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EnviTreat

TECHNICAL WHITE PAPER

MUNICIPAL ENHANCED NUTRIENT REMOVAL PLANT OPERATIONS

Common Issues, Remedies, and Opportunities for Improving Operational Efficiency

ABSTRACT

The move toward enhanced nutrient removal (ENR) in wastewater treatment plants has been gaining ground for some time and is the future of wastewater treatment. Proper operation of ENR plants requires an understanding of the fundamentals behind their operation and the issues that may arise that could cause these systems to have poor or inadequate treatment outcomes or failure. This paper is intended to briefly address these issues. An introduction to biological operations for carbon, ammonia, and nitrogen removal is presented. In addition, operational controls based on solids retention time (SRT), the effects of varying SRT, and proper control of SRT is discussed. A method for optimizing SRT using oxygen uptake rates is presented. The importance of macro (nitrogen and phosphorus)- and micro- nutrients (trace minerals) and their effects on plant performance is described. The impact of industrial discharges to a municipal plant—especially chemicals such as peroxyacetic acid (PAA) and quaternary ammonium compounds (Quats)—and their effect on optimum oxygen uptake rate (OUR) and SRT is also described. Finally, case studies are presented throughout the paper to illustrate topics and findings discussed.

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BACKGROUND

The impact that wastewater places on the environment has been a concern for decades. Initially, environmental impact was reduced by control and reduction of organics in wastewater discharges. Lower organic loadings on waterbodies substantially reduced oxygen demand and concurrent environmental effects such as fish kills due to fish asphyxiation. Subsequently, recognition that nitrogen and phosphorus discharges were responsible for lake and stream eutrophication further spurred activity and research into methods for lowering or removing those elements from wastewater discharges. Success in mathematical modeling, especially of nitrification kinetics, fostered rapid progress in and understanding of how to reduce nitrogen in effluents. Processes designed to take advantage of advances developed steadily from the 1960's into the 1990's. Concurrently to some extent, advances were being made in biological phosphorus removal and physical/chemical methods to treat phosphorus in final effluent.

Biological nutrient removal was introduced to the Chesapeake Bay region in 1984.[1] The development of nutrient removal strategies both in the USA and in Europe led to the production of several Nutrient Control Design Manuals by the USEPA. These manuals describe the use of both biological and physical/chemical techniques to achieve reduction in organics, nitrogen, and phosphorus in wastewater discharged to receiving streams. The term "enhanced nutrient removal" (ENR) is somewhat vague but the goal of the "Enhanced Nutrient Removal Program" is described on the Maryland Department of the Environment (MDE) web page as: "…plants are expected to reduce total nitrogen and phosphorus in the wastewater down to 3 mg/L and 0.3 mg/L total phosphorus…".[2] Sixty-seven major wastewater treatment facilities in Maryland were targeted for ENR upgrade with 65 upgrades completed by 2020.[3] The nature of the process upgrades for the facilities is beyond the scope of this paper. Upgrade technology selection varied in accordance with the condition of the facilities and multiple other site and wastewater characteristics.

The purpose of this paper is to:

1. Review the methods of nutrient removal and characteristics of the methods.
2. Describe commonly observed issues at ENR facilities based on EnviTreat's experience in identifying and diagnosing process issues.
3. Present an operational control strategy that relies on solids retention time (SRT) as the controlling parameter for ENR facilities.
4. Describe common toxicants that effect facility operation and the threshold toxicity for theses toxicants.
5. Describe methods for detection, correction, and recovery of a plant from toxic impact based on EnviTreat's experience using oxygen uptake rate (OUR) data.

[1] Cadmus Group, pg. 1-2
[2] Maryland Department of the Environment, https://mde.state.md.us/programs/water/BayRestorationFund/Pages/evolution_enr.aspx
[3] Maryland Department of the Environment, https://mde. maryland.gov/programs/Water/BayRestorationFund/Documents/7-21-BRF-WWTP%20Update%20for%20BayStat.pdf

NUTRIENT REMOVAL METHODS

ORGANIC REMOVAL

Organic compounds are composed of carbon with varying amounts of hydrogen, oxygen, nitrogen, and other trace materials. These materials are consumed by many organisms as a source of energy and as food for growth. Microbiological organisms that consume organics as a source of cell carbon are called heterotrophs. In this paper, we will generally be considering the readily biodegradable organics that exist in typical domestic wastewater. There are a number of organics such as halogenated species that are more difficult to degrade or are non-biodegradable.

Wastewater treatment involves reduction of organic material to a low level, typically below 30 mg/L.To achieve these low levels, aerobic biological systems are typically required.

Anaerobic systems are also capable of removing organics in wastewater. However, reduction to the very low levels required for ENR is difficult. Anaerobic processes will not evaluated in this paper.

The aerobic removal of organics progresses according to the following simplified equation:

$$\text{Organic substrate} + O_2 \longrightarrow CO_2 + \text{Biomass} \qquad (1)$$

The organics that go into Equation 1 supply the biomass with both carbon for energy and for cell growth (biomass production). Heterotrophic organisms need a supply of oxygen and their numbers can require so much oxygen that they cause the depletion of oxygen in rivers, lakes, and waterbodies in general. Oxygen depletion can cause the suffocation of fish and other aquatic life.

The reactions occur best at a pH range of 6.5 – 8.5 but can happen outside of this range. Low temperatures cause the reactions to slow. Very high temperatures can be problematic and can kill biomass. Temperatures above 100 degrees Fahrenheit may cause sterilization (death) of the biomass and should be avoided.

Growth of heterotrophic biomass requires that adequate nitrogen, phosphorus and micronutrients be present. These are used in the formation of proteins, enzymes, and to facilitate chemical reactions within the cells. EnviTreat analyzes cell composition on a regular basis for municipal and industrial clients to evaluate the health of biological systems and has developed a typical nutrient and mineral content for cells in wastewater treatment facilities (Table 1).

NUTRIENT/MINERAL	ENVITREAT % CELL	OTHERS[4]
Nitrogen	7%	12%
Phosphorus	0.80%	2.00%
Potassium	0.50%	1.00%
Calcium	2.00%	0.50%
Magnesium	0.25%	0.50%
Sodium	0.40%	1.00%
Iron	0.10%	0.20%
Zinc	0.09%	
Sulfur	0.10%	
Copper	0.02%	
Cobalt	0.006%	
Selenium	0.002%	
Nickel	0.002%	
Manganese	0.010%	
Molybdenum	0.002%	
Boron	0.002%	

Table 1 | Typical Wastewater Treatment Biomass Nutrient and Mineral Composition

Biomass content in a biological reactor is typically measured as mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS). However, only a fraction of these solids are active and at work degrading organics that enter the wastewater plant for treatment. EnviTreat routinely measures the activity of biomass samples and has observed that healthy activated sludge plants have a biomass which is 15% - 30 % active biomass. Others have posited higher active biomass proportions.[5] Activity tests also reveal the presence of extracellular polymeric substances (EPS) which is an indicator of reactor stress and can cause sludge bulking and poor effluent quality (Figure 1).

[4] Chen, pg. 17
[5] Chen, pg. 128

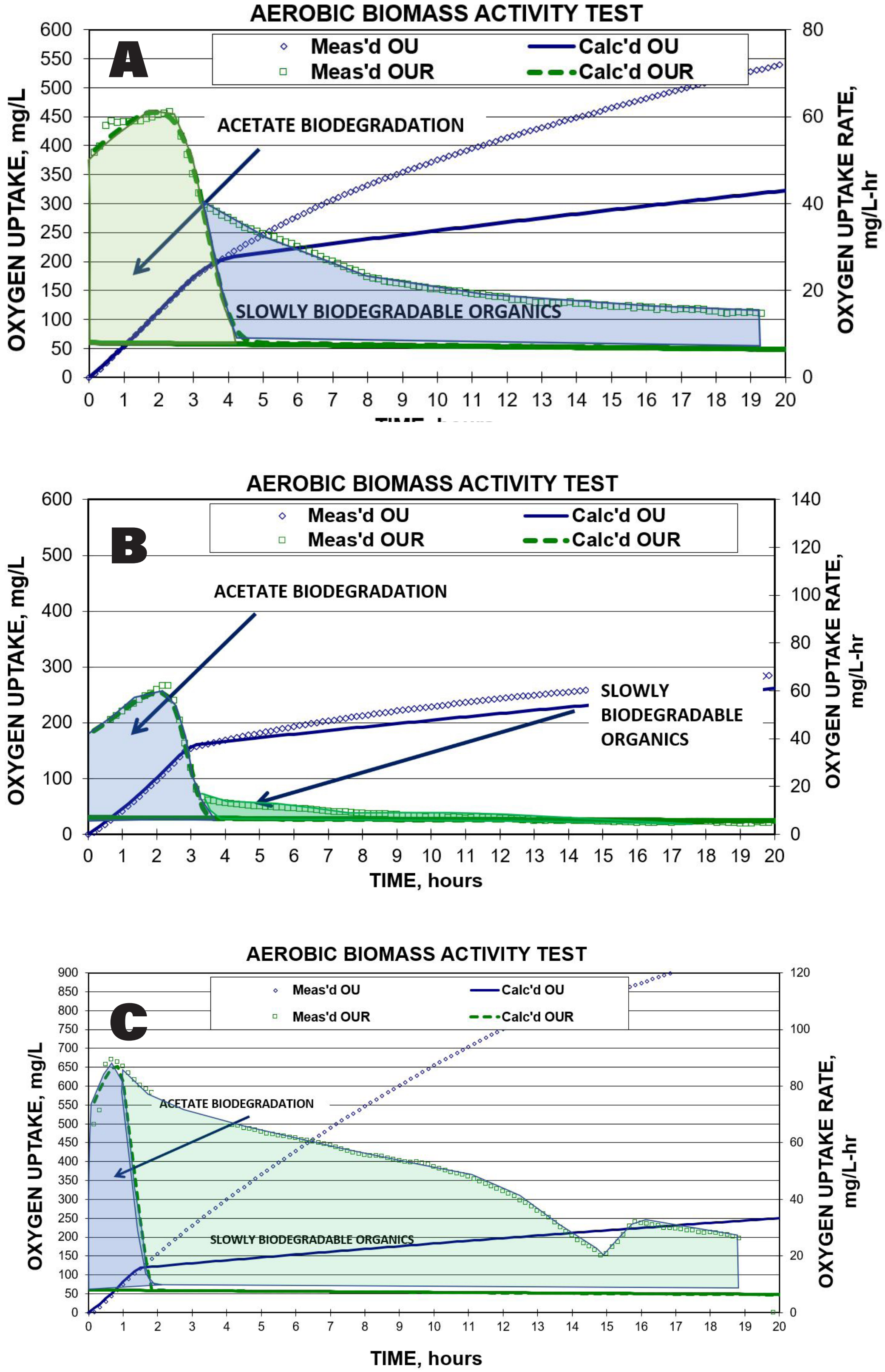


FIGURE 1 | A) Municipal MBR with 5.5% activity and moderate slowly degradable material. B) Landfill MBR with 3.5% activity and very low slowly biodegradable material. C) Brewery suspended growth system with 16% activity and very high slowly biodegradable material.

CASE STUDY

An industrial manufacturer had major problems with sludge bulking and poor effluent quality. Sludge bulking was causing high effluent TSS that was blinding the effluent filtration system. EnviTreat analyzed the biomass and the sludge and discovered excessive amounts of biopolymer and nutrient deficiencies in the biomass. A recommended nutrient supplement formula was created and given to the operator. Two weeks after adding nutrient supplementation the plant MLSS turned bright green as the biomass began to adjust to the new nutrient. Three weeks after nutrient supplementation the MLSS had returned to normal color and biopolymer had been reduced to levels typically seen in healthy treatment systems. The plant has been able to meet effluent requirements since that time.

NITROGEN REMOVAL

Nitrogen is a major component of wastewater. It typically enters the treatment system in the form of Total Kjeldahl nitrogen which is composed of ammonia nitrogen and organic nitrogen. Organic nitrogen is typically released as ammonia during the course of wastewater treatment as the organics that it was associated with are degraded.

Nitrogen is necessary for cell growth so some removal is achieved during normal growth of organic consuming microoganisms. In industrial systems it is common for the wastewater treatment system to need nitrogen supplementation to ensure enough is available for cell growth. In municipal systems, however, nitrogen is typically present in excess of the quantity needed for cell growth. Ammonia is most efficiently and cost effectively removed through the biological processes of nitrification and denitrification. Nitrification is a series of steps in which a population of bacteria convert ammonia to nitrate. Denitrification is a process by which another population of bacteria use the oxygen attached to nitrate and reduce the nitrogen to gas which is released into the atmosphere.

All reactions relative to nitrogen are sensitive to temperature and slow down considerably at low temperatures. Low temperature operation requires a larger biomass population to perform the same reactions in a similar amount of time. Upper temperature limits are similar to those of organic reactions and should not exceed 100 degrees Fahrenheit.

Nitrification

Nitrification is a stepwise transformation in which ammonia is first transformed into nitrite (NO_2^-) and then to nitrate (NO_3^-). The microbial communities that perform this transformation are autotrophic and use carbon dioxide as the carbon source for cell growth. They use the transformation of ammonia as a source of energy requiring oxygen to affect the transformation. The simplified reaction for the series of steps in growth and ammonia conversion is provided in Equation 2.

$$NH_3 + O_2 + CO_2 \longrightarrow NO_3 + \text{Biomass} \qquad (2)$$

There are a number of bacterial populations that perform this transformation. The population that is generally associated with the conversion of ammonia to nitrite is most important with regard to nitrification because it is the rate limiting population, slow growing, and is generally the most sensitive to toxic impact or process upset. The characteristics of this population have several consequences for ENR system operation:

1. The hydraulic detention time in the nitrification reactor must be sufficient for the nitrification reactions to occur.
2. The SRT of the system must be long enough that nitrifying biomass is not washed out due to their slow growth.
3. Toxicity to the system will affect nitrifiers first and result in poor nitrification.

Nitrifiers require sufficient oxygen for nitrification. Approximately 4.33 grams of oxygen are needed to convert 1 gram of ammonia-N. This takes into account the amount of nitrogen taken up by the organisms for cell growth. Nitrifiers can be very sensitive to low oxygen levels and levels below 2 mg O2/L can cause nitrification inhibition.

Nitrification consumes quite a lot of alkalinity. Conversion of 1 g of ammonia-N requires 7.14 g of alkalinity. This means that close observation and control of alkalinity is required in a nitrifying system. If all the alkalinity in a system is consumed, pH of the system will be very difficult to control and likely drop to levels that will kill the biomass.

Nitrifiers perform best a pH of 7 – 8.5. If pH is outside of this range, nitrification will either cease or be sub-optimal.

Nitrifier activity can be determined in a system in a manner similar to the determination of organic bacterial activity. Normal active nitrifier population is 1%-3% of the VSS concentration.

Due to the slow growth of nitrifiers, a long SRT must be maintained to allow sufficient time for nitrifiers to grow and avoid biomass washout. Typically, manuals show a SRT of 5 – 10 days being required to avoid washout. However, the entire volume of the system, including anoxic areas must be considered in the SRT as nitrifiers are being recycled through the entire system and cannot grow in anaerobic or anoxic conditions. In practice, an SRT of 15 – 20 days is typically needed to maintain a stable and healthy nitrifier population.

Denitrification

In denitrification, a consortium of heterotrophic bacteria uses the nitrate molecules as an oxygen source and reduces nitrogen to N2 which is released harmlessly to the atmosphere.

These organisms require enough carbon to support cell growth. The simplified equation for denitrification is presented in Equation 3.

$$\text{Organics} + NO_3 \longrightarrow CO_3 + \text{Biomass} \quad (3)$$

Denitrification is most effective in environments that do not contain dissolved oxygen as O2. This is called an anoxic environment. Optimal pH for denitrifiers is 7 – 8.

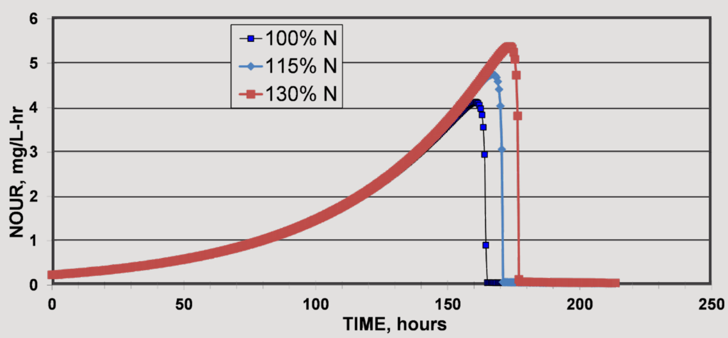
Denitrification results in the release of alkalinity and 3.57 g of alkalinity can be recovered per g nitrate-N denitrified. Theoretical COD requirement for denitrification is 3.66 g COD/g NO3-N. Typical loading for denitrification is 0.10 g NO3-N/g VSS/day

Denitrifiers are essentially the same population of organisms that perform organic carbon reduction reactions and thus are similarly sensitive to toxicants. They are faster growing and more robust than nitrifying populations.

CASE STUDY

A membrane bioreactor (MBR) system treating landfill leachate primarily for nitrogen removal was having problems with nitrification. The system was designed for a flow of 75,000 gallons per day but was only receiving 54,000 gallons per day. The operators were trying to increase the flow to the plant to reach design capacity. However every time the flow was increased, effluent ammonia would rise above permitted limits forcing the operators to lower feed rates. A nitrifier activity test was performed and showed that the nitrifier population was only 0.01% of the biomass. Increases in loading required extended detention times within the reactor for complete conversion to nitrate. An increase in nitrogen would take several hours more to be converted to nitrate. With the slow glowing nitrifiers, this meant that increases in ammonia loading needed to occur very gradually. This process is still ongoing at the plant. Figure 2 shows an example of nitrogenous oxygen uptake rate and the extended time needed to consume increased amounts of nitrogen.

FIGURE 2 | Nitrogenous oxygen uptake rate (NOUR) when a reactor was fed 100% of normal loading, 115% of normal loading, and 130% of normal loading.



PHOSPHORUS REMOVAL

The second major nutrient to be removed by ENR plants is phosphorus. Phosphorus exists in wastewater as an organic or as phosphate (PO43-). Phosphorus, unlike nitrogen, is a relatively uncommon element and is not contained in the atmosphere. However, it is essential for biological growth. Phosphorus can be removed by both biological and physical/chemical methods. Biological methods can be effective for phosphorus levels typically seen in municipal plants. Removal of phosphorus to very low levels typically requires some form of physical/ chemical co-treatment.

Biological P Removal

Biological phosphorus removal occurs when microorganisms take phosphorus into their cells from the wastewater. Wasting of biomass removes the cells from the wastewater and the phosphorus they contain along with the cells. A small amount of phosphorus is taken up by cells as a normal part of growth. Cell phosphorus content was shown in Table 1. Phosphorus often needs to be supplemented in industrial wastewater treatment systems to allow for proper biomass health. In municipal systems, phosphorus removed by cell growth is not enough to satisfy ENR goals. There are, however, a group of organisms known as phosphorus accumulating organisms (PAOs) which can take additional phosphorus into their cells and increase the biological removal potential of biomass. Biological phosphorus removal uses the biological characteristics of these PAOs to encourage their growth. With large populations of PAOs in the system, large masses of phosphorus can be removed from the wastewater.

PAOs are organisms that form polyphosphates under aerobic conditions. When placed in anaerobic conditions, the polyphosphates are used to allow the cells to accumulate organics in the form of poly-β- hydroxyalkanoates (PHAs). When the cells are placed back into aerobic conditions the stored PHAs are used for cell growth and new polyphosphates are formed both in old cells and in newly grown cells.

The key to biological phosphorus removal is creating conditions where the PAOs can compete well with other heterotrophic organisms. This requires that there be a high content of volatile fatty acids and a completely anaerobic environment. PAOs have high yield and decay slowly so SRTs of 3 – 5 days suit them well. System pH that is acceptable for other biological processes is acceptable for PAOs although slightly higher pH ranges have been shown to give them somewhat of an advantage in the anaerobic step of the process.[6] PAOs are relatively tolerant to toxicants however the presence of oxygen and nitrate (oxygen source) in the anaerobic step reduces phosphorus uptake, most likely due to ineffective competition for organics in an environment that contains oxygen.

A large number of process configurations have been developed to take advantage of PAOs and encourage their growth.[7] Some of these are shown in Figure 3.

[6] Chen, pg. 255
[7] Cadmus Group Inc.

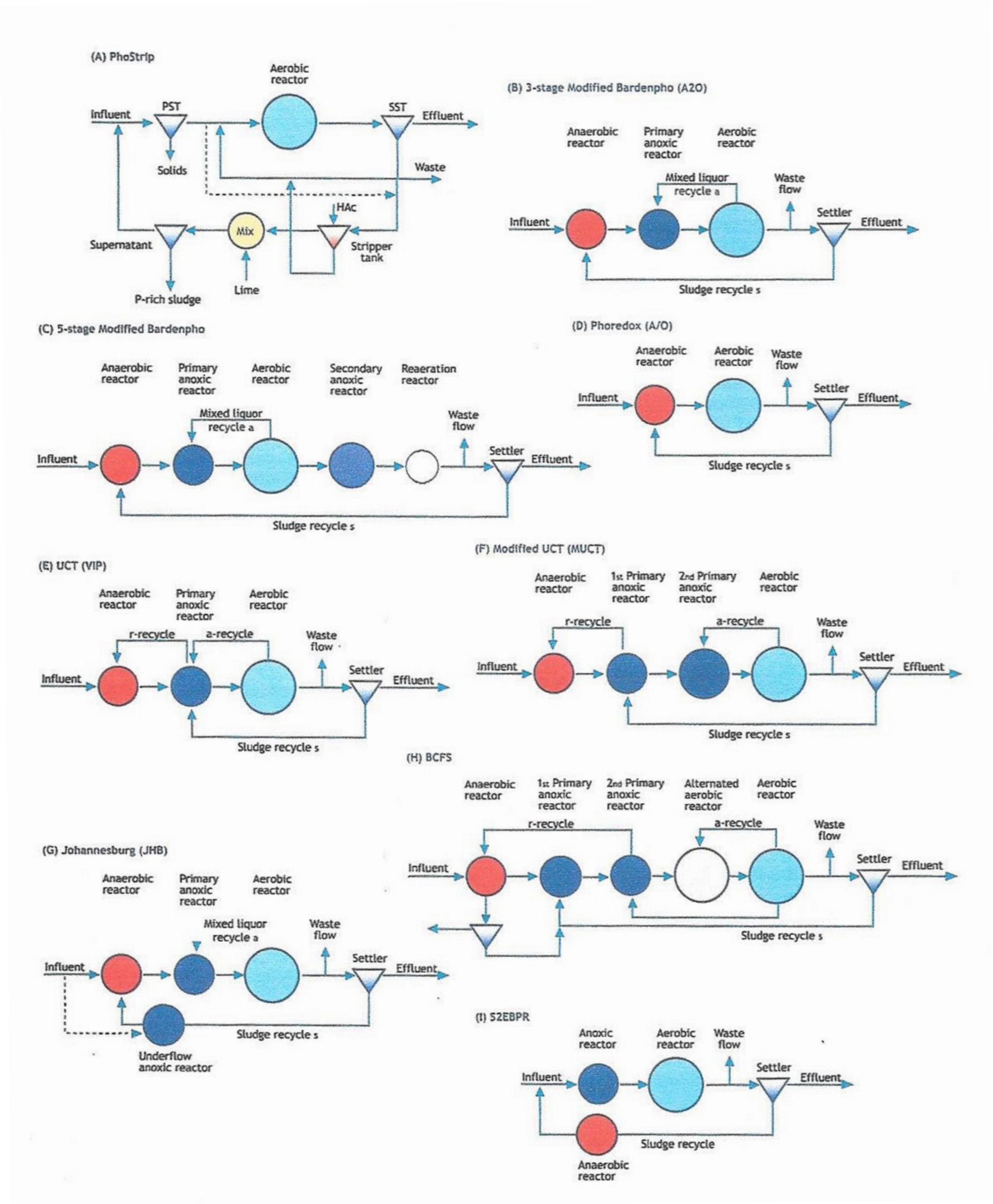


FIGURE 3 | Various process configurations for biological phosphorus removal.[8]

[8] Chen, pg. 255

Physical/Chemical

Physical/chemical methods of phosphorus removal typically involve the addition of metal salts such as aluminum, iron, or calcium to precipitate phosphorus out of solution. Settling alone is often sufficient to meet ENR requirements but to reach very low levels of phosphorus, filtration is often required. This can be achieved with a number of filtration mechanisms. Adsorption of phosphorus onto media such as granular ferric oxide is an effective method to remove phosphate from solution but requires concurrent filtration, often with the same media used for adsorption, to remove trace phosphorus contained in colloidal organics.

CASE STUDY

A large brewery had a 5 MGD biological treatment system. The purpose of the system was to remove both organics and phosphorus from the brewing process. A new tertiary filter with chemical coagulant was added but the system was still not meeting their total. The biomass was analyzed and discovered to have significant amounts of biopolymer as well as being deficient in nitrogen as well as some other trace minerals. A site visit revealed that the bulking caused by the biopolymer was causing the tertiary filter to be overloaded leading to breakthrough of colloidal organics containing phosphorus. In addition, sludge was discharged to a holding pond daily. The pond was cleaned yearly. Each day, the amount discharged to the pond was returned to the head of treatment plant. Due to the conditions in the pond, phophorus that had be captured in the biomass and by chemical removal was released. The return liquid from the pond had high phosphorus content which increased the phosphorus loading on the plant. The solution was to provide nitrogen and micronutrients to the biomass so that biopolymer would be reduced and the tertiary filter could work properly.

CASE STUDY

EnviTreat has been performing tests on fish hatchery effluent with the goal of reaching very low phosphorus limits. The goal of the project is to reach an effluent total phosphorus concentration of 0.025 mg/L P. A number of technologies are currently being tested. The test results have shown that a number of ways can be used to meet these low limits. The apparent easiest to implement is simple coagulation/flocculation with the addition of sand filtration. The current testing uses a sand filter with 1.2 mm dimeter sand particles followed by a sand filter with 0.6 mm diameter sand particles. This method is able to achieve effluent total P of <0.015 mg/L P.

SYSTEM CONTROL USING SRT

A typical parameter used by operators to control biological systems is MLSS or MLVSS in the reactor. The target solids concentrations for systems are typically developed during design and are carried through the life of the system. The solids concentration is developed based on a mass of mixed liquor in the system that takes into account biomass growth, decay, and sludge wasting. This method of control can be applied successfully because daily influent flow and characteristics are relatively stable. However, changes in the character of the both the system and influent over time make use of design MLSS concentrations misleading. Especially in the frequent case where systems are overdesigned due to safety factors applied to design to ensure effective treatment.

The reliance on MLSS concentration as a control parameter often leads to systems with MLSS concentrations that are far above what is required or desirable for a particular system. Excess MLSS in a system can have a number of undesirable consequences:

1. Reduces the proportion of active microorganisms in the biomass
2. Reduces the efficiency of air transfer to the active biomass
3. Increase the power needed for pumping sludge, aeration, and other system operations
4. Increases the loading on membranes decreasing their efficiency
5. Increases SRT resulting in poor sludge settling characteristics

The proportion of active biomass in a mixed liquor is important as these organisms are doing the work and, in the case of PAOs, accumulating and removing phosphorus. Low active biomass proportions in a system mean that a system is not as well able to react to varying influent conditions and more susceptible to system upset. A system with mostly inactive biomass cannot be loaded at the same rate per unit biomass as a system with a high proportion of active organisms.

A large mass of inactive biomass in a system causes all the mechanical units and possibly some of the chemical units in the system are being used inefficiently. Pumps need to pump more sludge, aeration transfer efficiency is reduced requiring more aeration power, and membranes have increased loadings requiring more frequent cleaning and reduction in membrane lifespan. The additional inactive material has no positive benefits to system operation.

EnviTreat has observed many instances that optimum settling in achieved at SRTs in the range of 5 – 20 days. As SRTs begin to extend to beyond 20 and to 40 days, Slude Volume Index (SVI) and other settling characteristics become poorer. This decline in settling characteristics affects the ability of clarifiers to operate and increases the amount of chemical needed to achieve effective settling (in cases where chemical is used).

Operating a system based on SRT is relatively simple and requires wasting a set volume of mixed liquor from the aerated portion of the system daily. The wasting should be performed during the aeration cycle while the basin is well mixed. A common practice is to waste sludge from the underflow of the system. This practice is to be discouraged because the concentration of sludge in the underflow is variable and mass of wasted material is not consistent from day to day. The concentration of solids in the well mixed portion of the reactor, on the contrary, is very consistent from day to day[9] (Figure 4).

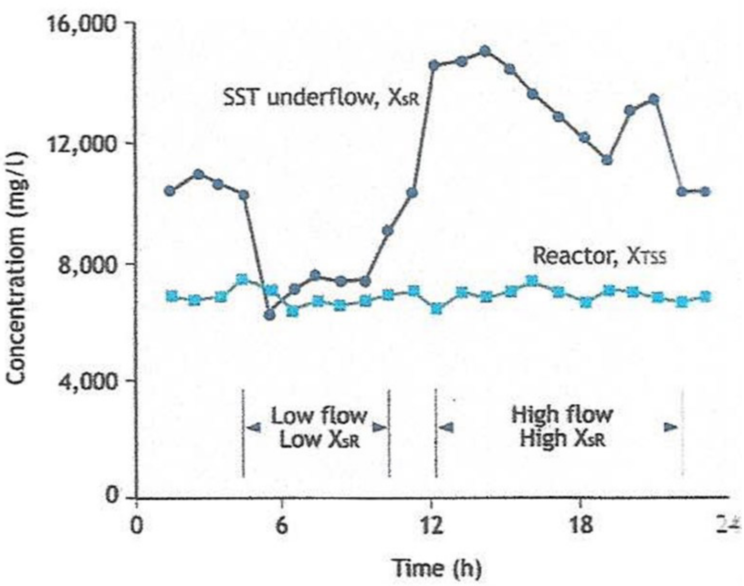


FIGURE 4 | Underflow VSS in comparison to reactor TSS.[10]

The wasted volume should be the volume of the entire system divided by the target SRT. Volume of the system should include anerobic and anoxic zones in the system as sludge is constantly being recirculated though the entire system. This strategy will allow a constant SRT to be maintained regardless of the daily flow or changes in loading. The system will then self-correct for changes in loading, flows, and season.

Membrane bioreactor (MBR) systems are often operated at very high SRTs simply because they are able to do so. However, these systems are often overdesigned and do not need such high solids content. The majority of the solids in the system are doing nothing but recirculating. This recirculation puts stress on the membranes and pumping systems requiring more frequent cleaning and membrane changeout. The ability of the MBR to maintain very high solids is only useful if the system is receiving loading that requires such high solids content. This ability to maintain high active solids content with loading similar to other suspended growth systems is what allows MBRs to be smaller in size. Operating the system based on SRT control and wasting sludge out of the aerated portion of the system, not the membrane chamber, will allow the system to self-adjust to the appropriate MLSS concentration. At the same time, the benefit of clarified effluent due to the action of the membranes is retained and stress on the membranes is reduced to whatever level is required by the system.

[9] Chen, pg. 142
[10] Ibid

In an ENR system, SRT should be in the range of 10 – 30 days with SRT of 10 – 20 days likely being optimal. This SRT range is long enough to develop a robust nitrifier population and not excessively long causing buildup of useless organic by-products. It also allows wasting of PAOs at a rate that still provides good, if not optimal, phosphorus removal via biological mechanisms.

CASE STUDY

A municipality using an MBR was having problems with early membrane failure. EnviTreat examined the biomass composition and system operating parameters. It was determined that the biomass appeared to be healthy but had excess slowly biodegradable material as well as low activity (<6%). SRT of the system was calculated to be 223 days based on the plant loading. Discussion with the operator revealed that he was wasting at a rate that should have established a 46-day SRT. This finding along with microscopic fibers observed under the microscope suggested that excessive solids were being discharged into the treatment plant and should be removed to improve plant performance. EnviTreat advised the municipality that replacement or upgrade of their primary influent screening would likely improve plant performance. Subsequent investigation by operations staff discovered that the influent screening mechanism was not working properly. Once the screening mechanism was fixed, the plant was able to operate much more effectively.

TOXIC IMPACT OF VARIOUS CHEMICALS

Toxic impacts on ENR systems are usually caused by discharge of chemicals from industrial users. These users may have a unique chemical that causes toxicity to the system or use a widely accepted chemical in proportions that cause toxicity to the municipal biology. In the cases where a new industrial user is going to be put online, EnviTreat recommends that the effluent from the new user be evaluated for its effect on the municipal system. This type of testing is performed regularly by some municipalities as their industrial users change processes, chemicals, or materials manufactured (such as vaccines). This testing applies to landfill and other discharges to the municipality which are not necessarily industrial in nature but have characteristics that differ from those of municipal wastewater and may be variable over time.

Chemicals the EnviTreat has routinely observed to cause problems at treatment plants are:

- Peroxyacetic acid
- Quaternary ammonium compounds
- Tertiary amines
- Sodium dodecylbenzene sulfonate
- Sodium hypochlorite
- Ethers
- Nonionic surfactants
- Phenols

In the case of these more routine chemicals, the most effective method of determining toxicity is a chemical use survey. The Safety Data Sheets (SDS) and daily volumes used should be evaluated. The chemical loading on the plant should be evaluated based on these to determine whether toxic impact is likely. Analytic methods that rely on testing for a specific chemical in the treatment plant are not reliable and often do not identify the chemical of concern or report incorrect concentrations. This is especially true of chemicals such as peroxyacetic acid (PAA) and quaternary ammonium compounds.

Table 2 shows an example chemical use survey with plant flow rate and volume, commercially available chemicals, and toxic thresholds. In the example, it is apparent that the plant was receiving sodium dodecylbenzensulfonate and hypochlorite loads that should not affect the treatment plant. Quaternary ammonium and PAA loading, however, exceeded the toxicity threshold. Discharge of these chemical should be investigated and reduced.

Chemical Use Survey | 2021		
Volume =	1	MG
Flow =	2000000	gpd
HRT =	0.5	days

Commercial Products	Ingredients	Lb/day average use	SG	Gal/day average use	Chemicals of Concern									
					Quats/ triamines	PAA	SDDBS/ XSA	Hypo chlorite	Polyalkyl ethers	Alkylamine oxides	LGFA	H2O2	Nonionic Surfactants	Phenols
Synergex	Sulfuric acid (30%); Peroxide (10.7%), Alkanesulphonates (10%); acetic acid (5%); Peroxyacetic acid (2.38%)	152.00	1.22	15.0		0.434	1.823					0.195		
Vektor 100	Ethoxylate (10%); Alkylamines (5%); butoxyethanol (5%); primary, secondary, tertiary alkylamines (5%); Propylene glycol (5%)	43	1.02	5.0	0.511		0.255							
Foam 19	Phosphoric Acid (15-30%); Acetic Acid (1-5%); Amines, C12-14 - alkyldimethyl, N Oxides (1-5%); Citric acid (1-5%); 2-(2-Butoxethoxy) etanol; Dipropyleneglycolmonomethylether (1-5%)	42	1.15	5.0					0.250	0.250				
Foam Alkachlor	Sodium Hypochlorite (1-5%); Potassium Hydroxide (1-5%); Sodium Hydroxide (1-5%); Nonionic Surfactant (1-5%)	834	1.13	100.0				5.002					5.002	
Oxivit Aktiv Plus	hydrogen peroxide (15-30%); Acetic acid (5-15%); Peracetic Acid (5-15%)	25	1.10	3.0		0.450						0.900		
Benefit Botanical Decon 30 Disinfectant	Oils, thyme (0.01 - 0.1 %) - (Thymol??)	25	1.01	3.0										0.003
OdoBan	Water (>90%); Isopropanol (4%); Alkyl(C12-16) dimethylbenzylammonium chloride (2%)	83	0.99	10.0	0.198									
Clorox Healthcare Hydrogen Peroxide Cleaner Disinfectant	Hydrogen peroxid (1-5%); Benzyl Alcohol (1-5%)	834	1.00	100.0								5.002		
				Total, mg/L-day =	0.71	0.88	2.08	5.00	0.25	0.25	0.00	6.10	5.00	0.00
				Limit, mg/L-day =	0.5	0.5	5.0	20	40	40	100	20	15	14
				Mixed Liquor, mg/L	0.35	0.44	1.0	2.5	0.1	0.1	0.00	3.05	2.50	0.00

TABLE 2 | Chemical use survey example.

It is important to note that in most systems, the loading in mg/L-day is the most important factor. This is because the discharge comes into the system gradually, not all at once, and due to recycle rates of these complex systems the chemicals are dispersed throughout the plant quickly. However, in cases where a process in the system retains the influent wastewater for a period of time prior to distribution to the whole system, analysis of the load on that smaller unit may be warranted.

SYSTEM RECOVERY USING OUR SETPOINT

Municipal activated sludge systems that receive discharge from industrial facilities may have system upsets from occasional shock loads. The shock loads could be from a number chemical or organic products used by industries in their operations and cleaning activities. In addition, low activity in biomass can leave plants vulnerable to shock loading of high strength organic (high BOD) discharges. When activity is low, a plant has lower capability to adapt to higher-than- normal loading rates. The result of either chemical or organic shock loads is reduced treatment plant performance and poor effluent quality.

OUR setpoint control (OSC) is a method for operating activated sludge systems based on mass of active microorganisms. This method helps optimize mixed liquor suspended solids (MLSS) concentrations, solids retention times (SRT), and sludge wasting rates.

A 6-liter bench scale reactor was seeded with return activated sludge from a local municipal wastewater treatment plant (West Side Wastewater Treatment Facility in Fayetteville, AR). The reactor was operated for a week. Reactor feed stock was ethylene glycol and nutrient solution. The reactor was loaded at 1.2 g COD/L-d. Reactor HRT was 10 hours, SRT was 10 days, F/M ratio was ~0.524. Operating characteristics for the reactor are presented in Table 3 and the reactor setup is shown in Figure 5. Feed and waste schedule is presented in Table 4. A sludge reactor was operated in parallel to the main reactor to be a source of biomass for OSC.

PROCESS PARAMETER	
Biomass Yield, g VSS/g CODr	0.5
Decay rate, /d	0.24
SHT, days =	10
HRT, days =	1.0
Biodegradable Feed COD, mg/L	1200
TKN, mg/L as N	40
LOAD RATE, g sCOD/L-d=	1.20
EXPECTED MLVSS, mg/L =	2289
Expected VSS/TSS, %	85.0%
F/M ratio, kg COD/kg VSS/d =	0.524
Nitr. loading, kg N/kg TSS/d =	0.017

TABLE 3 | Reactor operating conditions.

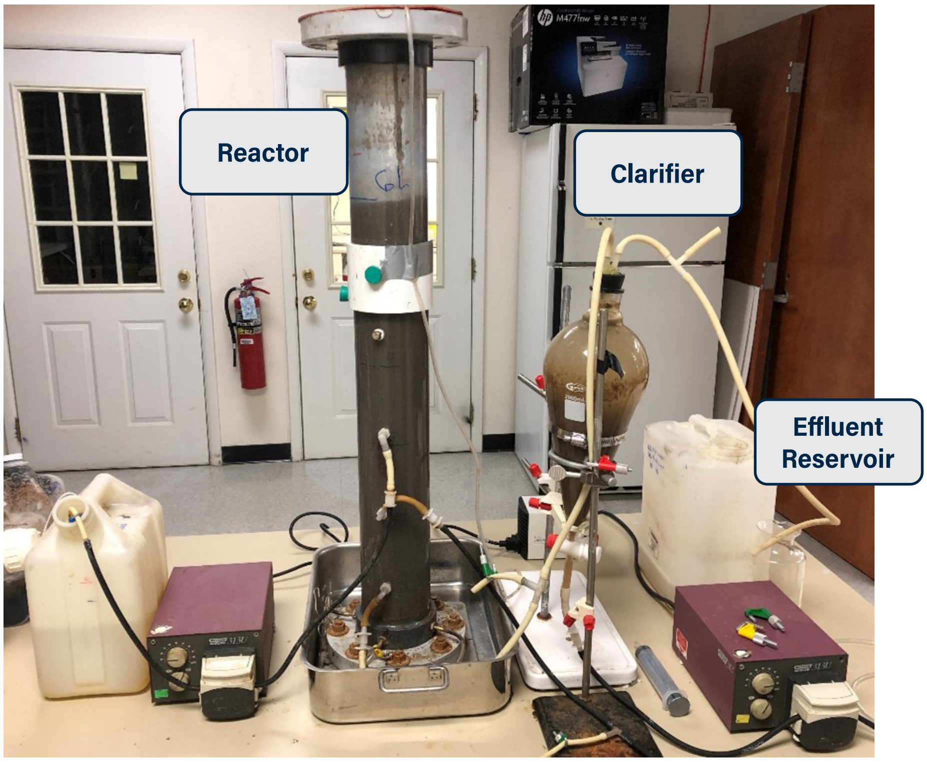


FIGURE 5 | Lab-scale OUR recovery test reactor.

REACTOR	FEEDSTOCK L/day	COD, mg/L	MIXED LIQOR WASTE (ml/day)	REPLACEMENT WATER (ml/day)
Main Reactor	6	1,290	600	600
Sludge Source	6	1,290	600	600

TABLE 4 | Bench reactor and Sludge tank feed schedule.

After a week of operation, the reactor was dosed with 1 ml of 20% quaternary ammonium (quat) disinfectant leading to an applied concentration in the reactor of approximately 35 mg/l quats. Activity testing was performed by taking mixed liquor from the reactor and placing it in 0.5 L serum bottles, adding 400 mg/l of acetate/nutrient and monitoring the oxygen uptake reaction using an aerobic respirometer. A base line OUR test was performed before quat application followed by a second OUR after quat application. Biomass was added from the sludge reactor to approximately double the active VSS and a third OUR test was performed. Results from the quat shock test are presented in Figure 6.

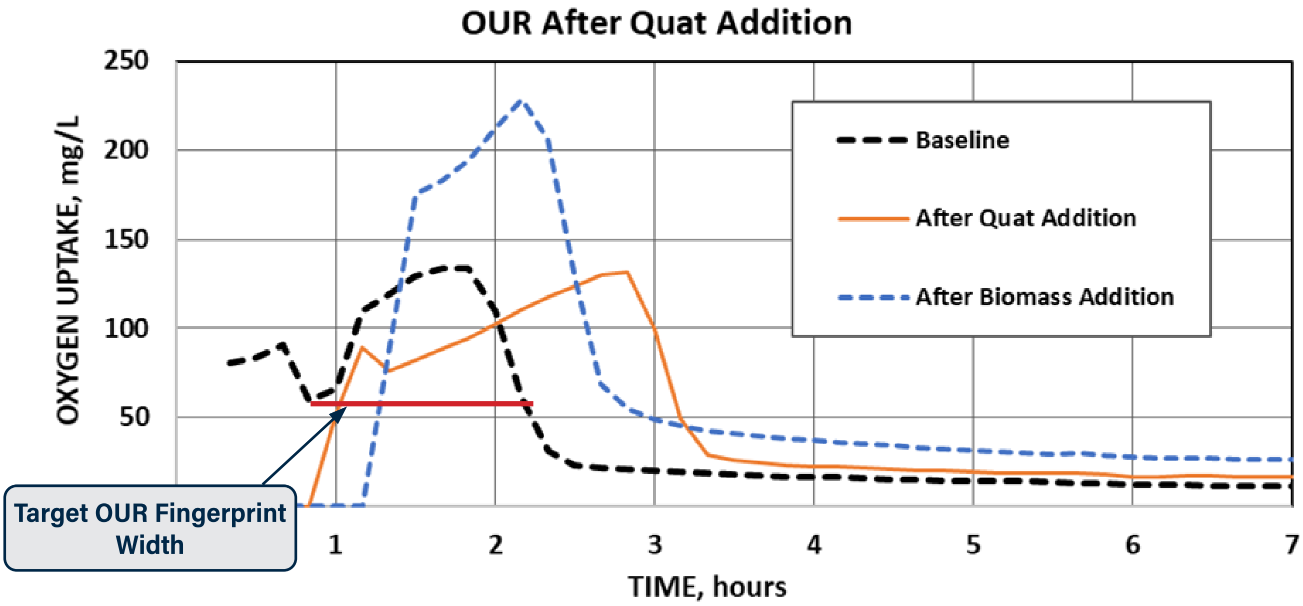


FIGURE 6 | OUR fingerprints for reactor biomass during 35 mg/l shock quat testing.

These tests showed that the quaternary ammonium shock extended the time needed to fully consume the acetate. Increasing the VSS allowed the biomass to consume the acetate in approximately the same amount of time as in the baseline test. In a full-scale system, this would mean that the reactor would be able to process influent waste at the same rate as before the toxic event, thereby leading to stable effluent quality.

Biomass stored in a sludge tank that has not aged excessively could be used to recover systems impacted from chemicals or suddenly high organic loadings. After the addition of sludge, operation of the system as described under the SRT control system would remove excess and biomass out of the system over time.

CONCLUSIONS

ENR systems have been an important development for biological systems over the last half century. With the increasing demand on water resources, it is likely that treatment requirements will become more stringent over time. SRT control of ENR systems allows more stable operation of the systems than MLSS control and enables the system to adapt to changing influent, flow, and temperature conditions. Toxicant impact on systems that receive waste streams other than municipal wastes can severely impair the system's ability to treat wastewater. This is especially true of systems that are designed to remove ammonia as nitrifiers are especially sensitive to chemicals of all kinds. A chemical use survey is the most reliable way to establish toxicant loading and to identify causes of toxic impact. Finally, systems may be able to recover faster from toxicant and organic loadings if they are operated using oxygen uptake as a monitor of system health. A decline in oxygen uptake rate of the biomass can warn of toxic impact and signal that an increase in active organisms is needed to maintain effective treatment. The maintenance of a short-term digester that can quickly provide active biomass in the case of toxic impact may allow systems to recover much more quickly in the case of an upset.

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