Orange County Sanitation District Report

Prepared by Raven Althouse, Serene Hayes, Marco Kleimans, Marella Schammel,
and Connor Sauceda

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I. Orange County Sanitation District Wastewater Treatment

Background

The Orange County Sanitation District (OCSD) is a publicly owned wastewater treatment agency which provides wastewater collection and treatment services for a population of approximately 2.6 million people. The OCSD collects wastewater from residential, commercial, and industrial users across Orange County, and treats the wastewater at one of two treatment plants. The first treatment plant, Plant No. 1, is located in Fountain Valley, California. Plant No. 1 treats approximately 120 million gallons per day (MGD) of sewage from the inland and eastern portions of Orange County. The majority of the effluent from this plant goes on to further treatment for reuse at the Orange County Groundwater Replenishment System (GWRS). Wastewater produced downstream of, or diverted past Plant No. 1, is conveyed to Plant No. 2, which is located in Huntington Beach. Plant No. 2 treats additional wastewater from the western and coastal regions of Orange County. Plant No. 2 treats approximately 70 MGD of wastewater, and discharges its effluent into the Pacific Ocean (OCSD, 2020).

Treatment Configuration

The treatment configurations and treatment technologies used at both Plant No. 1 and Plant No. 2 are fairly similar, despite the fact that the two plants receive sewage at considerably different flow rates. For simplicity purposes, this paper will focus on the treatment processes at Plant No. 1 as an example, bearing in mind that the configurations of the two plants are comparable.

For primary treatment, Plant No. 1 uses traditional physical separation technologies including bar screens, grit chambers, and primary clarifiers to ensure that large particles are settled out of the wastewater prior to biological treatment. Ferric chloride and an anionic polymer is added to the wastewater upstream of the primary clarifiers in order to encourage floc formation and better settling. This methodology is called chemically enhanced primary treatment (CEPT). CEPT also helps remove hydrogen sulfide gas in the primary sludge, which is beneficial later when the sludge is digested.

For biological (secondary) treatment, a combination of both trickling filter and conventional activated sludge technology is utilized. Only approximately 20 percent of the flow through Plant No. 1 is diverted to the two 166-foot diameter trickling filter facilities. The GWRS requires relatively high quality effluent, and because the trickling filter water quality is lower than that of conventional activated sludge treatment processes, the flow of influent to the trickling filters is limited. In turn, the bulk of the secondary treatment takes place in one of the two activated sludge facilities, AS-1 or AS-2. Each activated sludge facility consists of multiple aeration basins and secondary clarifiers, and can be operated in different treatment modes. Both facilities can alternate between nitrification/denitrification mode and BOD mode (Carollo 2017). Effluent from both the trickling filter and activated sludge secondary clarifiers is sent to the GWRS. At Plant No. 2, effluent from the plant is discharged via two lines (one is 4.5 miles, and the other is 1.5 miles in length) into the ocean.

The trickling filters recycle any microorganisms prior to settling in the trickling filter clarifier. Sludge settled in the trickling filter clarifiers is not recycled, and is instead pumped upstream of the activated sludge aeration basins for further treatment. Sludge formed in the activated sludge clarifiers is either returned upstream of the aeration basins for recycle, or wasted (Stacklin 2015). Wasted sludge from the activated sludge clarifier is sent to dissolved air flotation thickeners, which thicken the sludge prior to digestion. Sludge is then diverted to anaerobic digesters in order to produce biogas for electricity generation. The electricity powers approximately 60 percent of the OCSD facilities (OCSD, 2020). A cationic polymer is then added to the sludge after digestion to encourage dewatering, and then sent to centrifuges. These centrifuges remove the remaining water in the sludge, producing a solid cake that is used as fertilizer for agricultural land application or is disposed of in a landfill. A process flow chart of Plant No. 1 can be seen in Figure 1. Figure 1 includes a listing of designated nodes that correspond to water quality sampling stations along the treatment processes. Table 1 includes a summary of the influent, effluent, and solids handling in fiscal year 2018-2019 for all of the major constituents included in the process flow diagram. The green numbered nodes in Figure 1 correspond to the sampling locations designated in Table 1.

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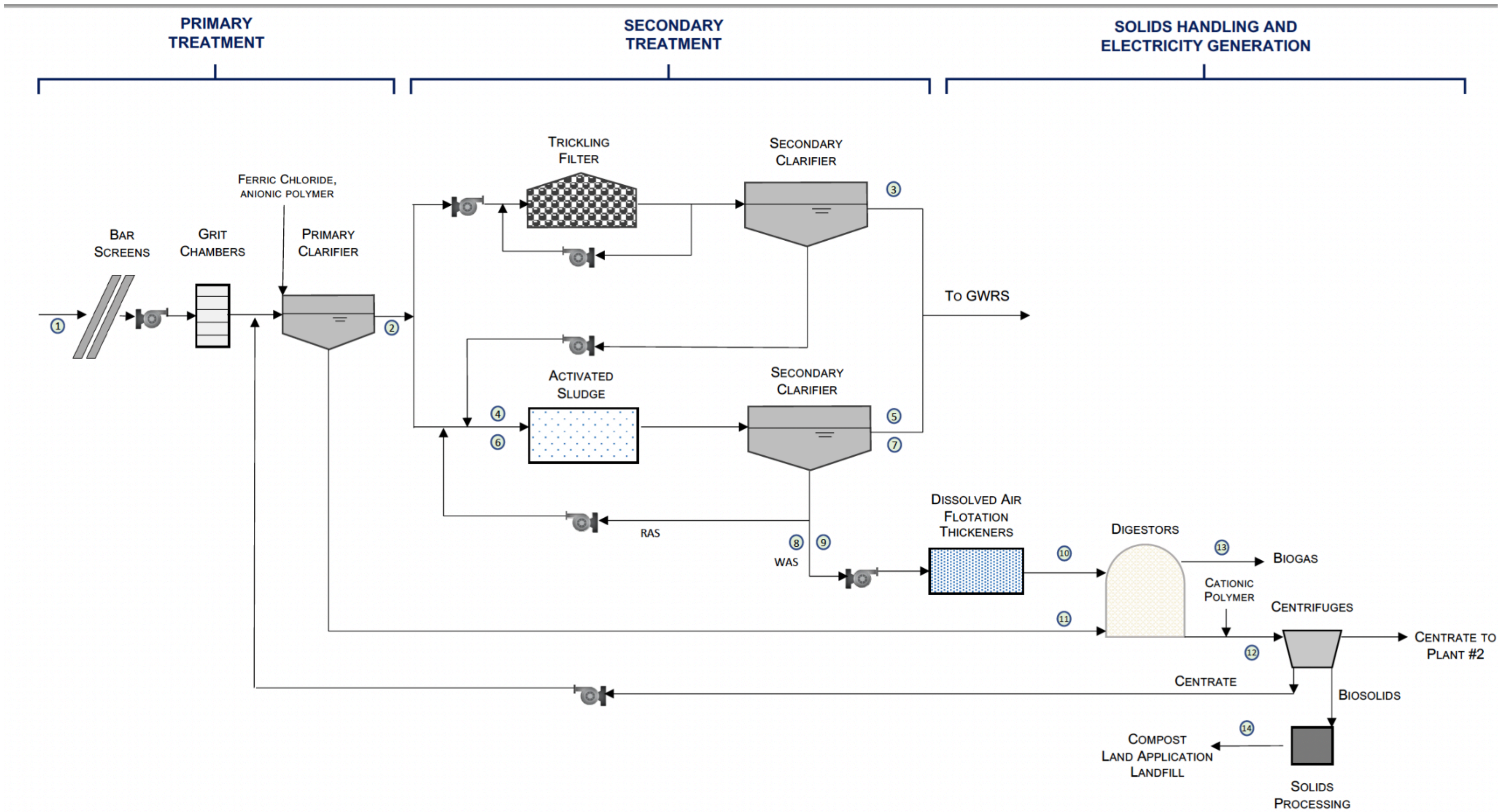


Figure 1 - OCSD Plant No. 1 Process Flow Diagram

Table 1- OCSD Plant No. 1 Influent/Effluent Concentrations

Node	Description	Flow (mgd)	Total BOD (mg/L)	TSS (mg/L)	VSS (mg/L)	Ammonia-N (mg/L)
1	Plant Influent	121.0	215	355	311	36.1
2	Primary Treatment Effluent	-	156	72	-	-
3	Trickling Filter Effluent	23.6	14.8	17.8		13.6
4	**Activated Sludge Train 1 (AS1) Influent**	**61.0***	**107**	**61**	**51**	**27**
5	Activated Sludge Train 1 (AS1) Effluent	47.9	5.0	7.5	7.5	0.5
6	Activated Sludge Train 2 (AS2) Influent	60.0*	149	71	57	38
7	Activated Sludge Train 2 (AS2) Effluent	56.0	4.7	5.0	4.4	1.2

OCSD Solids Handling and Digestion

Node	Description	Flow (mgd)
8	AS1 Waste Activated Sludge (WAS) Effluent	0.47
9	AS2 Waste Activated Sludge (WAS) Effluent	0.78

Node	Description	Sludge Flow (ft^3/day)	Total Solids %
10	DAF Thickener Effluent	25,500	-
11	Primary Sludge Effluent	92,891	3.24
12	Digested Sludge/Centrifuge Feed	-	1.96

Node	Description		
13	Digester Gas	54 million	ft^3/month
14	Bisolids Cake Production	11,328	wet tons/month

Regulatory Setting

Discharge requirements for the OCSD are governed by both the United States Environmental Protection Agency (USEPA), Region 9, and the California Regional Water Quality Control Board (RWQCB), Santa Ana Region 8. The USEPA and RWQCB manage and monitor the OCSD National Pollutant Discharge Elimination System (NPDES) permit for OCSD, which sets the effluent discharge limits for both the OCSD Plant No. 1 and No. 2. The NPDES permit program was authorized by the federal passage of the Clean Water Act in 1972. As a part of its NPDES program, OCSD utilizes a rigorous source protection program which monitors and regulates which types of waste that can be discharged into its sewage conveyance system. OCSD is currently permitted to discharge it's effluent to the Pacific Ocean, or via overflow weirs into the adjacent Santa Ana River during emergency conditions (RWQCB & USEPA, 2012). The California Department of Health Services (DHS) also monitors discharges from the two treatment plants to ensure the protection of human health.

The effluent discharge limits designated by the USEPA are split into two categories: technology-based effluent limitations (TBELs) and water quality-based effluent limitations (WQBELs). TBELs require certain basic levels of treatment that allow the OCSD to use any control technique they'd like as long as they meet effluent limits for key parameters. The baseline standards for TBELs include effluent limits on carbonaceous five-day biological oxygen demand (BOD5), total suspended solids, pH, oil and grease, settleable solids, and turbidity.

WQBELs are based on total maximum daily loads (TMDLs) of certain pollutants into impaired waterbodies. TMDLs are determined by the state. Some of the WQBELs for OCSD include limits on chlorine residual, acute and chronic toxicity, benzidine, hexachlorobenzene, polychlorinated biphenyls (PCBs), 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) equivalents, and toxaphene. Water quality sampling for both TBELs and WQBELs are typically done on a weekly basis, however some pollutants require daily monitoring (USEPA, n.d.).

Future Plans and Upgrades

The OCSD has released several reports on recent research projects they have conducted on new technologies to improve treatment efficiency and reduce operating cost. One study examined primary effluent filtration (PEF). PEF treats primary effluent, reducing TSS, BOD, and other contaminants, without the use of secondary treatment (Brown & Wistrom, 2017). All three types of filters they tested successfully met daily ocean discharge requirements for TSS and BOD 100% and 97% of the time, respectively (2017). While operating costs would vary based on type of filter used and power requirements, the costs are projected to be substantially lower than those of advanced primary treatment or activated sludge treatment, so PFE is a successful alternative treatment method (2017).

There are many anticipated future upgrades to the OCSD facilities, focusing mostly on upgrading and rehabilitating existing structures ("Design Services Request for Proposal Activity", 2021). These projects would include repairing the Plant No. 2 digesters, replacing sedimentation basins, and improving several buildings and structures to reduce risk of failure during seismic events (2021). The proposed projects total over $530,000,000 for upgrades to occur over the next two years.

II. BioWin Modeling of OCSD

Modeling

BioWin was used to model the secondary treatment process at OCSD's Plant 1. While the plant's secondary treatment includes a trickling filter, for the purpose of modeling, the trickling filter was excluded from this scenario. Additionally, as previously discussed in the section above, Plant 1 has two activated sludge facilities, AS-1 and AS-2. For the scenario modeled, only AS-1 was considered. Therefore, the modeled secondary treatment consisted of influent going into an activated sludge basin, traveling to a secondary clarifier, and from the clarifier the flow was split between return activated sludge (RAS), waste activated sludge (WAS), and effluent (see Figure 2).

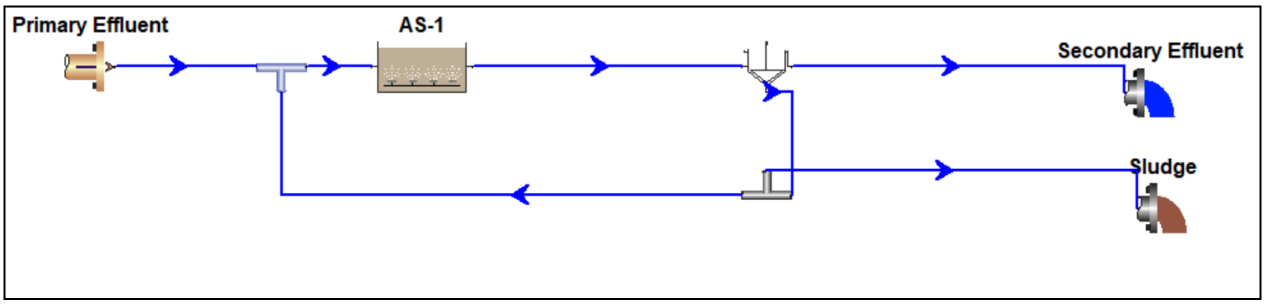


Figure 2 – BioWin Model for OSCD Secondary Treatment

BioWin Parameters

The wastewater characteristics that were provided by OCSD and discussed in *Section I* (Table 1) were inputted into this model. These include the average activated sludge train influent concentrations and flow rates into the AS basin and secondary clarifier (Figure 3). Although flow rates for each activated sludge basin were not specified, it was assumed that approximately half of the total plant influent flows through the AS basin (61 MGD of 121 MGD). Flow rate data for RAS and WAS were also used in order to accurately model sludge recirculation and discharge. In order to model OCSD's secondary treatment, the kinetic and stoichiometric parameters had to be considered and updated. For kinetic parameters, ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB) and ordinary heterotrophic organisms (OHO) were all considered. Table 2 lists all kinetic parameters that were inputted into the model, while other parameters remained default values. Likewise, for the stoichiometric parameters, the yields of AOB, NOB, and OHO were all inputted into the model (Table 3).

Kinetic parameters were assumed based on calculations discussed in this course and performed in homework assignments. It is important to note that it was assumed that the scenario modeled was occurring in the summer months of the year, thus all kinetic parameters were based on temperatures of 20 - 25°C. Stoichiometric parameters were assumed based off of the standards discussed in *Biological Wastewater Treatment* (Grady et al. 2011), which are found to be BioWin's automated values and are found in the BioWin Help Manual. To ensure accuracy, these automated stoichiometric values are supported by those solved for in various homework assignments for this course. Similarly, the wastewater fractions used were those that the BioWin Help Manual Tutorials instructed users to input into their scenarios (EnviroSim, 2011).

Table 2 **–** Kinetic Parameters

AOB		
Parameter	***Units***	
Maximum specific growth rate (μ_{max})	d^{-1}	0.768
Substrate (NH_4) half saturation (K_S)	mg N/L	0.2
AOB denitrification half saturation	mg/L	0.75
Aerobic Decay Rate	d^{-1}	0.072
NOB		
Parameter	***Units***	
Maximum specific growth rate (μ_{max})	d^{-1}	0.768
Aerobic Decay Rate	d^{-1}	0.072
OHO		
Parameter	***Units***	
Maximum specific growth rate (μ_{max})	d^{-1}	9.6
Substrate half saturation (K_S)	mg COD/L	20
Aerobic Decay Rate	d^{-1}	0.096

Table 3 **–** Stoichiometric Parameters

Parameter	***Units***	
$Yield_{AOB}$	mg COD/mg N	0.2
$Yield_{NOB}$	mg COD/mg N	0.2
$Yield_{OHO}$	Aerobic	0.5

Table 4 – Wastewater Fractions

Fraction	
Fbs	0.3094
Fxsp	0.8235
Fus	9.00 E-04
Fup	0.1848
Fna	0.64
Fnox	0.392
Fnus	0.0357

Results and Discussion

The results of the BioWin modeling of the OCSD treatment plant are summarized below (see Table 5). As seen, the modeled results are quite close to the observed values for effluent concentrations of COD, BOD, TSS, and Ammonia. Although ammonia-N is not a direct input value into the model, Total Kjeldahl Nitrogen was used as an input proxy, along with the ratio of Ammonia-N to TKN found above in Table 4 (Fna = 0.64). Removal efficiency of COD in the model is much higher than that observed in the treatment plant, which could be explained by the model setup. Given that a BOD influent was used in the model, COD was not directly controlled and thus was not able to be input exactly as in the OCSD data. Wastewater fractions were manipulated in order to get COD close to the actual input value, but was still somewhat lower (199mg/L). It should be noted, however, that even when different values for COD were input, the effluent quality did not change significantly, showing the system's resilience to organic loading. Additionally, although COD was not represented well in this model, BOD values in the model align closely with those observed in the OCSD system.

BOD input was able to be controlled precisely, and subsequent BOD removal was very close to observed values (95% compared to 94%). Additionally, TSS removal in the model was somewhat lower, with a modeled removal rate of 83% compared to the observed 88%. This may be a result of the clarifier model, as specific dimensions of the clarifier were not accounted for in the model and only flow split is able to be controlled. It should also be noted that HRT and SRT were not controlled for in this model, which could be a contributing factor in removal rates. Ammonia-N removal in the model was also very close to the observed removal rate, and actually somewhat better than the observed rate (99% compared to 98%) but the difference in effluent ammonia-N concentration is likely insignificant (0.32 mg/L vs 0.5 mg/L).

Given that limited data was available for the model and most kinetic, stoichiometric, and wastewater fraction parameter values were based on assumptions and previous assignments, the model is well aligned with the treatment performance of the OCSD reclamation plant. Additionally, the wastewater characteristics in this model (see Table 1) were all based on average values over the course of an 8-month observation period, which is likely to capture a lot of noise within the influent and effluent data, as well as contribute inconsistencies to the model inputs.

Table 5 – Biowin Model Results Summary

	AS-1 Influent	AS-1 Effluent	Modeled Effluent	% Removal (Actual)	% Removal (Model)
Total COD (mg/L)	260*	38	15.57	85%	92%*
Total BOD (mg/L)	107	5.0	6.69	95%	94%
TSS (mg/L)	61	7.5	10.24	88%	83%
Ammonia-N (mg/L)	27	0.5	0.32	98%	99%

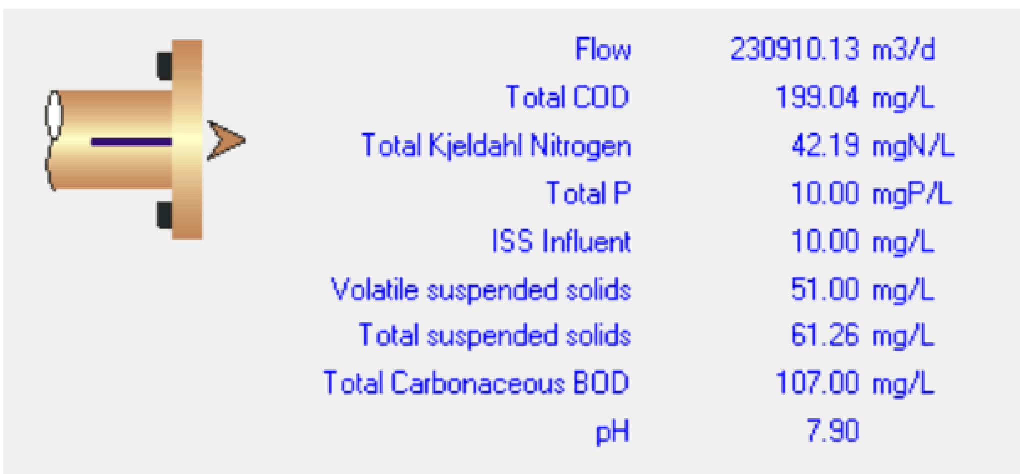
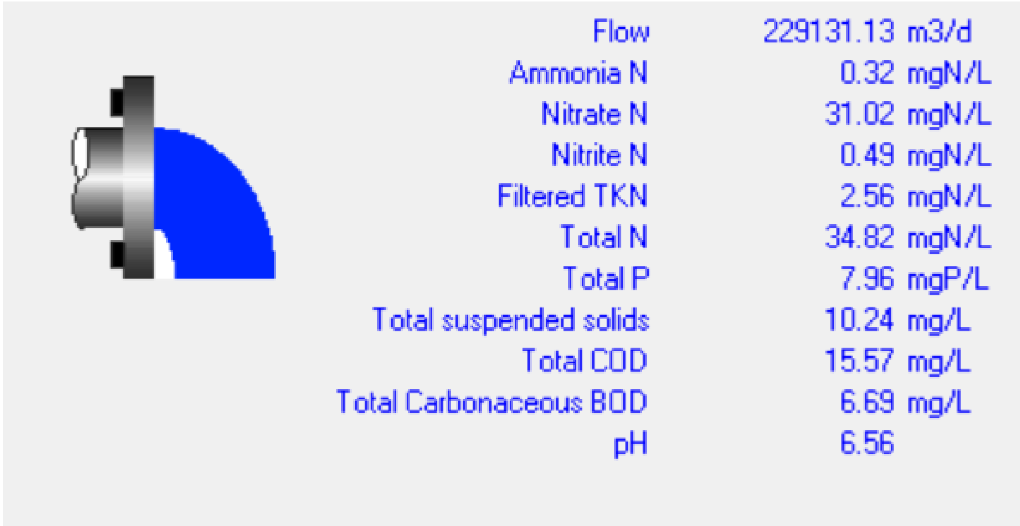


Figure 3 – BioWin Model Influent Quality



Flow	229131.13	m3/d
Ammonia N	0.32	mgN/L
Nitrate N	31.02	mgN/L
Nitrite N	0.49	mgN/L
Filtered TKN	2.56	mgN/L
Total N	34.82	mgN/L
Total P	7.96	mgP/L
Total suspended solids	10.24	mg/L
Total COD	15.57	mg/L
Total Carbonaceous BOD	6.69	mg/L
pH	6.56	

Figure 4 **–** BioWin Model Effluent Quality

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III. Emerging Technology: Integrated Fixed-film Activated Sludge (IFAS) Systems with Biological Phosphorus Removal

Introduction

In industrialized countries, activated sludge is the most ubiquitous water treatment technology for biological removal. This process - though well studied - is significantly impacted by the settleability of the solids present in the system. With increasing pressure to reduce impacts on the environment, wastewater treatment facilities are in continuous search for improved methods to treat the wastewater while addressing the settling of solids. Poor settling leads to increased solids treatments costs, decreased disinfection rate, increased presence of solids in the effluent, and increased public health hazards and ecosystem degradation (Hyun-su et al., 2010). Along with the need to diminish the physical, chemical, and ecological footprints, regulations that require better nutrient removal (particularly nitrogen and phosphorus) become increasingly stringent.

Integrated Fixed-film Activated Sludge (IFAS) (anaerobic/aerobic with returning activated sludge) has been gaining popularity as it enhances overall reactor performance of by creating suspended growth systems with biomass development attached to the solid media (Hyun-su et al., 2010), while allowing the co-generation of suspended sludge along the attached biomass in a single bioreactor. This allows the decoupling of the solids retention time (SRT) enabling higher biomass concentration and volumetric treatment capacity compared to conventional systems (Jabari et al., 2016). IFAS also has the ability to promote full nitrification-denitrification (Hooshyari et al., 2009) of incoming wastewater. Moreover, it enables reduced footprint and better removal of composites of anthropogenic origin (Waqas et al., 2020). With over 90% chemical oxygen demand (COD) and ammonia removal, IFAS is an attractive alternative to retrofit existing facilities as it does not require the construction of new reactors, while providing the aforementioned benefits (Hyun-su et al., 2010).

Simultaneously, the effectiveness of IFAS in removing phosphorus is not as extensively documented as the effects on nitrogen. Phosphorus is usually removed through chemical precipitation, biological precipitation by PAOs (Polyphosphate Accumulating Microorganisms), crystallization, and biosorption, but these processes are very sensitive to change and usually produce excess sludge (Hooshyari et al., 2009). Due to its slow natural cycle, phosphorus is a scarce mineral that is crucial for the phosphate and agricultural industry (fertilizers), and the need to maximize the recovery rate in nutrient rich wastewater is fundamental for a more sustainable system. One of the most common processes involved in phosphorus removal is known as Enhanced Biological Phosphorus Removal (EBPR) which relies on the production of phosphate by PAOs through the breakdown of Poly-p in anaerobic conditions (no oxygen or nitrogen present). Studies have shown that, even though possible, there are several factors affecting the coupling of these technologies to attain reasonable COD reduction, nitrogen, and phosphorus removal: the biomass distribution between suspended and attached growth media, the presence of carbon source in the anaerobic zone (Jabari et al., 2016), and the static nature of biomass, fixed in one specific location (Hooshyari et al., 2009).

One potentially major advantage - not fully explored - of EBPR-IFAS systems is that it allows for the simultaneous growth of rapidly growing heterotrophs including PAOs and denitrifiers and slowly growing nitrifiers, thus enabling separate SRT control for optimized effluent quality. This assumption is based on the theory that denitrifiers and PAOs prefer to circulate in the mixed liquor, as PAOs require alternating aerobic/anoxic/aerobic conditions, while nitrifiers prefer remain attached on the carrier media (Onnis-Hayden et al., 2011).

Phosphorus removal has been a challenge for treatment plants, as increasingly strict discharge limits are enforced, requiring more advanced treatment processes. These processes come with a higher operating cost, so a more efficient system can help a facility save money while still meeting regulatory limits. When compared to other advanced treatment methods such as the Modified University of Cape Town process, five-stage Bardenpho Process, and membrane bioreactors, the IFAS-EBPR was the most cost-efficient process (Bashar et al., 2018). This was primarily due to low chemical requirements and ability to change SRT without reducing nitrification ability (2018). The IFAS-EBPR system was found to cost $42.25 per lb of P removed, while membrane bioreactors cost $60.89 per lb of P removed (2018). As such, IFAS-EBPR could be a successful option for advanced treatment.

Recent Studies and Applications of IFAS/EBPR

While IFAS systems have been in use at some full-scale treatment plants for over two decades, the addition of EBPR to the set-up has only recently been studied and implemented (Copithorn et al., 2006; Onnis-Hayden et al., 2008). A 2008 study by Onnis-Hayden et al. examined the performance of IFAS-EBPR at a full-scale plant for the first time. Their study focused on the ability of the IFAS-EBPR system to successfully maintain a population of N- and P-removing organisms (Onnis-Hayden et al., 2008). They found that the system was able to maintain a population of PAOs, but only measured P uptake rate (2008).

Nutrient removal was examined at a full-scale IFAS-EBPR facility (Bai et al., 2016). They observed 80% COD removal efficiency over variable influent concentrations high nitrogen removal (2016). Effluent ammonia concentration was variable, effluent nitrite concentration was nearly undetectable, and nitrate was the dominant N-species in the effluent (2016). These results indicate that near complete nitrification occurred, resulting in > 95% removal efficiency of ammonia and average total nitrogen removal of 70% (2016). Total phosphorus removal ranged from 68 to 90% depending on influent P-concentration, but was found to increase with higher influent COD levels (2016). Organic substrates are consumed by PAOs and transformed into PHAs in the anaerobic zone, which then serve as an energy source for PAOs in the aerobic zone, increasing P-removal (2016).

IFAS-EBPR displayed steady COD removal and capacity to resist variable organic loading and was able to reduce N- and P-concentrations to below discharge requirements (Bai et al, 2016). It was also found to be highly cost effective when compared to other advanced treatment processes (Bashar et al., 2018). Based on research of its performance at both pilot plants and full-scale treatment plants, IFAS-EBPR is a promising new biotechnology for wastewater treatment.

Orange County Sanitation District Applications of IFAS-EBPR

The OCSD NPDES permit does not currently have any effluent restrictions on phosphorus, and is only limited on ammonia for the shorter of the two ocean outfalls. Because of this, it's reasonable to assume that the influent to the two OCSD plants does not have high nutrient concentrations. In turn, IFAS-EBPR may not be an appropriate treatment technology to utilize at OCSD. IFAS-EBPR should instead be a considered technology for influent waters that have high nutrient concentrations or if the discharge locations have ecosystems that are highly sensitive to nutrients and/or are prone to eutrophication.

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