Evaluation of Common Practices of Adopting Energy Efficiency Technologies in Municipal Wastewater Treatment Facilities

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ABSTRACT

This paper presents findings of applying energy efficient technologies in municipal wastewater treatment plants (MWWTP), resulting from detailed surveys of designers, vendors, and MWWTPs about technology options and application of energy efficient technologies in MWWTP. Based upon literature review and communications with subject matter experts, we first designed the survey questionnaire for designers, vendors, and municipal wastewater treatment plants, respectively; and conducted the surveys between 2015 and 2016. The reviews and surveys are used to identify the technologies that are currently used in MWWTPs in Pacific Gas and Electric Company (PG&E) service territory in Northern and Central California, and compare market penetration of energy efficient technologies and processes in MWWTPs. The paper presents technology options and identifies Common Practice (CP) with higher market penetration in MWWTPs than other technologies available for the same wastewater treatment process. The common practices based on this 2016 survey study are compared to findings from a similar study in 2006. Discussions of major energy efficiency opportunities in MWWTPs are also included.

Introduction

According to a report by the U.S. Environmental Protection Agency (EPA2013), the electricity use for municipal wastewater treatment plants (MWWTP) in the U.S. has grown substantially in the past 20 years, e.g., from approximately 17.4 billion kWh/yr. in 1996 to 30.2 billion kWh/yr. in 2013 with an increase of 74%, equivalent to an average of about 3.1% per year. The 2013 electricity usage of MWWTPs accounted for approximately 0.8% of total electricity consumption in the U.S. The continuing growth of electricity usage of municipal wastewater treatment is mainly due to capacity expansion triggered by population growth and more stringent environmental regulations that require more complex treatments and advanced processes. Such treatments and processes require advanced technologies that are more energy intensive, e.g., sequencing batch reactors, membrane bioreactors, UV disinfection, and various filtration methods.

Figure 1 shows a general process flow diagram of MWWTPs. Secondary treatment commonly uses activated sludge aeration systems with diffused aeration or mechanical aerators. According to the EPA (2013) report, typically aeration is the highest energy end-user in MWWTPs, which uses about half of the electricity consumed at the plant, followed by biosolids handling, pumping and disinfection energy usages. Refer to the *Major Processes and Systems in MWWTPs* section of this paper for a brief discussion of various processes.

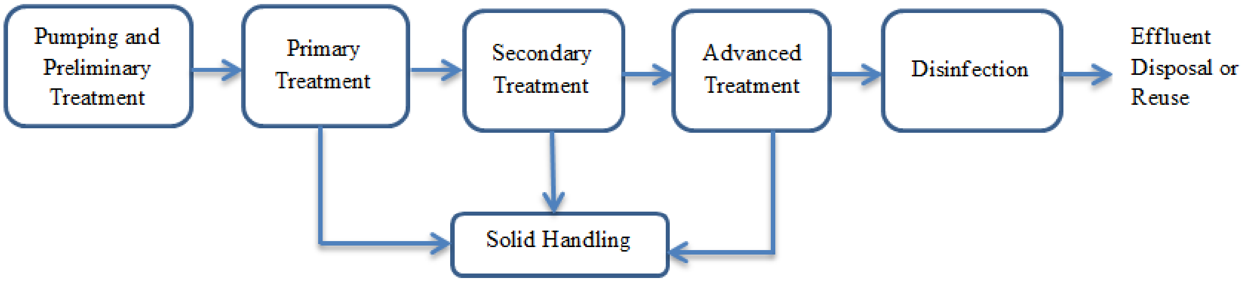

Figure 1. General process flow diagram in municipal wastewater treatment plants

Every four years, the U.S. EPA conducts the Clean Watersheds Needs Survey (CWNS) that collects information on publicly owned treatment works. According to CWNS (2012), there were a total of about 14,581 MWWTPs in the U.S., of which 532 (or 3.6% of the total plants) have a design flow of more than 10 million gallon per day (MGD), accounting for 62% of the total design flow of MWWTPs. It is projected that in 2032 the number of plants would grow to 859 MWWTPs (or 5.7% of the total plants), with their aggregate flow accounting for 71.3% of the total treatment capacity in the U.S.

CWNS (2012) also reported that 4,971 MWWTPs (or 34.1% of the total plants) had treatment levels greater than Secondary and accounted for 57% of the total design flow and served 53.8% of the associated population. It is projected that by 2032 there would be 6,041 MWWTPs (or 39.9% of the total plants) that will have treatment levels greater than Secondary and they would account for 61.4% of the total design flow, and serve 59.4% of the associated population. This data shows that more wastewater will be treated to higher levels, which implies that electricity consumption of municipal wastewater treatment will continue to grow.

Based on an energy efficiency potential study (EPRI 2009), it is estimated that the overall realistic achievable potential energy savings for water and wastewater industry by 2030 is approximately 5% if compared to the energy usage in 2010. However, there are numerous barriers that could prevent energy efficiency projects being implemented. According to a 2015 survey study funded by the Water Environment Research Foundation (WERF) (Willis et al. 2016), significant barriers that stop energy efficiency projects, in descending order, include funding, feasibility study, project approval, identifying opportunities, design initiation, etc.

This paper identifies the technologies that are currently used in MWWTPs and their market penetration, and discusses common practices and energy efficiency opportunities. The results of this paper may be used in providing solutions to overcome the barriers of feasibility study and identification of opportunities for energy efficient technologies in MWWTPs.

This paper defines the term Common Practice (CP) to represent the application of technology that has higher market penetration in MWWTPs than other technologies available for the same wastewater treatment process. Survey instruments were developed in 2016 and distributed to three expert groups including municipal wastewater treatment plants, design firms and vendors/distributors. The survey was designed with the following objectives:

- To identify the technology options that are currently used in MWWTPs in PG&E service territory in Northern and Central California
- To understand market penetration and adoption of MWWT technologies
- To evaluate MWWT technologies for common practices (CP) compared to the 2006 Survey Study

Major Processes and Systems in MWWTPs

The wastewater treatment systems and processes may vary from facility to facility depending on the treatment capacity, regional regulations, plant age and other factors. A brief discussion of various wastewater treatment systems and processes are summarized in the following sections.

Primary Treatment

Primary treatment involves removal of floating and suspended particulates in the wastewater stream. Major primary treatment processes can be categorized as conventional primary treatment or chemically enhanced primary treatment.

Secondary Treatment

The role of secondary treatment is to reduce the biological oxygen demand of the remaining material after primary treatment and further remove biodegradable organic matter and suspended solids. This process typically removes approximately 70% to 85% of the biological oxygen demand (BOD) from the wastewater. Secondary treatment typically involves a biological process which may include: trickling filters, anaerobic biological treatment, oxidation ditches, aerated lagoons or ponds, constructed wetlands, sequencing batch reactors, etc.

Tertiary (Advanced) Treatment

Tertiary or advanced treatment is any additional treatment beyond secondary treatment to further remove impurities from the wastewater. Filtration is commonly used as a tertiary process and involves removing organic matter and suspended solids beyond what secondary treatment can treat to meet more stringent discharge and reuse requirements. The three different categories of filtration systems use are:

- Depth filtration (sand filtration, porous medium filtration)
- Surface filtration (earth filtration, cloth or screen filtration)
- Membrane filtration (microfiltration, ultrafiltration, nano-filtration, reverse osmosis)

Disinfection

Disinfection is used to destroy disease-causing organisms. Disinfection is typically accomplished using: chlorine, ozone, UV radiation and bromine. Chlorine is the most commonly used method of disinfecting wastewater in the world.

Sludge Management

Sludge is generated from essentially all wastewater treatment processes, from the primary treatment process through tertiary treatment. The U.S. EPA has established regulations for the reuse and disposal of solids generated from municipal wastewater treatment plants (Pakenas 1995).

Thickening is the first step to reduce the volume of sludge removed from the wastewater. *Sludge thickening* can increase the dry solids concentration anywhere from 1% to 8%. Thickening is generally accomplished by physical means including co-settling, gravity settling, digestion, flotation, centrifugation, gravity belt, and rotary drum.

Sludge dewatering is typically one of the final steps for solid management at wastewater treatment plants. Sludge dewatering can increase the dry solids concentration to 32%. Since wastewater facilities usually pay for sludge disposal by weight, the more water that is removed from the sludge, the lighter the weight of the solids means less cost to dispose of the sludge. Devices commonly used for dewatering (ranked by energy intensity from highest to lowest) include: vacuum filtration, centrifuge, recessed chamber press, belt filter presses, screw press, rotary press and drying beds.

Sludge drying process reduces mass and volume of the product, making its storage and transporting easier and also enables incineration or co-incineration of sludge. Sludge drying can increase the total possible dry solids concentration to 62% compared to 6% obtained by thickening and 32% by dewatering. Thermal drying can result in even higher dry solids concentration, greater than 90% solids. The main types of sludge dryers used in municipal wastewater treatment plants are: sludge drying beds, solar drying, mixed drying (combination of belt dryer with hot air), direct heat drying and indirect heat drying.

Common Practice Determination Factors

Although we have specifically defined Common Practice as we use it in this paper, it is important to note that the term common practice may have a different meaning to others, as its determination can be affected by a combination of factors, such as regional factors that include locally available resources, local governments and regulatory agencies, non-energy benefits, ease or difficulty of adoption, initial cost, capital availability, market saturation, regulations and codes, and so on.

The Industry Standard Practice (ISP) Study on MWWTPs (Chow et al. 2016) follows California's regulation guidance per the California Public Utilities Commission (CPUC) to evaluate the ISPs mainly based on current market trend of technology selection instead of in-situ market penetration, which is the focus of this paper.

Given various technology options for each wastewater treatment process, the technology with higher market penetration is considered as the Common Practice. The technologies that use less energy compared to more traditional technologies are considered as the energy efficient technologies (EETs). Refer to the *Energy Efficiency Opportunities in MWWTPs* section of this paper for discussion of EETs at different wastewater treatment processes.

2016 Survey on Municipal Wastewater Treatment Plants

A survey was conducted in 2016 to evaluate the technology options and common practices in MWWTPs. Survey distributions and participant response rates were as follows:

- 140 MWWTPs in PG&E service territory through email or phone calls with a response rate of about 30% (42 respondents).
- 30 MWWTP design engineering firms serving MWWTPs with a response rate of about 33% (10 respondents).
- 30 vendors/distributors of MWWT technologies with a response rate of about 30% (9 respondents).

Summary of Survey Results

The survey that was distributed to 140 municipal wastewater treatment plants in PG&E territory asked "Which of the following energy efficient technologies (EET) are being used at your plant". Figure 2 shows the distribution of answers from plant operators. Each bar indicates the market penetration calculated by the number of plant operators confirming the adoption of the technology in their plants divided by the number of plant operators responding to the question. For example, of the 42 plant operators who responded to the survey, only 32 plant operators answered the question shown in Figure 2. Among the 32 operators, 28 plant operators confirmed that they have installed the VSD on pumps in their plants. As a result, the bar shows that 88% of 32 plants use VSDs on pumps. Other EETs with over 50% plant adoption rate also include automatic DO control, fine pore diffusers and SCADA control. On the other hand, none of the 32 plant operators reported installation of microwave UV disinfection or magnetic ballasted sedimentation in their plants.

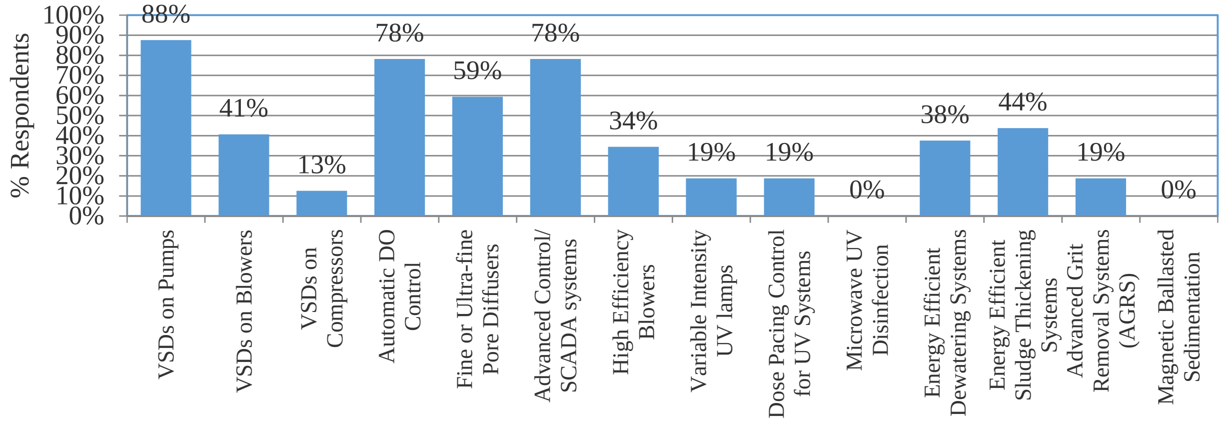

Figure 2. Energy efficiency technologies used in surveyed MWWTPs (based on a sample size of 42 plants with 32 plants responding to this particular question)

The survey that was distributed to 30 MWWTP designers asked "How often do you recommend the following energy efficient technologies (EET) to your MWWTP customers?" while they were given the opportunities to select among "Less than or ~25% of the time," "~50% of the time," "Greater than 50% of the time," and "Not applicable." Figure 3 shows the distribution of answers from design firms based on their experience in most recent three to five years. Each bar indicates the market trend calculated by the number of designers confirming the likelihood of technology recommendation divided by the number of designers responding to the option. For example, of the 10 designers who responded to the survey, 9 designers confirmed that they recommended VSD on pumps for greater than 50% of the time, and 1 designer recommended the VSD on pumps for about 50% of the time to their MWTP customers. As a result, Figure 3 shows that except three EETs most EETs were recommended by 50% or more of the designers for greater than 50% of the time.

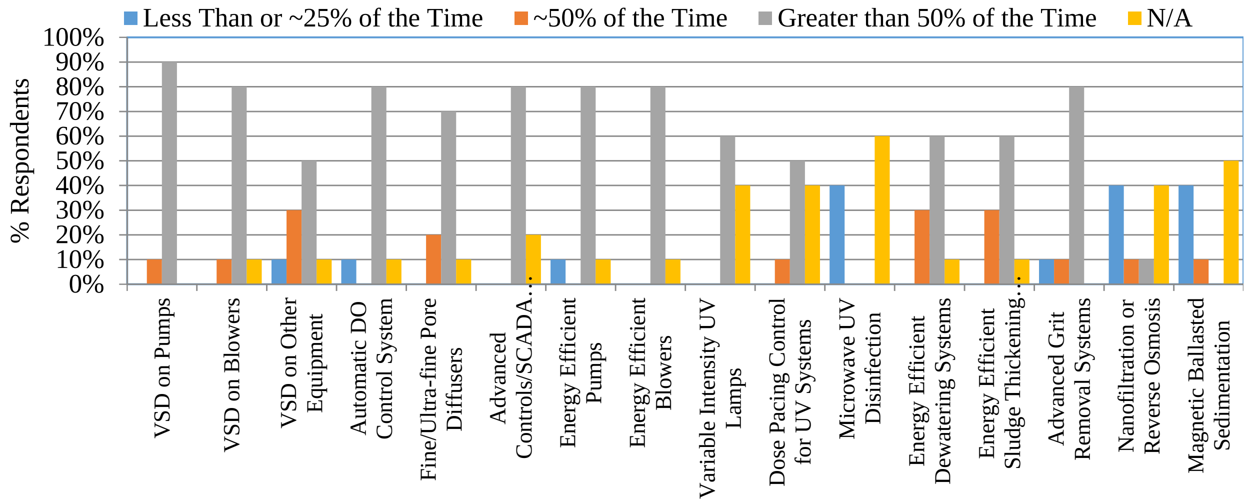

Figure 3. Energy efficiency technologies recommended by design engineers (total of 10 responses)
Note: Some options were not selected by any respondents and hence no bar is shown in the figure.

The survey that was distributed to 30 MWWTP vendors/distributors asked "Which of the following energy efficient technologies for MWWTPs are commonly purchased by your customers?" while they were given the opportunities to select among "Less than or ~25% of the time," "~50% of the time," "Greater than 50% of the time," and "Not applicable." Figure 4 shows the distribution of answers from vendors based on their experience in most recent three to five years. Each bar indicates the market trend calculated by the number of vendors confirming the likelihood of technology purchased by their MWWTP customers divided by the number of vendors responding to the option. For example, of the 9 vendors who responded to the survey, 5 vendors (or 56%) confirmed that their customers purchased VSD on pumps for greater than 50% of the time, and 2 vendors (22%) confirmed that their customers purchased VSD on pumps for less than 25% of the time. As a result, Figure 4 shows that most EETs were purchased by less than 50% of the MWWTP customers for greater than 50% of the time.

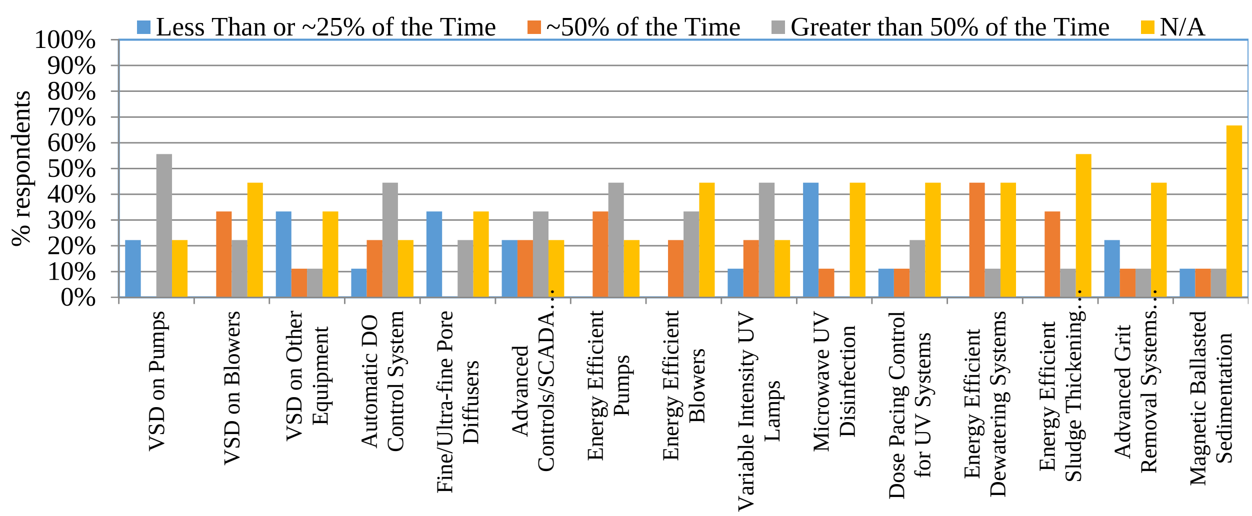

Figure 4. Energy efficiency technologies commonly purchased by customers (based on 9 responses)
Note: Some options were not selected by any respondents and hence no bar is shown in the figure.

Summary of 2016 Common Practices and Comparison with 2006 Study

Under each wastewater treatment process, the survey listed various technology options and asked the plants to select the technology/equipment that is used at their facility. Based on the survey results, technologies with higher market penetration in MWWTPs are identified and considered as the common practices (CP) in this paper. For example, the survey asked MWWTPs what diffuser type was used at their plants given the technology options of coarse bubble, fine bubble and ultra-fine bubble diffusers. Based on the survey responses, fine bubble diffuser has higher market penetration than other options in MWWTPs and therefore it is considered as the CP. Table 1 summarizes the technology options, common practices and energy efficiency opportunities for each process in MWWTPs. All survey questionnaires and responses are documented in the 2016 ISP Study (Chow et al. 2016).

Table 1. Summary of technology options, common practices, and energy efficiency opportunities in MWWTPs (2016)

Technology/process	Components	Technology options and common practices (in bold)	Energy efficiency opportunities
Primary treatment	Screening/flocculation	**Conventional** Chemically enhanced	Chemically enhanced primary treatment system
Secondary treatment (Mechanical aeration)	Aerators	Brush Low speed surface **High speed vertical turbine** Induced surface Submerged turbine	Low-speed mechanical aerators Brush aerators Fine bubble diffused aeration systems Mechanical aerators with multiple impellers Ultra-fine bubble diffused aeration system
	Aerator control	No control Manual control Timer control **Automatic control based on dissolved oxygen (DO)**	Automatic control based on dissolved oxygen (DO)
Secondary treatment (Diffused aeration)	Diffusers	Coarse bubble **Fine bubble** Ultra-fine bubble	Ultra-fine bubble diffusers Panel diffusers (membrane-type diffusers built onto rectangular panels) Aerostrip (long strip diffuser with large aspect ratio)
	Blowers	Positive displacement (Constant/variable speed) Multi-stage centrifugal Single-stage centrifugal (Constant/variable speed) **High speed turbo**	High-speed gearless blowers (i.e. Turbo blowers, Turblex blowers) Centrifugal blowers with VSD Single-stage centrifugal blowers with energy efficient load modulation (i.e. variable speed drives, inlet guide vanes, variable diffuser vanes)
	Aeration control	No control Manual control Timer control **Automatic control based on Dissolved oxygen (DO)**	Most open valve (MOV) control Integrated air flow control Respirometry Critical oxygen point control Determination Off-gas analysis (monitor and control a process continuously) Bioprocess intelligent optimization system (BIOS) (based on the dynamically changing biological activity)
Tertiary treatment (filtration)	Filtration	**Sand filter** Membrane bioreactor	Cloth media filter Compressible media filter

		Low-pressure membrane High-pressure membrane Dissolved air floatation Cloth media Compressible media	
Disinfection (ultraviolet)	Lamps	**Medium-pressure, high-intensity** Low-pressure, high-intensity Low-pressure, low-intensity	Low-pressure, Low-intensity UV lamps UV LEDs – an emerging technology
	Control	No control Manual control **Control based on flow** Control based on dosage	Control UV system based on dose pacing Control UV lamps with turbidity Sensors – optimizes the number or intensity of operating UV lamps based on total suspended solids, levels and flow. This reduces energy consumption while ensuring adequate exposure to UV light
Sludge management	Thickening	Gravity thickener **Gravity belt thickener** **Dissolved air floatation** Centrifugal Rotary drum	Gravity belt thickener Rotary drum thickener Gravity thickener
	Dewatering	**Centrifuge** Belt filter press Screw press Rotary press Vacuum filtration Drying beds	Screw press Rotary press
Pumping system	Pumps	Efficiency varies depending on pump type, flow and head requirements	Higher efficiency pumps
	Control	No control On/off control Throttle/bypass control **Variable speed control**	Variable speed control
Plant control system	Controls	Manual control **Supervisory control and data Acquisition (SCADA) system**	Advanced SCADA
Anaerobic digester	Mixing	**Mechanical mixing** Gas mixing	Mechanical mixing

In 2006 BASE Energy conducted the first survey and literature review to evaluate the energy efficiency issues in MWWTP in PG&E service territory to determine the common practices for analysis of energy efficiency opportunities in MWWTPs. The 2006 survey was distributed to about 480 PG&E's MWWTP customers with a response rate of about 20% (99 respondents). Ten years later in 2016 we developed an updated survey and performed literature reviews to advance understanding of updated processes and technology options in MWWTPs, and to summarize information on common practices. A comparison of 2006 common practices with 2016 common practices for various municipal wastewater treatment technologies is shown in Table 2.

Table 2. Comparison of 2006 versus 2016 common practices for various MWWT technologies

Technology	2006 common practice*	2016 common practice
Primary treatment	N/A	Conventional primary clarifier
Aeration system	Constant Speed Motor	

(Mechanical aerators)	N/A	High speed vertical turbine
Aeration system (diffused aeration)	Coarse-bubble diffuser	Fine-bubble diffuser
	Inlet/discharge vane or no control multi-stage centrifugal	High speed turbo blower
	Blowers with average efficiency from fan system assessment tool	Average blower efficiency from 3 different manufacturers
Dissolved Oxygen Control	Manual control	Automatic dissolved oxygen with traditional proportional integral derivative (PID) control
Ultraviolet Radiation Disinfection	Medium-pressure, high intensity lamps	Medium-pressure, high intensity lamps
	On/off control	Control based on flow
Sludge Thickening	Centrifuge thickening system	Gravity belt thickener and dissolved air floatation
Sludge Dewatering	Centrifuge	Centrifuge
Pumps	Hydraulic institute (HI) achievable efficiency	Average pump efficiency from at least 3 manufacturers
	Water or hydraulic-oil driven or pneumatic system	
	Control – throttle/bypass or no control	Variable speed drive control on pumps
Air Compressor	Air compressor modulating w/ unloading	CA Title 24
Motors	1992 EPAct standard efficiency motors	NEMA premium efficiency motors
Plant Control System	Manual control	Supervisory control and data acquisition (SCADA) control system
Anaerobic Treatment System	N/A	Mechanical mixing
Sludge Treatment	Aerobic treatment system	Anaerobic treatment system

* *Source*: BASE Energy, Inc. 2006.

Energy Efficiency Opportunities in MWWTPs

The following sections present major energy efficiency opportunities identified from this study.

Primary Treatment

Primary treatment involves the basic processes to remove suspended solids and biological oxygen demand (BOD) from the wastewater stream before it enters the energy-intensive secondary treatment. The more solids and BOD that can be removed in the primary treatment stage, the less energy is required in the secondary treatment stage. Some technologies include:

- Conventional primary treatment – screening, settling and clarification
- Chemically-enhanced primary treatment – chemical enhancement process that employs coagulation and flocculation by adding chemicals *(energy efficient)*
- Primary effluent filtration – placing the filtration system as an intermediary step between the primary clarifier and secondary treatment process *(energy efficient)*

Pumping Systems

Variable speed drives (VSDs) reduce the electrical energy consumed by a motor by matching the motor's speed to the load, allowing the motor to continually adjust relative to the power needed. In wastewater treatment facilities, typical equipment to which VSDs are applicable includes pumps and blowers.

Mechanical Aerators

Mechanical aeration systems introduce air from the atmosphere into the wastewater by agitating the wastewater with propellers, blades or brushes.

The two typical groups of mechanical aerators are surface aerators and submerged aerators. Table 3 shows the various types of mechanical aerators typically used and their respective oxygen transfer rates (Environmental Dynamics, Inc. 2003).

Table 3. Types of mechanical aerators

Type of mechanical aerator	Oxygen transfer rate (lbs O_2/hp-hr)
Brush aerators	2.5 to 3.5
Slow speed surface aerators	3.0 to 3.5
Vertical turbine (high speed surface) aerators	2.5 to 3.25
Induced surface aerators	1.0 to 1.5
Submerged turbine (turbine mixer & compressor)	1.5 to 2.5

Blowers

Blowers are typically used in secondary and tertiary treatment processes for providing aeration to the wastewater or activated sludge. The main types of blowers and their nominal efficiencies are shown in Table 4 below.

Table 4. Typical blowers used in MWWT plants

Blower type	Nominal blower efficiency (%)	Nominal blower turndown (% of rated flow)
Positive displacement	45-65	50
Multi-stage centrifugal (inlet throttled)	50-70	60
Multi-stage centrifugal (variable speed)	60-70	50
Single-stage centrifugal (integrally geared)	70-80	45
Single-stage centrifugal, gearless (e.g. high-speed turbo)	70-80	50

Source: EPA 2010.

Diffusers

Diffused aeration is a subsurface system that introduces air into the wastewater by diffusers. The types of diffusers commonly used in municipal wastewater treatment systems are shown in Table 5 below.

Table 5. Oxygen transfer efficiency for various diffusers ranked by efficiency

Diffuser type	Size of bubbles (mm)	Oxygen transfer rate (lb/hp-hr)	Range of standard oxygen transfer efficiency* (SOTE)
Coarse bubble	3 – 50mm	1.5 – 3.5	6-12%
Fine bubble	2 – 3 mm	3.5 – 6.5	18-32%
Ultra-fine bubble	0.2 – 1 mm	10 – 27	37.5-45%

*At 15 feet submergence in clean water based on information from various diffuser manufacturers .

The oxygen transfer efficiencies vary based on the material and type of diffusers installed. Table 6 summarizes the clean water oxygen transfer efficiency for various diffuser types and material.

Table 6. Oxygen transfer efficiency variation for diffuser material and types

Diffuser material and type		Range of standard oxygen transfer efficiency (SOTE)
Ceramic	Discs	26-33%
	Domes	25-40%
	Plates	27-39%
Plastic	Discs	24-35%
	Tubes	26-36%
Perforated membrane	Discs	16-38%
	Tubes	22-29%

Source: EPA 1989.

Automatic Dissolved Oxygen Control

Installing sensors to detect the amount of dissolved oxygen in the wastewater and adjusting the aeration needs accordingly result in better control of the aeration system and significant energy savings due to not having to over-aerate the water.

Ultraviolet Lamps

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. UV lamp efficiency has increased over time. The three common types of UV lamps are:

- Medium-pressure, high-intensity (MPHI) UV lamps *(least energy efficient)*
- Low-pressure, high-intensity (LPHI) UV lamps
- Low-pressure, low-intensity (LPLI) UV lamps *(most energy efficient)*

Sludge Thickening Systems

Thickening sludge increases the solids content of the sludge, which is beneficial to subsequent processes such as digestion, dewatering and drying. The more common sludge thickening methods are shown in Table 7 below.

Table 7. Common sludge thickening methods

Method	Type of solids	Solids concentration	Solids capture efficiency[£]	Energy requirements
Gravity thickener	Treated/untreated primary and waste activated	Varies greatly	98%	Minimal
Gravity belt thickener	Waste activated sludge	3% to 6+%	90-98%	Low
Dissolved air floatation thickener	Untreated primary and waste activated	2% to 3%	85-98%	High
Centrifugal thickener	Waste activated sludge	4% to 6%	90-95%	High
Rotary drum thickening	Waste activated sludge	4% to 6+%	90-98%	Medium

Source: Metcalf & Eddy, Inc. 2003.
[£] Amount of solids captured in the thickened sludge

Sludge Dewatering Systems

Sludge dewatering is done to reduce the moisture content of sludge and biosolids. The dewatering equipment selected depends on the type of sludge, characteristics of the dewatered product, operating costs, regulations and available space, as summarized in Table 8 for more common methods. Sludge dewatering can be done using mechanical equipment or by natural evaporation and percolation.

Table 8. Comparison of common mechanical dewatering alternatives

Selection factor	Belt filter press	Centrifuge	Screw press	Rotary press
Performance				
% Discharge solids	20%	25%	20%	15-28%
Solids capture efficiency	85-95%	85-90%	90-95%%	>98%
Operator attention requirement	High	Low	Low	Low
Energy requirement	Medium	High	Low	Low
Maintenance	Medium	High	High	Unsure
Wash water requirements	High	Low	Low	Medium
Physical				
Physical footprint	Large	Small	Medium	Small
Other Factors				
Odor potential	High	Low	Low	Low
Noise level	Low	Low	Low	Low
Capital Costs				
Equipment costs	Low	High	Medium	High

Source: Brown and Caldwell 2009.

Conclusions

Electricity costs at wastewater treatment plants account for 25-40% (EPA 2013) of the operating budget and will continue to grow due to population growth and more stringent environmental regulations which require higher treatment level. Therefore, it is essential to solve the challenges and overcome the barriers opposing implementation of efficiency projects.

Overall results of the survey findings are:

- In general there are various technology options available for each MWWT process and the market is active in developing higher energy efficiency technologies as summarized in Table 1. Based on feedbacks from vendors and designers, in the MWWT industry, technologies typically don't change within three-year periods. Also, according to an EPA publication (Tetra Tech, Inc. 2013), technologies are not considered "established" until they have become widely available and have been implemented for more than five years. Therefore, it is expected that more emerging technologies will become more commonly adopted in the future.
- Some of the energy efficiency technologies (EET) evaluated in the 2006 Survey Study have been adopted by over 50% of the plants in the 2016 Survey Study as shown in Table 2. These EETs include: VSD on pumps, automatic DO control, fine pore diffused aeration system, high speed turbo blower and SCADA control

systems. The EET adoption data implies that despite various barriers to energy efficiency, the industry is not technologically stagnant but they move towards energy efficiency at a slow pace.

- Even though some of the EETs have become the CPs in the 2016 Survey Study, there are still significant opportunities for adoption of the CP technologies in MWWTPs that use technologies below the CPs efficiency as shown in Figure 2.
- The respondent rates of some EET selection were higher from design engineers compared to the selection rates from plants and vendors as shown in figures 2 to 4. This result implies that even though some EETs are recommended by design engineers for new projects such EETs are not yet selected or widely implemented in MWWTPs. Therefore, there is market potential for more EET adoption in MWWTPs.

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