Photo by Paul Cockrell Photography

Weak-In Worked Out

Economical modifications help attain better biological phosphorus removal

Jon van Dommelen and Rob Smith

Many small water resource recovery facilities (WRRFs) are turning to biological nutrient removal (BNR) activated sludge upgrades to contribute cleaner water to their receiving lakes and streams and to meet tighter National Pollutant Discharge Elimination System (NPDES) limits on their effluents. Operators care about the detrimental effects of excess nitrogen and phosphorus loads and take pride in the idea of being a steward of the natural environment. However, the new systems often fall short of expectations and may even be in noncompliance with their NPDES permit.

A common problem for achieving biological phosphorus removal at small facilities is weak influent. Conventional BNR requires an ample source of readily degradable organic material in the wastewater to drive the biochemical reactions that convert nitrate to nitrogen gas and dissolved phosphorus to particulates. Unfortunately, many wastewaters do not have sufficient carbon for nutrient removal. Effective process control is one of the keys to overcoming this problem to make the proper adjustments to the wastewater treatment tanks to avoid noncompliance.

BNR requires zone integrity by maintaining three separate environments: anaerobic, anoxic, and oxic. Without proper process control, the tank label may not match the environment. For example, an "anaerobic tank" may actually have an anoxic environment. The environments are defined in terms of dissolved oxygen (DO) and nitrate. However, orthophosphate and oxidation reduction potential are other parameters that provide insight into the environment. From a treatment perspective, the chemical environment is more relevant than how the tank is labelled.

Diagnosing the System

One of the first things that should be done to troubleshoot a noncompliant system is to characterize the environments in each tank by performing a nutrient profile. This involves measuring ammonia, nitrate, and orthophosphate in grab samples taken from the outlet of each tank. With the help of a portable multiparameter photometer, the chemical results can be known in less than 2 hours.

Prior to taking any actions, setting up a datalogging monitoring system can be important for monitoring the environment in each tank. This is especially true during the hours when the WRRF is not staffed, such as in the middle of the night or between diurnal peak flow hours. The monitoring system typically consists of three sets of ammonium, nitrate, and DO probes; one set goes in each of the so-called anoxic, anaerobic, and oxic tanks. Online monitoring enables the effects of any changes to be quickly and continuously displayed or analyzed, even after the fact, to spot patterns that might affect the processes. It also provides an objective evaluation of the effect of process control changes. Not only does this datalogging monitoring system drastically speed up troubleshooting, it also enables operators to directly observe the effects of changes and provides assurances that the process will meet permit limits.

The most common process control remedies for BNR systems involve adjustments to aeration, sludge wasting, and mixed liquor recycle, if the proper controls for these adjustments are built into the treatment system. Sometimes these controls are not built in and this limits the available remedies. In addition, mixing control is a key factor for manipulating the process.

Bradford, Ohio

I was invited to the Village of Bradford, Ohio, because their 4-year-old BNR facility was having trouble meeting its effluent total phosphorus (TP) limit. The WRRF had been out of compliance for all but 9 months its first 53 months of operation.

The Bradford facility is an oxidation ditch system with two small anaerobic tanks in series, a large anoxic tank, and an oxidation ditch with two vertically oriented 20-hp aerators equipped with variable frequency drivers (VFDs) in the oxic tank. It has a design capacity of 1.817 million L/d (0.480 mgd). The current daily average flow is 2.08 million L/d (0.55 mgd) and is heavily influenced by inflow and infiltration. Influent carbonaceous biochemical oxygen demand (cBOD5) averages 95.

First, influent and return activated sludge (RAS) flow into the anaerobic tanks. Then, anaerobic tank effluent flows through a gate on the upstream side of the anoxic tank and nitrified mixed liquor recycle flows through a gate on the downstream end of the oxic tank, and into the anoxic tank to be denitrified. Thus, the Bradford system had two desirable features: adjustable aeration control and mixed liquor recycle control.

The initial nutrient profile showed that all three tanks had pretty much the same environment. Each had 10 to 14 mg/L of nitrate. The ammonia concentration in the oxic zone was below the detection limit demonstrating complete nitrification, but denitrification was ineffective likely due to insufficient carbon or too much nitrate.

Tank profiles. Superintendent Jay Roberts was somewhat skeptical regarding my presence, but curious. Like many operators of small systems, he had not received enough training on the BNR system, let alone on proper process control.

Small system operators typically might check DO or run a settleometer in addition to effluent permit testing. Furthermore, they do not have the time to do more advanced process control testing because of the other duties that demand their attention.

As I worked, Jay watched and asked questions but mostly he just tolerated my presence on that first visit.

Jay's skepticism disappeared when I explained the findings from the nutrient profile. He had never seen this type of analysis but quickly understood the implications and was very interested in how to remedy the situation.

The nutrient profile clearly demonstrated that the system was overwhelmed with nitrate. This is a problem for phosphorus removal. Biological phosphorus removal requires two environments:

- an anaerobic environment deprived of oxygen and nitrate where phosphate release occurs and
- an oxic environment with enough DO to drive the phosphate uptake.

If there is nitrate present in the anaerobic tank then, by definition, it is not an anaerobic environment. Until we could get the nitrate concentrations down, there was no hope to achieve the objective of an effluent TP within his limit of 1 mg/L by only biological means.

Taking action. The first thing we did was to reduce the nitrate recycle by partially closing the recycle gate. The internal recycle was not necessary to meet the conditions of the discharge permit, which did not include a limit for total nitrogen.

The rotor in this tank was run at minimum hertz to gain simultaneous denitrification on the back side of the oxidation ditch. Jon van Dommelen

This worked to some degree. Nitrates fell to around 6 mg/L in the various tanks. We still needed to reduce the nitrate concentration further.

We took drastic measures. Because the system was somewhat advanced, it had a lot of nice features. The oxic tank aerators had VFDs. We turned down the VFD on the upstream aerator from about 55 Hz to 38 Hz (the downstream aerator was already off). The objective was to create conditions for simultaneous nitrification–denitrification on the backside of the oxidation ditch and reduce the nitrate going into the anoxic tank.

The DO in the oxic tank fell to less than 0.30 mg/L. More importantly though, nitrification was sustained. Jay watched the ammonia in the oxic tank effluent from the oxic tank monitoring system. It rose slightly from below the detection limit to about 0.3 mg/L of ammonia, still safely within permit limits. Then we shut the nitrate feed gate completely.

Low DO operation further decreased the nitrates but there was still a problem. The soluble carbon in the wastewater was insufficient to support denitrification of RAS and phosphate release. Since the tank geometry is fixed by the concrete, we had to make other changes to the process to get the bacteria to do what they are supposed to do.

Process control was modified to create a mixed liquor fermentation configuration. The system was mixed intermittently using an in-line mixer. Jay had timers installed on the mixers in the anaerobic and anoxic tanks and we shut the mixers down for 3.5 hours and then turned them back on for 0.5 hours. The objective was to convert the anaerobic and anoxic tanks into a large fermentation zone. In the settled sludge blanket that formed when the mixers were turned off, any nitrate in the blanket would be denitrified. When the nitrates were gone and some bacteria cells would lyse, soluble carbon would be released. This would drive the phosphorus accumulating organisms (PAOs) to release orthophosphate.

The process control scheme responded quickly and worked beautifully. By the second sample of the month, TP was low enough that they were under the monthly permitted average of 1 mg P/L. Jay was convinced enough that he shut off the alum feed. They met the TP limit the next month despite not feeding alum.

Ongoing results and trust. The facility is putting out better effluent at a significant operational cost savings. The monthly average for TP was achieved 6 of the first 7 months of the new operational regime. The one monthly violation for TP load in that interval occurred when the WRRF averaged double the design flow for the month. In addition, the effluent nitrates have been very low as well. The community also saved up to $1,000 USD/month on alum as well as on their energy consumption through efficient operation of the main rotor at near minimum speed and cycling off the anaerobic and anoxic mixers.

Earning Jay's trust was a critical part of a durable solution as he was going to be the person who would ultimately determine success or failure. Jay learned fast and now performs nutrient profiling across his system once or twice per week, and even more frequently if the orthophosphate begins to increase near the 1 mg/L limit.

Since this project, I have been to more biological nutrient removal systems that have not been working as designed. They are mostly, but not exclusively, small systems that do not have enough soluble carbon in their influents to drive the orthophosphate release nor to drive the denitrification in the anoxic zone.

Niles, Ohio

Another system that suffered from this condition and from noncompliance with a total phosphorus limit is the city of Niles, Ohio.

Niles is a fairly large city and recently upgraded its WRRF from an extended aeration to BNR. The upgrade consisted of converting the three diffused aeration oxidation ditches with internal clarifiers into three, three-zone BNR systems with external clarifiers.

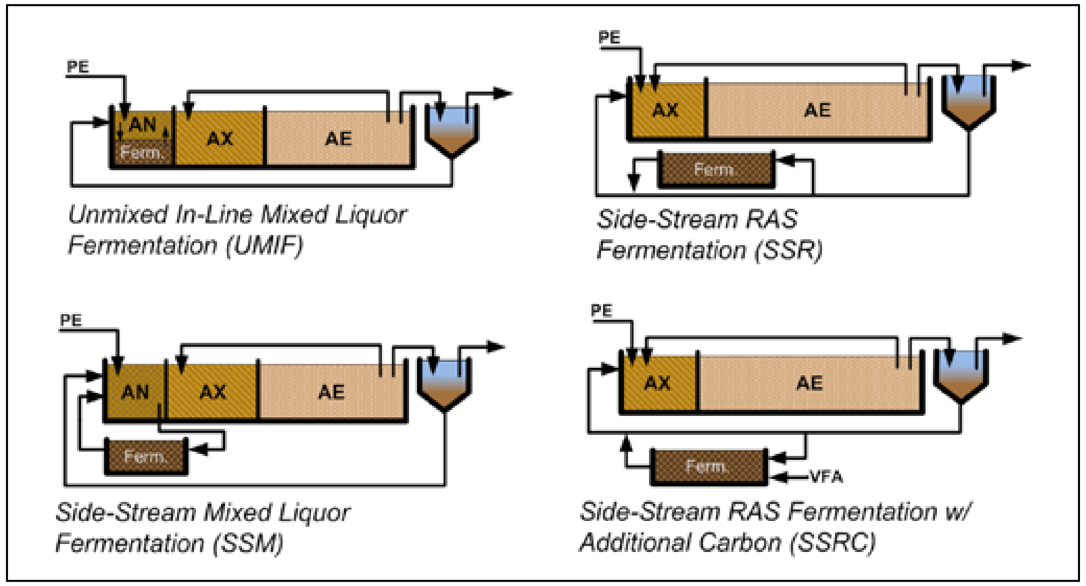
After construction, the WRRF entered its one-year certification period to certify that the treatment system was working as designed and meeting its permit limits. The problem was that the system was not working as designed.

Tank profiles. The operators could not get the treatment system to remove TP down to less than 1 mg/L, which is their monthly TP limit. The superintended called and asked me to come up and evaluate the system.

Before I made the trip to Niles, I pulled the monthly operating reports to check the influent monitoring. As expected, influent $cBOD_5$ typically was less than 100 mg/L. This indicated that there was not enough soluble carbon in the influent to drive orthophosphate release or denitrification.

Taking action. Because the concrete was already a fixed volume, we could not manipulate tank size, but we could repeat what we did in Bradford. We could cycle the mixers on and off. The only problem in Niles was that they did not have timers on their mixers. But they did have operators on duty around the clock. So instead of timers, the superintendent proposed to have his

Figure 1. Several Side-Stream Enhanced Biological Phosphorus Removal Configurations



staff manually turn the mixers off for 3.5 hours and turn them back on for 0.5 hours.

Results. This plan started one week before the State of Ohio went into the COVID-19 "work from home" period. I was not able to go back to Niles to monitor the system, run nutrient profiles, or provide any of the support that I was to offer Bradford. But, as it turned out, I did not need to go back. I worked with the superintendent and the lab technician by phone and text. And soon the treatment processes started to perform.

In fact, once we started cycling the mixers, the total phosphorus concentration dropped to below their permit level. It has stayed there now since April 2020.

Wider Application

I have been able to use this same mixer pattern — 3.5 hours off and 0.5 hours on — at other systems. Because this works, I believe that the "sweet spot" for fermenting mixed liquor must be wide. This pattern is a good starting point to achieve orthophosphate release when the influent has low soluble carbon, but operators should experiment at their facilities to find their own sweet spots.

I stand by the premise that each environment must be conducive to the conditions that will get the bacteria to respond properly. Whether it is shutting down nitrate recycles to flow rates to avoid overwhelming the anoxic and anaerobic zones or shutting off mixers to create the environmental conditions in the settled sludge blanket to coax bacteria to denitrify and the PAOs to release orthophosphate, the environments have to be right.

Likewise, operational staff need to know if the conditions are correct. They need to have the equipment to profile the nutrients frequently enough so that they know that the system is performing properly. Only when the environment of the chemistry inside the tanks match the label will the proper biochemical reactions occur. Process control and creative workarounds on fixed concrete tanks really are the keys for compliance for any BNR system.

Sources for Help

A recent innovation to overcome carbon limitations is sidestream enhanced biological phosphorus removal (S2EBPR). In S2EBPR, a stable source of readily biodegradable COD (rbCOD) is generated by fermenting RAS or mixed liquor. Several S2EBPR configurations are shown in Figure 1 (above). An important feature of S2EBPR is that it can be easily retrofit into existing facilities with conventional EBPR flowsheets. In some cases, it can be implemented with only changes to process control. But in Ohio, problem WRRFs have somewhere to turn.

On the operational side, the Ohio EPA Compliance Assistance Unit (CAU) is a public service to the regulated community of WRRFs. WRRFs can seek help from CAU for no charge to use the CAU. And, importantly, CAU is not part of inspection and enforcement. Public utilities can work with CAU in good confidence without fear of being reported to enforcement.

The CAU visits all varieties of WRRFs that are not working properly. CAU staff members have seen a lot and learned from each experience.

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