CustomSource/Downloads/uGetExecutiveSummary.cfm?FILE=ES-OWSO3R07.pdf&ContentFileID=7538	Discusses international practice for energy and resource recovery from sludge. Explains influence of market and regulatory drivers on sludge end-products.
	Improving Wastewater Treatment Plant Operations Efficiency and Effectiveness (1999)	http://www.werf.org/AM/Template.cfm?Section=Research_Profile&Template=/CustomSource/Research/PublicationProfile.cfm&id=97-CTS-1	Includes more than 40 case studies of approaches and methods for improving plant performance and productivity, and reducing service costs.

Type	Name/ Organization	Web link[1]	Description
	Sensing and Control Systems: A Review of Municipal and Industrial Experiences (2002)	http://www.werf.org/AM/Template.cfm?Section=Research_Profile&Template=/CustomSource/Research/PublicationProfile.cfm&id=99-WWF-4	Provides guidelines on automation of WWTPs.
	Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches (2010)	http://www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/PublicationProfile.cfm&id=OWSO4R07e	Includes recommendations on incremental improvements through optimization of existing operations and more substantial improvements from adoption of novel technologies.
	Sustainable Treatment: Best Practices from the Strass in Zillertal Wastewater Treatment Plant	http://www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/PublicationProfile.cfm&id=OWSO4R07b	Report highlights one of the best performing wastewater treatment plants in Europe - a facility that produces more energy than it requires for operations.
	WERF Best Practices for Sustainable Wastewater Treatment: Initial Case Study Incorporating European Experience and Evaluation Tool Concept (2009)	http://www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/PublicationProfile.cfm&id=OWSO4R07a	Evaluates the European experience with energy reduction and best practices at wastewater treatment plants. Highlights Strass im Zillertal WWTP, a municipal facility that provides for both nitrogen and phosphorus removal while producing more electricity on an annual basis than it consumes.
Conference Proceedings	Sustainability 2008: Green Practices for the Water Environment (put on by WEF)	See Note 4	Sessions on energy management and renewables.
	WEFTEC 2002 – 2008	See Note 4	Multiple sessions on energy management and optimization.
	WEF Residuals and Biosolids Management Conference 2002 – 2008	See Note 4	Sessions on sustainability.
	WEF Utility Management Conference 2008	See Note 4	Session on advanced tools.
	WEF Membrane Technology Conference	See Note 4	Sessions on energy and optimization of membrane systems.
	WEF and American Water Works Association (AWWA) Joint Management Conference Proceedings	See Note 4	Session on innovative energy ideas.

Type	Name/ Organization	Web link[1]	Description
Journals	WEF's Water Environment and Technology (WE&T)	http://www.wef.org/Publications/page_wet.aspx	WEF membership required to access full articles.
	WEF's Water Environment Research (WER)	http://www.wef.org/Publications/page_detail.aspx?id=796	Requires special subscription from WEF.
	ASCE Journal of Environmental Engineering	http://pubs.asce.org/journals/environmental/	ASCE membership required to access full articles.
	Water and Wastewater International	http://www.waterworld.com/index/world-regions.html	e-newsletter on international water and wastewater issues. Requires subscription.

Notes:
1. Web links are current as of February 8, 2010
2. Formerly the American Water Works Association Research Foundation (AwwaRF)
3. WERF reports available for purchase or through subscription.
4. WEF-sponsored conference proceedings can be accessed through this Web site: http://www.ingentaconnect.com/content/wef/wefproc