New Frontiers in Algae-Facilitated Biological Wastewater Treatment

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ABSTRACT

Aquanos has developed a combined secondary-tertiary municipal wastewater treatment process that attempts to resolve several limitations of the activated sludge process, namely high energy requirements for aeration, ineffective nutrient removal and production of nuisance sludge. The process utilizes algal photosynthesis to produce water that is supersaturated with dissolved oxygen. This oxygenated water is circulated through fixed-film bacterial reactors, meeting bacterial oxygen needs without the use of mechanical aeration systems. Nine months of data from a beta scale installation suggest that utilization of algal raceways with hydraulic residence times (HRT) of 18-24 hours is sufficient to reduce effluent biological oxygen demand below 10 mg/L, though longer HRTs may be necessary to meet nitrogen and phosphorus effluent targets. Based on these results, a third-party analysis of a small-scale wastewater plant found that the Aquanos process would save up to 72% in total energy requirements and 63% in operating costs over activated sludge.

KEYWORDS: Algae, Moving-Bed Biofilm, Photosynthetic, Dissolved Oxygen, Aeration, Footprint, Biological Nutrient Removal

INTRODUCTION

Wastewater treatment is a significant and growing energy consumer worldwide. In the US alone, electricity consumption for wastewater treatment at POTWs is expected to rise above 30 billion kWh/year in US by 2050 (EPRI 2002). Meanwhile, growing populations, increased urbanization, improving sewerage and sanitation coverage, and stricter treatment standards in developing countries are increasing the use of energy-intensive treatment technologies worldwide (Global Industry Analysts, 2014). Activated sludge remains by far the most widely used technology for the treatment of municipal sewage. Electricity requirements for simple activated sludge have been estimated at 0.349 kWh/m^3, on average, for POTWs in the United States, but this figure does not take nitrogen removal into account. As more regions adopt effluent limits on nitrogen, treatment energy requirements will rise to an estimated 0.505 kWh/m^3 for advanced systems including nitrification stages (EPRI, 2002). Increasing the energy efficiency of secondary and tertiary effluent treatment technologies is therefore critical, both for developed countries, which are increasingly focused on mitigation of greenhouse gas emissions associated with energy use, and for developing regions, where increasing energy demands for wastewater treatment add additional strain to limited per-capita energy resources, making effective urban and rural development more challenging.

Activated sludge (along with almost all other widely used secondary treatment technologies) is an aerobic biological process. Specialized bacterial populations consume organic matter and/or ammonia in metabolic processes that require available oxygen. This oxygen is supplied through mechanical aeration, which accounts for roughly half of the total energy requirements in most treatment systems (Environmental Protection Agency, 2013). As effluent standards tighten and biological nutrient removal becomes more common, even more aeration energy will be necessary to supply sufficient oxygen to nitrifying cultures at treatment works. Aquanos Ltd. has set out to address this issue by developing a new combined secondary-tertiary municipal wastewater treatment process that utilizes microalgae cultures to oxygenate wastewater without mechanical aeration.

Algae-facilitated Oxygen Production

Unlike the activated sludge process, which requires constant aeration to supply bacterial communities with sufficient oxygen to break down organic matter, algae ponds produce enough dissolved oxygen through photosynthesis alone to sufficiently oxidize available BOD (Hoffmann, 1998). Photosynthesizing organisms (chiefly algae) produce oxygen within their cells as a byproduct of photosynthesis, and release this oxygen in dissolved form to the surrounding fluid volume, raising the oxygen content of the water in which they grow. Unaerated lagoon treatment systems depend on this process for oxygenation, though their simple design necessitates very long hydraulic retention times (HRTs) to achieve target effluent qualities, and provides few options for troubleshooting or treatment optimization. Since early pioneering efforts in the 1960s, numerous researchers have studied the use of high-rate algae ponds for COD/BOD removal (Park *et al.* 2011) with some success, and a few companies have made forays into commercializing these technologies (Willimot, 2015).

The main problems with high-rate algae pond systems have always been primarily twofold: large land footprints and difficulty in algae-water separation. In the last twenty years, significant progress has been made in improving our ability to separate algae from effluent waters cost-effectively by using specialized flocculants, dissolved air flotation and floccing co-cultures (Niaghi *et al.* 2015, Van Den Hende *et al.* 2014). While solids separation techniques continue to improve, almost no significant headway has been made in reducing the cost-prohibitive land footprints necessary for algal wastewater treatment. This is because algae treatment processes generally require long HRTs and high surface area to volume ratios. The main limiting factor in pond design is the availability of sunlight for photosynthesis. High-rate algae wastewater treatment systems have generally been composed of *raceways*, long ponds with ends that form U-turns. These raceways are equipped with motorized paddlewheels which are intended to continuously mix light-limited algae cells from the deeper layers to the surface while maximizing contact between suspended heterotrophic bacteria and their growth substrate (dissolved organics). Despite paddlewheel mixing, shading effects reduce the effective depth of these raceways to less than 1m; even at this depth, photosynthesizing algae may grow past a maximally efficient culture density, producing significant self-shading. The availability of ample growth substrate (originating as influent organic matter) and dissolved oxygen (produced by algal photosynthesis) results in the growth of heterotrophic bacteria, which further contribute to shading effects. Additionally, dense populations of bacteria may inhibit bacterial growth (and *vice versa*) as a result of micro-scale resource competition as well as physiochemical interference competition (Cole, 1982; Egan *et al.* 2001; Qu *et al.* 2014). Since raceway depth is limited by the above factors, hydraulic residence time (HRT) is directly related to overall system footprint (and cost), since every increase in total raceway volume will necessitate a proportional increase in raceway surface area (footprint). For this reason, Aquanos Ltd. has made reducing raceway HRTs a central focus of its research and development efforts.

The novel contribution of the Aquanos system is the separation of the bacterial and algal populations into separate reactor vessels. By effectively separating the process of oxygen production (photosynthesis) from BOD/COD destruction (respiration), negative interactive effects between bacterial and algal populations can be minimized. At the same time, separating the populations allows the algae raceway to be designed for maximal oxygen production rather than BOD/COD destruction, allowing for lower algae densities (less self-shading and endogenous respiration) and shorter HRTs than previous algae-facilitated treatment designs.

Additional Benefits

In addition to eliminating the need for aeration, algae-facilitated treatment systems reduce nutrient levels by assimilating inorganic nitrogen and phosphorus. Photosynthetic microalgae uptake and utilize a range of inorganic nitrogen and phosphorus sources for the production of cellular biomass, including ammonium, nitrate, nitrite and phosphate. These algae are also known to absorb and store additional nutrients beyond their immediate metabolic requirements in a process termed *luxury uptake.* In combination, these processes are capable of reducing inorganic nitrogen and phosphorus levels in treatment effluent below discharge targets without relying on bacterial or chemical nutrient removal techniques (Van Den Hende *et al.* 2011).

Another benefit of algae-facilitated treatment is vastly improved solids management. Waste sludge produced by activated sludge systems (or other conventional aerobic process) are generally low in nutrients, have poor physical properties for use as soil amendments, and require significant processing before they are sufficiently stabilized for safe use in land application. For these reasons, municipal biosolids are difficult to sell or recycle, and most treatment works pay landfilling fees to dispose of biosolids. By contrast, algae biomass produced by photosynthetic activity contain much higher macro- and micro-nutrient contents and better physical characteristics when compared to conventional biosolids (Park *et al.* 2011), making them significantly more commercially desirable than bacterial sludge. Several companies have already begun purchasing algal biomass from municipal treatment facilities for use in bioplastics production or soil amendments (privileged communication). Also, by using longer HRTs, the Aquanos system experiences greater endogenous respiration and produces a much smaller volume of solids than comparable activated sludge systems, reducing sludge handling costs.

DESIGN APPROACH

The Aquanos process was designed according to the following main principals:

1. Prevent bacterial biomass from contaminating algal cultures.
2. Achieve maximum daytime dissolved oxygen concentrations in raceways
3. Minimize hydraulic residence time (HRT) to reduce land footprint

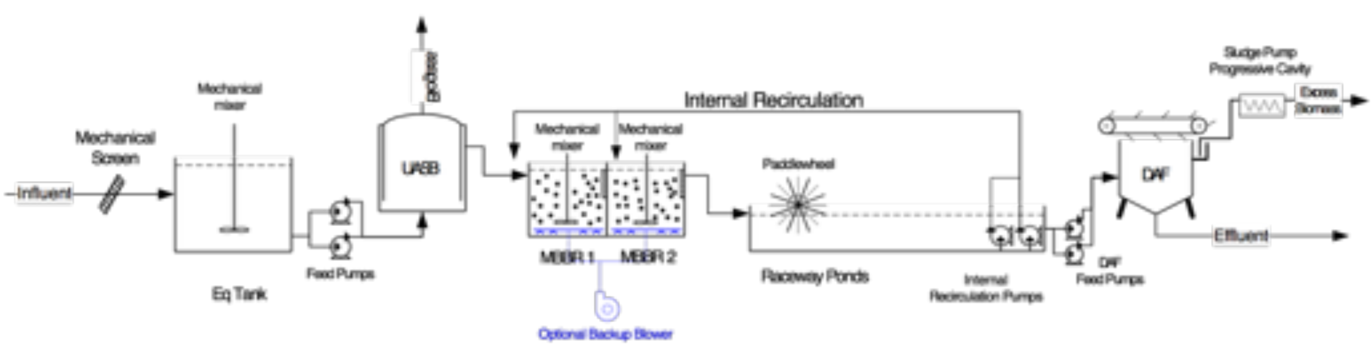
The core of the system is based on a patent-protected synthesis of moving bed biofilm reactors (MBBR) and algal raceways, intended to separate the heterotrophic and photosynthetic populations. In ‘standard’ MBBR systems, reactor tanks containing fixed-film carriers are rigged with air diffusers that supply oxygen to the heterotrophic bacterial population. The Aquanos process obviates blowers and diffusers by circulating MBBR effluent into algae raceways, where algal photosynthesis increases dissolved oxygen concentrations to more than 350% of saturation. By recirculating this oxygenated water back into the MBBR, dissolved oxygen is pumped directly into the biofilm reactor, where it is quickly utilized by the bacterial community. This oxygenation method avoids significant efficiency losses related to the relatively low percentage of oxygen in ambient air (21%), the limited diffusion rate of gases across bubble surfaces, and heat losses from compression of forced air. At the same time, the use of fixed-film media allows for the growth and retention of large bacterial populations within the reactor vessel, accomplishing three goals: (1) Increasing the rate of BOD destruction, (2) reducing BOD concentrations upstream of the photosynthetic raceways, thereby preventing/reducing the growth of bacteria within the algae culture; and (3) preventing washout of fixed bacterial populations.

Essentially, algae raceways are functioning as “photosynthetic blowers” within the Aquanos process; they produce dissolved oxygen through photosynthesis and deliver this dissolved oxygen to bacterial populations through the recycle stream. During process design, the effluent treatment rate is limited by oxygen availability to the bacterial population, which is determined by the rate of flow of oxygen-rich raceway water into the biofilm reactors, as well as the concentration of oxygen within the raceways. Raceway HRT must therefore be sufficient to maintain high levels of dissolved oxygen despite continuous export of oxygen-rich volume to the MBBR reactor and equivalent input of depleted reactor volume.

To reduce the necessary system footprint and energy requirements for recirculation of raceway water, anaerobic pretreatment of sewage influent is employed. This reduces the amount of BOD that must be respired in the MBBR reactor, subsequently reducing the necessary oxygen production rate and raceway HRT.

Process Flow

Figure 1 shows a process flow diagram of the complete Aquanos process. First, incoming sewage is screened and degritted, followed by equalization (EQ). Equalized flow is fed into an upflow anaerobic sludge blanket (UASB) reactor for additional removal of BOD/COD and TSS. UASB effluent is then passed into the first of two MBBR reactor vessels where contact time is achieved with the fixed-film media and oxygenated raceway recycle flow. For commercial installations, a backup blower and medium-bubble diffuser array is installed into the MBBR reactors. This allows for immediate conversion of the Aquanos system to a conventional MBBR process in the event of unforeseen problems in raceway oxygen production; simplifying the permitting process in regions where state or local authorities are hesitant to approve newly commercialized technologies. Effluent leaving the MBBR reactors flows into the first of several linked algal raceways via gravity. The number of individual algal raceways is determined by flow volume, influent strength, the shape of the available land area, and target HRTs. Following sufficient residence time in algae raceways, effluent is pumped to a solids separation unit. Based on successful small-scale testing, dissolved air flotation (DAF) with polymer flocculants was chosen as the preferred solids-separation technology for meeting effluent discharge targets and effectively thickening algal biomass. Additional testing is underway to test additional solids separation technologies.



Following harvesting of algal solids, DAF effluent meets TSS, COD, BOD (and nutrient, where applicable) discharge targets.

Figure 1: Process flow diagram of the Aquanos process, as installed at beta site and designed for upcoming Cape Cod commercialization.

Pilots and Beta Testing

The system was first tested for 18 months at small scale (3-5 m^3/day) within the Ra'anana (Israel) wastewater treatment plant (WWTP). The pilot system was able to consistently reduce soluble COD from a mean of 200 mg/L to a mean of 50 mg/L over the study period.

Following the successful result of the pilot, Aquanos scaled up the technology to a 10x

larger beta site on the grounds of the Dan region WWTP, treating a side-stream of the Dan Region plant. The beta site employed MBBR reactors with combined volume of 5m^3 and algal raceways with a surface area of 100 m^2 to treat (on average) 25m^3/day of municipal sewage. A scaled-up UASB reactor was also installed and operated with an average hydraulic retention time of 9 hours and upflow velocity of 0.5 m/hr. Table 1 shows average influent characteristics for the beta system. The system was brought online in early 2014, with data collection commencing in May 2015 and continuing through the time of this writing.

Table 1: Influent characteristics for beta Aquanos system treating 25m3/day at the

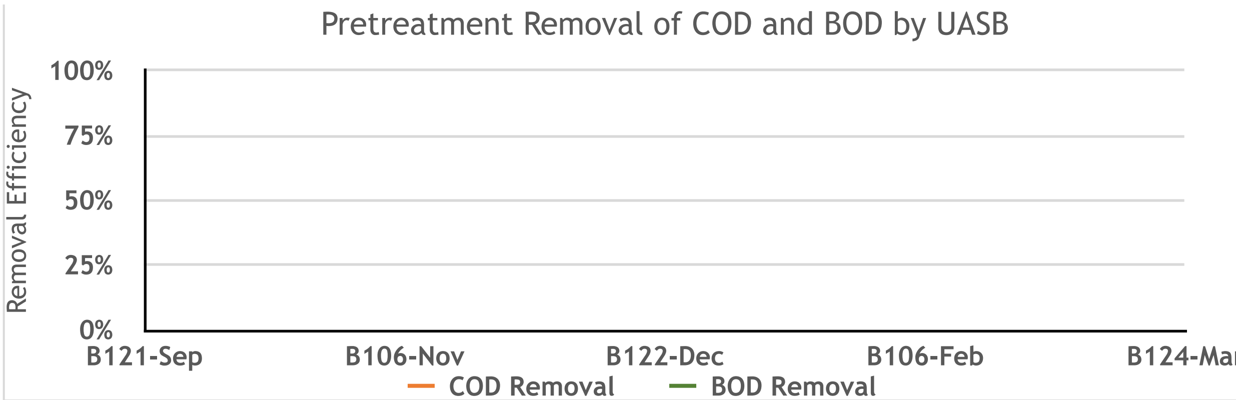
Dan region WWTP.

Influent Parameter	Average Value	Unit
COD	870	mg/L
BOD	396	mg/L
TSS	335	mg/L
NH4-N	27	mg/L
NO3-N	2	mg/L
PO4-N	6	mg/L

RESULTS

UASB Pretreatment

The UASB reactor design was tested for roughly 6 weeks at the Ra'anana pilot site, achieving consistent COD and TSS removal, with an average removal of 70% and 85% of the COD and TSS respectively. Based on this initial success, a scaled-up UASB design was constructed and installed at the beta site located at the Dan region municipal treatment plant. This unit initially demonstrated extremely high TSS removal (>90%) and moderate BOD removal (50-65%), but within two months of continuous feeding had stabilized to a slightly lower (80%) TSS and BOD removal. Time series data of COD, BOD and TSS removal at the beta site is presented below in Figure 3. High initial COD removals may be related to especially high TSS removal during sludge blanket development, since a large fraction of total COD is trapped in the suspended fraction, but this metric later stabilized roughly in line with BOD removal efficiencies as the sludge blanket matured. Overall, this 6-month time series demonstrates that small-scale UASB pretreatment of municipal effluent is able to effectively and consistently reduce BOD, COD and TSS levels by 75-80%.



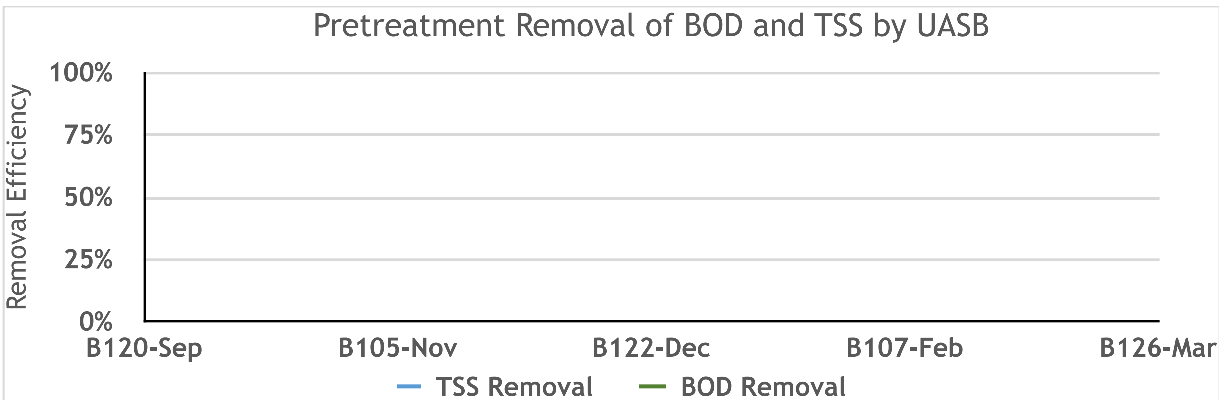


Figure 3: Time series of COD, BOD and TSS removal efficiency by beta site UASB pretreatment reactor.

Algal Raceway Oxygen Production

Algal cultures produce oxygen only during daylight hours, when sunlight is available for photosynthesis. As a result, dissolved oxygen concentrations in the raceways fluctuated from day to night (Figure 4). DO concentrations fell in conjunction with irradiance in the evening hours as oxygen consumption from respiration overtook photosynthetic oxygen production. DO concentrations reached a minimum (<1 mg/L) about an hour after sunset and remained low until morning twilight, when DO began to rise. Daily maximum DO concentrations occurred around noon, and generally remained above 20 mg/L (the upper-limit on our sensors) for several hours. Visiting researchers with higher-limit sensors measured DO concentrations in excess of 34mg/L during these periods. Strong variation was found between winter and summer maxima; daytime DO concentrations rarely rose above 12 mg/L between mid-December and late January, coinciding with the period of lowest winter irradiance. Despite reduced photosynthesis during the winter period, DO concentrations remained high enough to efficiently oxygenate fixed-film bacterial cultures throughout the year.

Another byproduct of photosynthesis is increased pH resulting from the utilization (removal) of dissolved carbon dioxide. This resulted in patterns of pH fluctuation which tracked DO concentrations (Figure 4), though pH was not found to rise above effluent limits at HRTs of 24-72 hours.

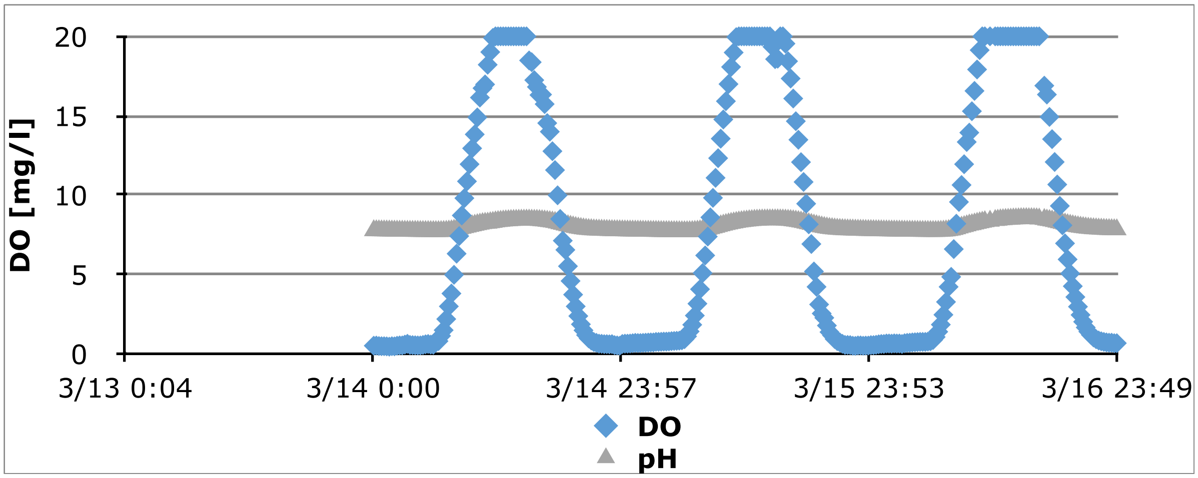


Figure 4: Fluctuating dissolved oxygen concentration and pH from day to night in beta site raceways.

BOD and COD removal

Both chemical and biological oxygen demand (COD and BOD, respectively) were measured at the beta site in order to quantify removal of dissolved organics. While COD is generally used in conjunction with a site-specific correction-factor as a proxy for BOD, these two metrics demonstrated very weak correlation in Aquanos system effluent, with only 12% of the variation in effluent BOD described by COD (Figure 5). It is unclear why COD:BOD ratios are especially unstable in Aquanos process effluent, though we hypothesize that the variable production of relatively refractory (not easily consumed) algal exudates may be contributing to variability in effluent CODs (see Aluwihare and Repeta, 1999). This suggests that COD should not be used as a proxy measure for BOD in Aquanos system effluent.

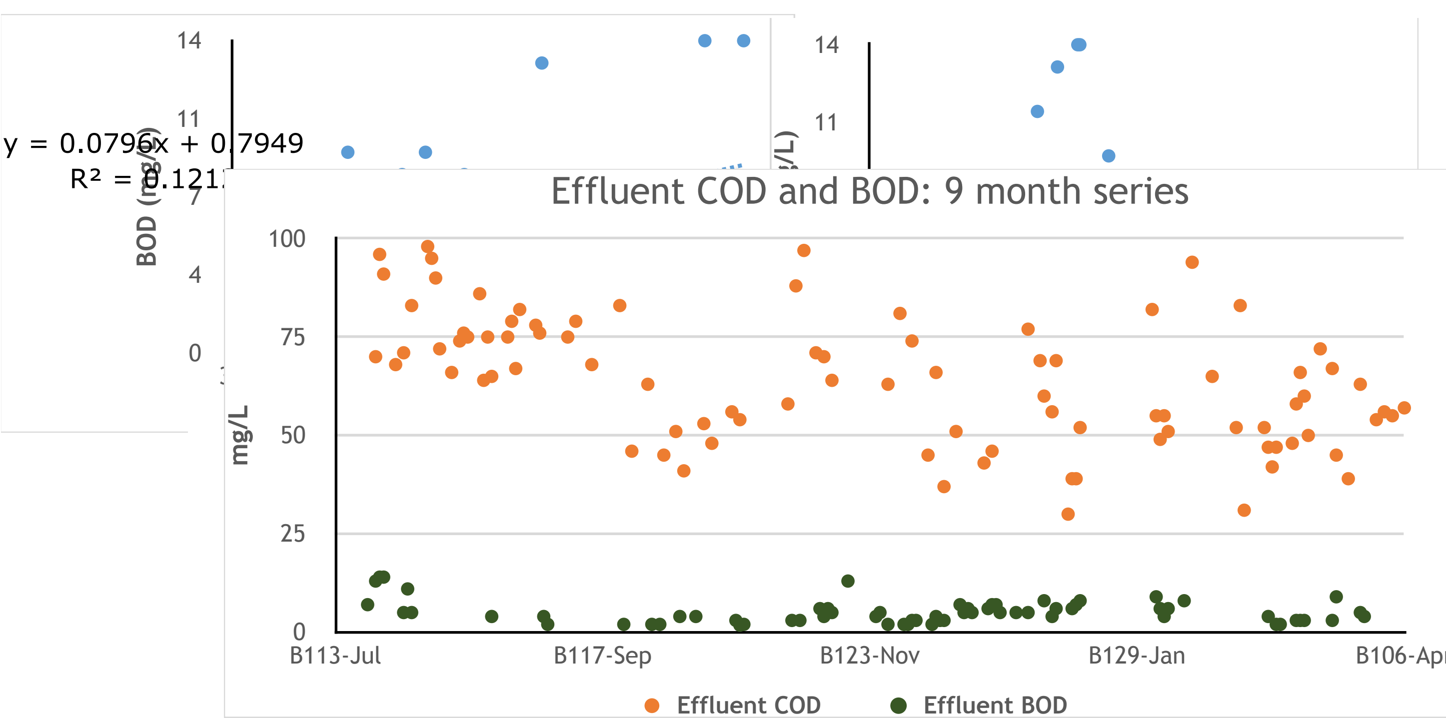


Figure 7: Nine-month time series of COD and BOD in beta site effluent.

Over nine months of continuous operation, the beta system was able to maintain effluent BOD levels below 10 mg/L on 61 of 66 sampling days, with an average effluent BOD of 5.1 mg/L for the entire period (Figure 7). During the same period, COD averaged 65 mg/L.

Hydraulic Residence Time

During nine months of BOD sampling at the beta site, daily influent flow volume was intentionally varied in order to test the effect of variable raceway HRTs on BOD removal. As can be seen in figure 6, effluent BOD (and COD) had no significant relationship to raceway HRT in this study. It is important to note that HRTs below 18 hours were not tested, since very short HRTs would lead to rapid washout of photosynthetic algae as cells are removed from the system faster than they are able to reproduce. Since effluent COD/BOD did not significantly correlate to HRT (at retention times between18 and 72 hours), we conclude that sufficient oxygen is produced from algal growth at 18 hours HRT to effectively and consistently reduce BOD below 10 mg/L. Thus, we could theoretically reduce HRTs even further while maintaining target effluent quality, as long as sufficient algae cell densities were maintained in the raceway.

Nutrient Removal

For the majority of this study, the Aquanos system was designed and tested to serve as a secondary treatment technology for removing soluble BOD/COD, rather than inorganic nutrients. Indeed, at low HRTs (18-30 hours), nutrient removal performance was insufficient to meet most regulatory limits for regions with nutrient limitations. This suggests that low HRT, low footprint Aquanos systems would be best suited for regions where effluent nutrient limits have not been imposed, or in designs with downstream nutrient treatment. For areas with effluent nutrient limits, another option is to increase

HRT to allow for greater assimilation of inorganic nitrogen and phosphorus. To test whether the Aquanos system could effectively reduce nitrogen and phosphorus levels below standard targets, HRT was increased to 5 days. At this HRT, significant ammonium and phosphate reductions were observed (Figure 8). Effluent from the Aquanos beta system functioning at 5 days HRT were able to meet most discharge standards, with total inorganic nitrogen levels of 4.5mg/L and phosphate levels < 2mg/L. Additional research is currently being conducted to try and reduce the necessary HRT (and footprint) necessary to achieve these nutrient targets.

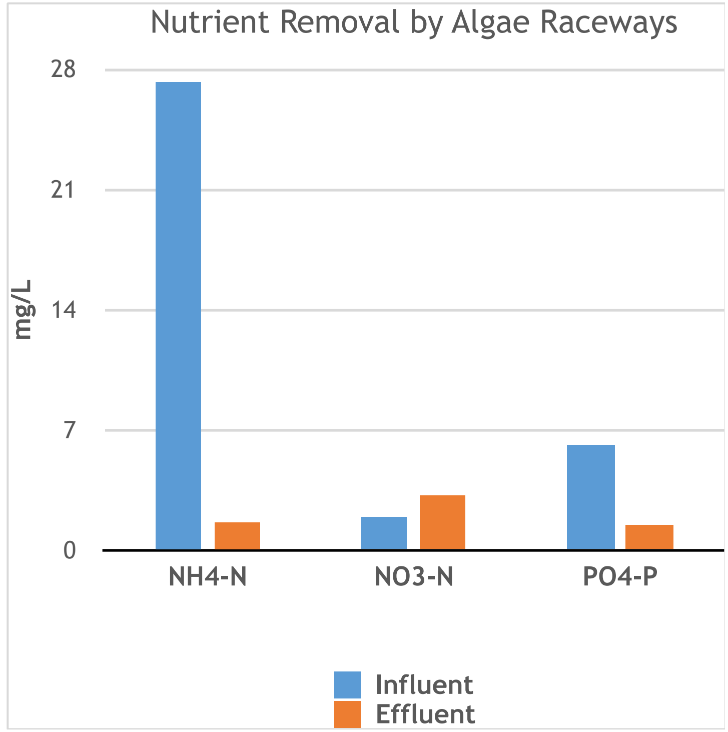


Figure 8: Comparison of ammonium nitrogen (NH_4-N), nitrate as nitrogen (NO_3-N) and phosphate as phosphorus (PO_4-P) concentrations before and after treatment in the Aquanos system beta site when raceway HRT was extended to 72 hours.

Energy and Cost Savings

The elimination of mechanical aeration equipment represents significant energy savings for wastewater treatment. As mentioned above, aeration generally accounts for about half of all energy use at a WWT plant, but replacing mechanical aeration equipment with an Aquanos system does not eliminate 100% of energy requirements, since energy is still required for pumping of recirculated effluent, MBBR reactor mixers and other processes. To examine the real energy and cost savings resulting from installation of an Aquanos system, we performed a case study analysis in conjunction with a municipal WWTP in the Philippines. Engineers from the local municipality were asked to compare the energy budget and operating costs of a small activated sludge plant treating 200m^3/d of domestic wastewater (without nutrient removal) to an Aquanos process installation (based on an actual project design prepared for the same plant). The results are described in table 2, with costs listed in local currency (Philippine peso). For aeration energy alone, activated sludge required 264 kWh/d to process treatment volumes at this plant. Comparatively, the Aquanos process required 120 kWh/d to treat the same flow (a 65% energy savings). Moreover, the Aquanos system produces a fraction of the solids that are produced during activated sludge treatment, and when sludge dewatering and disposal costs were taken into account, the Aquanos process was able to achieve a 57% reduction in total operating costs when compared with activated sludge.

Table 2: Comparison of operating costs between activated sludge and Aquanos process for a small domestic WWTP in the Philippines. All costs are in Phillipine pesos (Php).

			Cost in Php*	
BIOLOGICAL PROCESS POWER	kW	Hours	Activated Sludge	Aquanos System
Blowers	11	24	2144	0
Supplementary Blowers	2.1	24	0	410
MBBR Mixer	0.6	24	0	117
Recirculation (IR) Pump	1.3	12	0	127
Paddle Wheel	1.5	24	0	292
Flocculation Mixer	0.1	12	0	9.74
Dosing Pump	0.2	12	0	19.5
TOTAL, Php/day			2144	974
DEWATERING COST				
Sludge Yield, kg/kgBOD			0.8	0.02
Sludge Volume, m3/d			3.09	0.06
Dewatering Cost @ 1.02kWh/m3			3.16	0.06
TOTAL, Php/day			25.6	0.48
BIOSOLIDS HAULING COST**				
Biosolids Volume, m3/d			0.123	0.002
TOTAL, Php/d			74.76	1.4
TOTAL OPEX COST, Php/d			2244	976
in USD/d			$ 50.46	$ 21.95
OPEX SAVINGS PER DAY, Php				1268
				57%
OPEX SAVINGS PER M3, Php				6.34
in USD				**$ 0.14**
*Power Unit Cost: Php8.12/kWh or USD$0.18/kWh				
**Biosolids Hauling Cost: Php 609/m3 or USD$13.69/kWh				

In addition to the energy and cost savings itemized in table 1, the Aquanos process also produces energy as biogas in UASB pretreatment. For the example above, processing 200m^3 per day of sewage with influent COD of 275 mg/L would produce 13.2 m^3 of biogas composed of 75% methane, which represents 18.5kWh/day of energy produced. This represents 15.4% of the total energy requirements of the Aquanos system or an additional 7% reduction in energy requirements compared to activated sludge. Thus, when produced biogas energy is factored in, an Aquanos retrofit at this plant would save 72% in total energy requirements over activated sludge, resulting in a total operating cost reduction of 63%.

SUMMARY AND CONCLUSIONS:

Aquanos' pilot and beta systems have demonstrated the ability to treat municipal wastewater aerobically without mechanical aeration, while supplying oxygen to the aerobic process through an oxygen-rich stream of algae culture. With sufficient DO concentration maintained within the system, it consistently produced soluble COD/BOD removal rates equivalent to those found in conventional systems with mechanical aeration. In one case-study analysis, this resulted in a 65% energy savings (72% when offsets from produced biogas are considered) over conventional activated sludge. An 18-hour HRT algal raceway pond was found to be sufficient in size to produce the required quantity of oxygen required for breakdown of BOD in the wastewater. Since capital costs for construction of algal raceways are generally lower than capital costs of conventional systems, reducing system HRTs (and subsequent land footprints) makes the Aquanos process economically competitive with conventional technologies. Additional research is currently underway to reduce effective HRTs even further without washing out algal populations. At the same time, algal nutrient assimilation required significantly higher HRTs (3-5 days) than BOD removal alone, weakening the value proposition of the Aquanos process for regions with nutrient discharge limits. Research is in progress to bring the HRTs necessary for nutrient assimilation in line with those necessary for BOD removal. The production of valuable algae solids in lieu of nuisance sewage sludge represents an additional commercial and environmental advantage of the Aquanos technology when compared to other technologies for wastewater treatment. Taken together, all of these advantages translated into a total operating cost reduction of 63% over activated sludge, making the Aquanos process an attractive choice for municipalities where land availability and price is conducive to trading off larger land footprints for lower operating and capital equipment costs.

REFERENCES

Aluwihare L.I., Repeta D.J. (1999) A comparison of the chemical characteristics of oceanic DOM and extracellular DOM produced by marine algae. *Mar Ecol Prog Ser* **186**:105–117.

Brenner, A., and Abeliovich A. (2013) "Water Purification: Algae in Wastewater Oxidation Ponds." In *Handbook of Microalgal Culture*, 2nd ed.; Richmond, A. and Hu, Q. Eds.; 595–601. John Wiley & Sons, Ltd. Oxford, UK.

Cole, J. J. (1982) Interactions Between Bacteria and Algae in Aquatic Ecosystems. *Annual Review of Ecology and Systematics* **13**: 291–314.

Electric Power Research Institute (EPRI) (2002). *Water & Sustainability (Volume 4):U.S. Electricity Consumption for the Water Supply & Treatment–The Next Half Century.* Report 1006787. Palo Alto, CA.

Environmental Protection Agency (2013). *Energy Efficiency in Water and Wastewater Facilities. Local Government Climate and Energy Strategy Series.* EPA- 430-R-09-038. Washington, DC.

Global Industry Analysts, Inc. (2014). *Water and Wastewater Treatment Equipment—a Global Strategic Business Report.* MCP-3541. San Jose, CA.

Hoffmann, J. P. (1998) Wastewater Treatment with Suspended and Nonsuspended Algae. *J Phycology,* **34** (5): 757–63.

Niaghi M, Mahdavi M a., Gheshlaghi R (2015) Optimization of dissolved air flotation technique in harvesting microalgae from treated wastewater without flocculants addition. *J Renew Sustain Energy* **7**: 013130.

Park, J.B.K., Craggs, R.J., Shilton, N. (2011) Wastewater treatment high rate algal ponds for biofuel production. *Bioresour Technol* **102**:35–42

Suhelen, E., James, S., Holmström, C. and Kjelleberg, S. (2001) Inhibition of Algal Spore Germination by the Marine Bacterium Pseudoalteromonas Tunicata. *FEMS Microbiology Ecology,* **35** (1): 67–73.

Qu, Liang, Renjun Wang, Peng Zhao, Ruinan Chen, Wenli Zhou, Liuqing Tang, and Xuexi Tang. (2014) Interaction between Chlorella Vulgaris and Bacteria: Interference and Resource Competition. *Acta Oceanologica Sinica,* **33** (1): 135–40.

Van Den Hende S, Beelen V, Bore G, Boon N, Vervaeren H (2014) Up-scaling aquaculture wastewater treatment by microalgal bacterial flocs: from lab reactors to an outdoor raceway pond. *Bioresour Technol* **159**: 342–54

Van Den Hende S, Vervaeren H, Desmet S, Boon N (2011) Bioflocculation of microalgae and bacteria combined with flue gas to improve sewage treatment. *N Biotechnol* **29**: 23–31

Willimot, D. (2015, February 26) From Green Glop to Black Gold. *Huffington Post.* Retrieved from www.huffingtonpost.com/x-prize-foundation/from-green-glop-to-black_b_6762910.html