Achieving a Reduced Energy Bill: From Planning to Implementation

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Table 1. Summary of Existing Liquid Treatment Facility Design Criteria

Equipment System	Description	Units	Value
Screens	No. of units	no.	2
	Design capacity per unit	mgd	20
Grit removal	No. of units	no.	2
	Capacity per unit	mgd	15
Primary clarifiers	No. of units	no.	2
	Design capacity of each tank	mgd	4.2 average; 10.9 peak
	Dimension of each tank	dia x SWD	80 ft diameter x 12 ft
Aeration	No. of aeration basins	no.	3
	Design capacity per basin	mgd	9.45
	Dimension of each aeration basin	ft x ft x ft	195 x 65 x 12
	No. of mech. aerators per basin	no.	3
	Aerator size		(1) @ 125 HP (2) @ 100/56 HP
Secondary clarifier	No. of units	no.	4
	Design capacity of each tank	mgd	3.5 average; 8.6 peak
	Dimension of each tank	dia x SWD	90 ft diameter x 14 ft
Return activated sludge (RAS) pumping	No. of units	no.	4
	Design flowrate	gpm	3,200
	Total discharge head (TDH)	psi	63
	Power	hp	75

Figure 1. Plantation Regional Wastewater Treatment Plant

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The City of Plantation (city) owns and operates the Regional Wastewater Treatment Plant (RWWTP). The permitted plant capacity is 18.9 mil gal per day (mgd) based on a three-month average daily flow basis. The RWWTP utilizes an activated sludge treatment process for liquid treatment and an anaerobic sludge digestion system for handling the sludge produced from the liquid treatment process. The liquid treatment facilities include screening, grit removal, primary clarification, an activated sludge system with mechanical aerators, and secondary clarification. The solids treatment facilities include centrifuges/gravity belt thickeners, anaerobic digesters, and sludge dewatering by belt presses.

The plant effluent from the secondary clarifiers is discharged into two onsite 24-in. deep wells for injection to the Boulder Zone, between 3,000 and 3,500 ft below surface. The plant reuses about 1 mgd of the treated wastewater onsite for landscape irrigation and treatment process water. A summary of relevant existing liquid treatment process facility design criteria is presented in Table 1 and an aerial view of the RWWTP is shown in Figure 1.

A summary of discharge limits for the underground injection well system is presented in Table 2.

Hazen and Sawyer was retained by the city to perform an energy savings analysis for proposed energy conservation measures (ECMs) at the RWWTP and for the design of a new fine bubble diffuser aeration system to replace the existing mechanical surface aerators, which provide the required air to each aeration basin. Because the aeration treatment process consumes the majority of energy at this facility (as with most

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Table 2. Discharge Limits for Underground Injection Well System

Parameter	Limit	Basis
Effluent flow, (mgd)	24	Peak-hour flow
Carbonaceous BOD, five-day, 20°C, (mg/L)	20	Annual average
	30	Monthly average
	45	Weekly average
	60	Single sample max.
Total suspended solids, (mg/L)	20	Annual average
	30	Monthly average
	45	Weekly average
	60	Single sample max.
pH	6.0- 8.5	Minimum - maximum

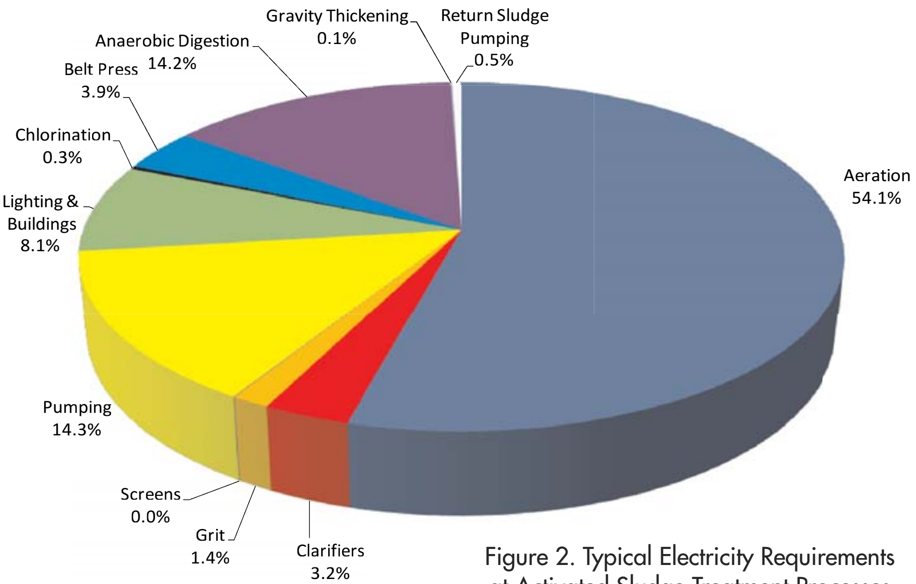

Figure 2. Typical Electricity Requirements at Activated Sludge Treatment Processes in the United States *(SAIC, 2006)*

Figure 3. Surface Mechanical Aerator at the Regional Wastewater Treatment Plant

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WWTPs), improving the efficiency of aeration can result in the largest cost and energy savings. It's been well established that diffused air systems, specifically fine bubble diffused air systems, are more efficient at oxygen transfer than the mechanical aeration systems. In addition to implementing fine bubble diffusers, another way that the RWWTP can save energy is by optimizing the amount of air that's supplied to the aeration basins from the blowers by implementing an automatic dissolved oxygen (DO) control system.

Aeration Systems in Activated Sludge

Approximately 70 percent of WWTPs in the United States exceeding 2.5 mgd utilize activated sludge secondary treatment, where 45 to 75 percent of electricity use is consumed in the aeration process (Rosso and Stenstrom, 2006). Because the aeration treatment process consumes the majority of energy in WWTPs utilizing secondary treatment, improving the efficiency of aeration can result in the largest cost and energy savings to utilities. Figure 2 demonstrates the typical energy usage at wastewater treatment facilities in the U.S. utilizing the activated sludge treatment process.

Existing Mechanical Aeration Process Versus Proposed More-Efficient Fine Bubble Diffused Aeration

The two most common methods of providing oxygen to wastewater in the aeration basin are mechanical aeration or diffused aeration systems. Mechanical aeration is provided by large impellers that are submerged in the wastewater and rotated using high-capacity electric motors, which consume a large amount of electricity. The RWWTP utilized six 100-horsepower (hp) and three 125-hp mechanical aerators in its aeration basins, for a total nameplate horsepower of 975 hp. The mechanical aerator impellers agitate the wastewater so that it's splashed into the air at the water surface, which increases the rate of transfer of oxygen from the atmosphere into the aqueous phase. A view of one of the old mechanical aerators at the RWWTP is provided as Figure 3.

Fine bubble diffused air systems are more efficient at oxygen transfer than mechanical aeration (Shammas et al., 2007). The small bubble size produced by the fine bubble diffusers has a high surface-area-to-volume ratio, which allows much higher oxygen transfer efficiency compared to mechanical aeration. Thus, the implementation of

Figure 4. Fine Bubble Diffuser
(photo: ITT Water and Wastewater – Sanitaire)

Figure 5. New Multistage Centrifugal Blowers at the Regional Wastewater Treatment Plant

fine bubble diffused aeration at the RWWTP will lead to cost and energy savings. A view of a fine bubble diffuser is provided as Figure 4.

Automatic Dissolved Oxygen Control

In addition to implementing fine bubble diffusers, another way that the RWWTP can save energy is by optimizing the amount of air that is supplied to the aeration basins from the blowers by continuously varying the amount of the air supplied based on the amount of oxygen required by the treatment process. An automatic DO control system utilizes DO sensors that are permanently submerged in the wastewater of the aeration basins and continuously take readings and "feedback" signals to a controller. The controller then automatically adjusts airflow to maintain a predetermined DO set point (typically 1 to 3 mg/L) by continuously adjusting the blowers and/or motor-operated air distribution control valves to each basin. The automatic DO control feedback strategy greatly reduces electricity costs when compared to manual DO control by preventing overaeration.

Diffused Aeration System

A summary of the proposed fine bubble diffused aeration system for the RWWTP includes:

- A multistage centrifugal blower arrangement of two 150-hp and two 300-hp multistage centrifugal blowers. This small-large blower arrangement allows for the automated blower system to provide adequate turndown and optimal efficiency throughout the entire range of current and future operation. Figure 5 shows the new blowers at the RWWTP.
- Flexible membrane disc diffusers were recommended for implementation at the RWWTP. It was proposed that the diffuser layout consist of four grid zones totaling 3,000 diffusers in each basin, for a total of 9,000 diffusers. Some of the unique features of the system include:
  - (a) The activated sludge process will also be used for odor control by directing foul air from the headworks to the fine bubble diffusers. This implementation resulted in significant capital savings for the city.
  - (b) The first zone was provided with an on-off modulating valve that would allow operation in anaerobic mode. Operation in this selector mode is anticipated to improve sludge settleability and potentially further reduce energy consumption.

Figure 6 shows a photo of the diffused aeration system at the RWWTP.

Evaluation of Energy Conservation Measures

A model was developed to estimate the energy savings and resulting cost savings that could be realized by implementing ECMs at the RWWTP. The model used historical plant monitoring data to project the energy savings achieved by implementing the improvements detailed previously. The energy savings were estimated at approximately 50 percent, for an annual savings of $200,000. A sensitivity analysis was also conducted and demonstrated that the energy savings do not deviate greatly from the base case when considering the effects of changes in key variables, with a variation in predicted energy savings of approximately 45 to 55 percent. The proposed ECMs will also result in a decrease in greenhouse gas emissions.

The estimated energy efficiency and resulting savings are shown in Table 3, and Figure 7 provides a graphical description of the implemented ECM. The predicted annual cost savings is based on the

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Figure 6. New Fine Bubble Diffused Aeration System at the Regional Wastewater Treatment Plant

Table 3. Regional Wastewater Treatment Plant: Estimated Energy and Cost Savings

Technology	Existing Mechanical Aeration	Proposed ECMs - 3 Basins Operating
Average air flowrate - 2012 to 2032 (SCFM)	-	9,270
Average operating power (hp)	780	370
Treatment efficiency (kWh/lb $CBOD_5$)	1.9	0.8
Treatment efficiency (kWh/mgd)	1,050	420
Annual energy cost savings ($)	**-**	**$200,000**
Average energy reduction (kW)	**-**	**300**
Efficiency gain (%)	**-**	**53%**

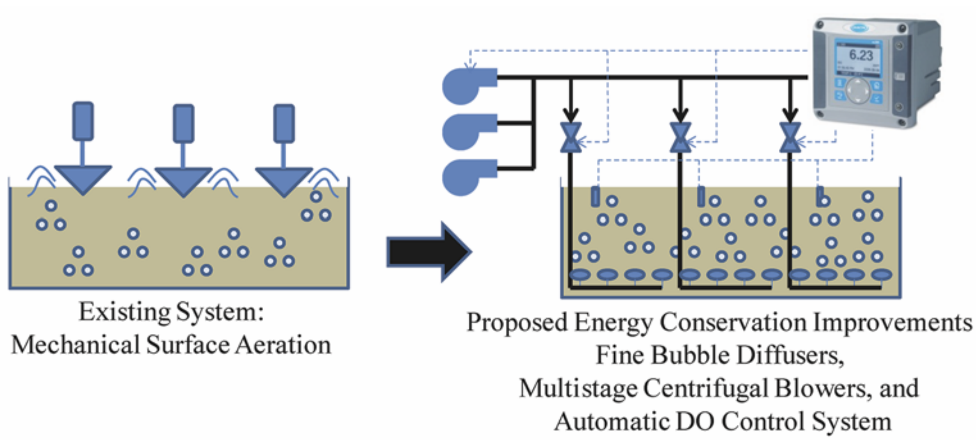

Figure 7. Regional Wastewater Treatment Plant Proposed Energy Conservation Measures

Table 4. Regional Wastewater Treatment Plant Plantation: Energy Efficiency Sensitivity Analysis

Case	Proposed ECMs - 3 Basins Operating	Estimated Annual Savings
Base	53%	$200K
+5% Blower efficiency	56%	$210K
-5% Blower efficiency	50%	$190K
3.0 mg/L DO	44%	$166K
1.0 mg/L DO	55%	$207K
0.45 Alpha factor	49%	$185K
0.55 Alpha factor	58%	$218K
Manufacturer's minimum SOTE[1]	48%	$180K
Range of deviation for all cases	44% to 58%	$166K to $218K

[1]The manufacturer provides two curves for the Standard Oxygen Transfer Efficiency (SOTE), average and minimum. The base calculations use the average curve; the minimum curve is assumed for the sensitiviy analysis

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RWWTP average cost per kilowatt hour (kWh) of $0.074 for 2011. The energy savings analysis performed prior to design and construction of the project was useful for the city to justify the project to the city council and other key decision makers.

Sensitivity Analysis

Key variables were isolated and manipulated in the model to determine their effects on the efficiency gain calculations, which are demonstrated in Table 4. The results generally do not deviate greatly from the base case, which indicates that the energy savings analysis for the RWWTP was generally resilient to certain variations in key variable values.

Greenhouse Gas Emissions

Table 5 presents the amount of total annual electricity saved by implementing the proposed ECMs at the RWWTP. The table also shows various greenhouse gas reduction measures that municipalities may employ and shows the equivalent units for each method that result in an equal amount of annual greenhouse gas emissions reduction.

Activated Sludge Diffusion for Foul Air Treatment

As mentioned, the activated sludge process will also be used for odor control by directing foul air from the headworks to the fine bubble diffusers; this process is referred herein as activated sludge diffusion (ASD). This involves collecting odorous air, directing it to the suction side of the aeration blowers, and diffusing it into activated sludge basins. The blowers then push the foul air through the fine bubble diffuser system and into the mixed liquor in the activated sludge treatment units. The odors are removed by a combination of mechanisms, including absorption, adsorption, condensation, and biological oxidation in the basins. Typical odor removal efficiencies for ASD are reported in the 80 to 99 percent range for moderate- to high-strength odors. This process is limited by the efficiency of the absorption of the gases from the vapor phase into the liquid phase, which is limited by pH.

The advantages of an ASD system include low capital and operating costs (if blowers and diffusers already exist), no chemical handling or storage, no spent media disposal, and the ability to accommodate wide fluctuations in hydrogen sulfide and other reduced sulfur compound loadings. Disadvantages include the potential corrosion of unprotected steel blower inlet filters and piping, and the buildup of a "tar-like" substance on internal components of the blowers. These disadvantages can be minimized through the use of inlet components constructed from corrosion-resistant materials, such as fiberglass reinforced plastic (FRP) or stainless steel. The tar-like substance can be removed by routine steam cleaning, by cleaning with a grease-cutting solvent, or by using protective coatings in the blowers and by installing grease filters upstream of the blowers.

By implementing ASD for the headworks foul air instead of a two-state wet scrubber system, the city accrued savings of approximately $800,000 in capital cost and $60,000 in annual operating cost.

Fine Bubble System Operation

Construction of the project started in January 2017. Aeration Basin (AB) No. 3 improvements were completed in October 2017, AB No. 2 in May 2018, and AB No. 1 in February 2019. The city started observing and accruing the energy savings since AB No. 3 was commissioned. In fact, the city received a call from the Florida Power & Light Company (FPL) asking the reason for the drastic reduction in energy consumption.

Figure 8 shows the historical energy bill for the RWWTP. The historical average energy consumption prior to October 2017 was 27,600 kWh/day. For the period between May 2018 to February 2019 (when the system has been running solely on fine bubble diffusion), the average energy consumption dropped to an average of 21,400 kWh/day. The 6,200 kWh drop in energy consumption is equivalent to 260 kW (350 hp) and represents an annual energy cost saving of approximately $170,000. These savings are just 15 percent short of the estimated $200,000 annual savings, but it's within the range shown in the sensitivity analysis. At the moment, the city is running with relatively high DO, typically higher than 2 mg/L, and these savings are expected to increase after final optimization and completion of the project.

Summary

After implementation of the fine bubble conversion project, the RWWTP is achieving an energy reduction of approximately 6,200 kWh/day, which is equivalent to 260 kW and represents an annual savings of approximately $170,000. These savings are in line with estimates from an energy savings analysis performed during the design phase, and are anticipated to increase over time with full utilization of DO control techniques. In addition, the activated sludge process is being used for odor control by directing foul air from the headworks to the fine bubble diffusers. The implementation of the activated sludge diffusion of the headworks' foul air results in additional $60,000 in annual savings for the city.

References

- Rosso, Diego and Stenstrom, Michael K. 2006. "Economic Implications of Fine-Pore Diffuser Aging." Water Environment Research, Volume 78, No. 8 (August): 810-815.
- Sanitaire. 2010. "Aeration Products for Energy-Efficient Biological Treatment." Company brochure.
- Shammas , N.K. et al., 2007. "Handbook of Environmental Engineering, Volume 5: Advanced Physicochemical Treatment Technologies." Totowa, N.J.: The Humana Press Inc.
- USEPA, 2011. EPA Greenhouse Gas Equivalency Calculator. http://www.epa.gov/cleanenergy/energy-resources/calculator.html. Accessed Sept. 10, 2011.

Table 5. Greenhouse Gas Prevention Equivalency

	Total
Total electricity saved (MWh [megawatt hour]/year)	3,000
Saving this amount of electricity annually is equivalent to preventing or sequestering CO_2 gas by the following methods:	
	Total
Release of metric tons of CO_2 (per year)	2,090
Converting from full-size pickup trucks to Toyota Prius hybrids (no. of vehicles) [a, c]	468
Sequestering carbon by planting tree seedlings grown for 10 years (no. of seedlings) [d]	177,030
Amount of pine forest acreage that sequesters an equivalent amount of CO_2 (no. of acres) [d]	1,472
Converting traffic signals from incandescent to LED bulbs (no. of signals) [b]	4,152

a Assumes average mi per gal being (mpg) increased from 16 to 46 mpg at 15,000 mi per driven annually

b Assumes signals are reduced from an average of 100W to 20W, for a savings of 730 kWh/year

c Calculations based on 8.92×10^{-3} metric tons CO_2/gal of gasoline and 6.8956×10^{-4} metric tons CO_2 / kWh (US EPA, 2011)

d Calculated using EPA's greenhouse gas equivalency calculator (EPA, 2011)

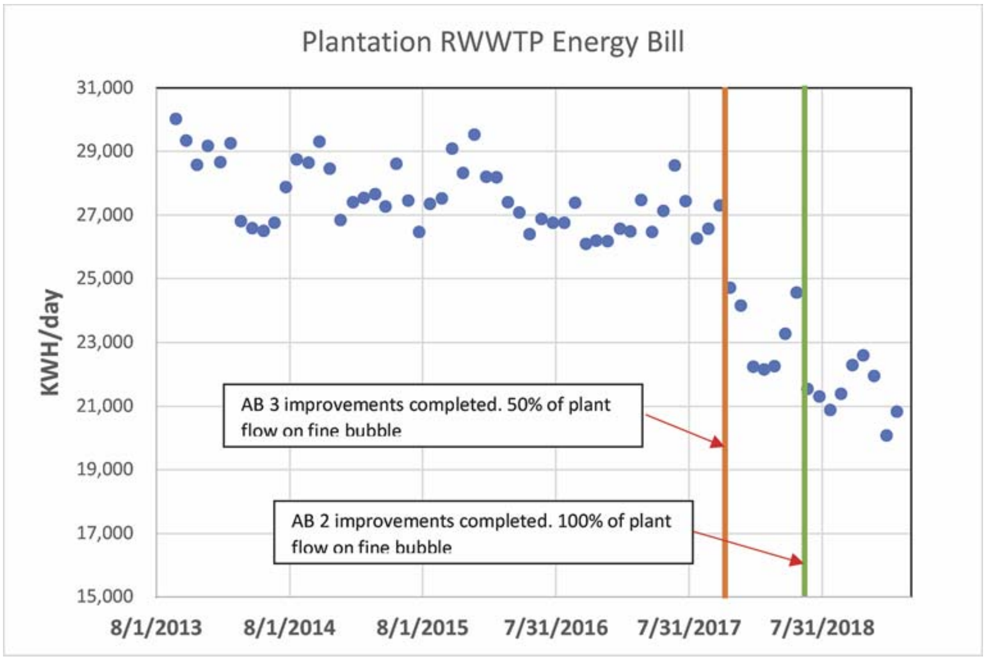

Figure 8. Regional Wastewater Treatment Plant Historical Energy Bill