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- Biological Nutrient Removal (BNR) For Industrial Waste Streams, pg. 24
- A Primer On Enhanced Biological Phosphorus Removal (EBPR), pg. 11
- Can Nitrogen Removal And EBPR Coexist?, pg. 18

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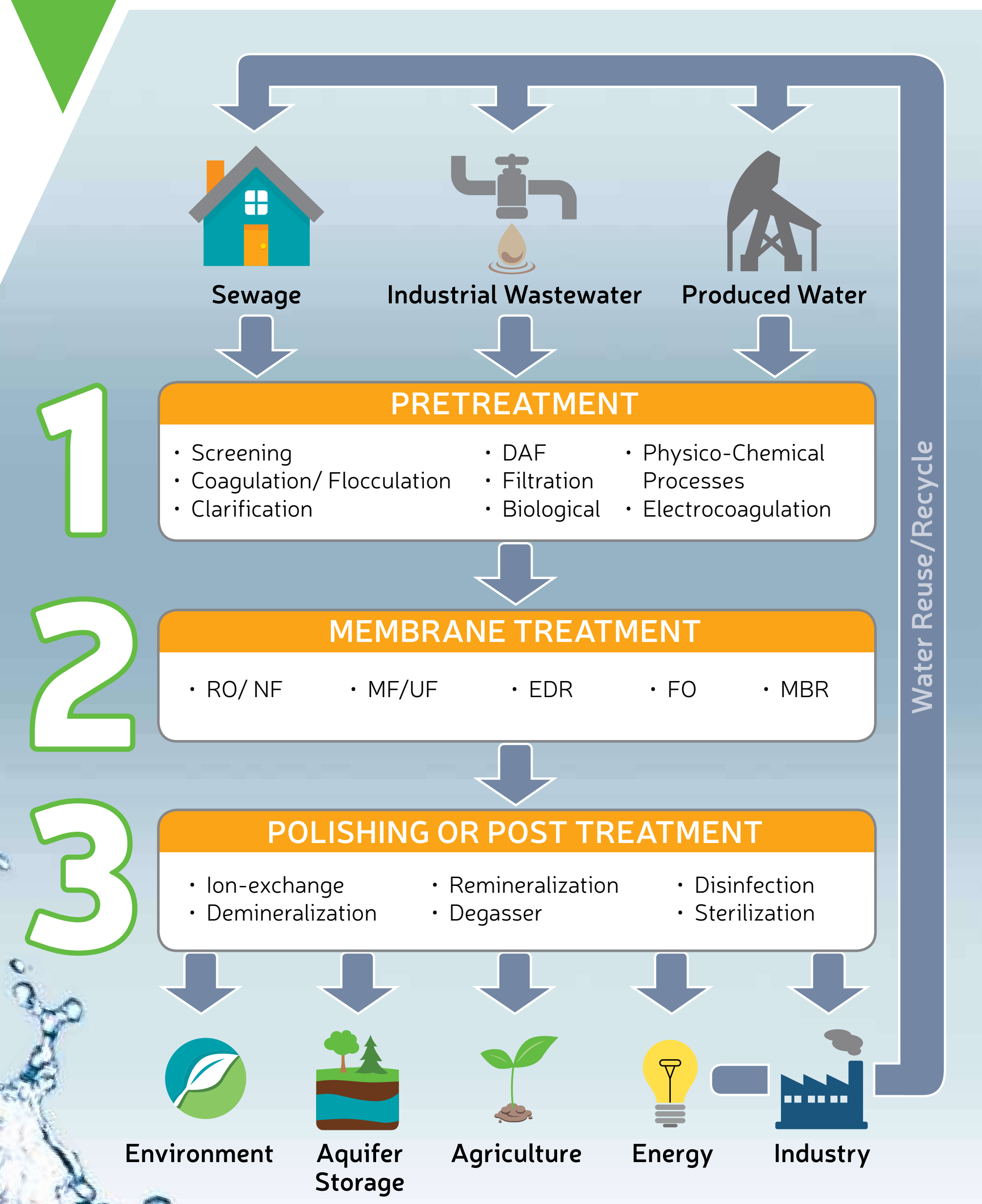

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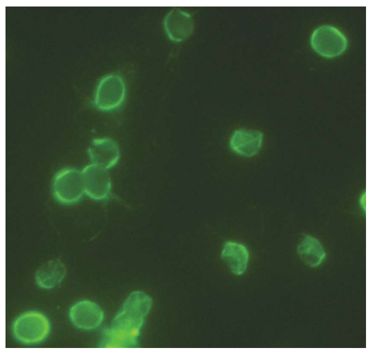
TABLE OF CONTENTS



Advertiser Index

Into The Storm: The Future Of WEF And The Water Industry

"With great power comes great responsibility." Whether you recognize the quote from Voltaire (1832) or Spider-Man (2002), it is an enduring truth. And while the world of water/wastewater may not excite like a superhero, the work is important. In early 2014, Eileen O'Neill inherited important responsibility by becoming the executive director of the Water Environment Federation (WEF). WEF's agenda for WEFTEC 2014 reflects the needs facing the water/wastewater community — infrastructure, financing, regulations, water quality, scarcity, et al — but it also pushes the industry by promoting best practices, new technologies, and solutions. I spoke to O'Neill about what needs to be done to maintain a supply for years to come.

Future Focus

O'Neill and WEF exert influence on the market by helping foster innovation, through both the Leaders Innovation Forum for Technology (LIFT) done in partnership with the Water Environment Research Foundation (WERF), and through WEFTEC's Innovation Pavilion.

"Supporting innovation is not a simple or single-dimensional challenge," said O'Neill. "Enabling innovation, or helping the innovation process move forward, requires a lot of the 'right' pieces to be in place. Of course you need the idea inventors — universities, start-ups, and sometimes established companies' R&D centers, or even utilities — to help start the process. You also need capital/funding to invest in the R&D and promotion, as well as a consultant and a utility that is willing to take some risk to try something new and innovative. Even if you have all of that in place, you then may need a regulator who is willing to approve that new technology/approach; so, policy plays a big role as well. The concept of risk and risk-sharing is increasingly recognized as a real issue."

Key Trends

What are the trending issues that innovation can solve? The biggest attention-getter may be stormwater management. WEF acknowledged this by introducing the inaugural WEFTEC Stormwater Congress last year and by expanding the 2014 program due to rising demand.

"We are all increasingly aware of the importance of stormwater management to address water quality and quantity challenges. In fact, since the passage of the Clean Water Act, the largest contributing force to water quality impairment has flipped from point sources to nonpoint sources," explained O'Neill. "Predictions for the market for stormwater technologies indicate expanding need not just here in the U.S., but globally. Many of our utility members are taking responsibility for management of stormwater, and we are also aware of a growing cadre of stormwater professionals looking for opportunities to exchange best practices and learn about cutting-edge approaches to stormwater treatment, management, and financing."

WEF's strategic direction, according to O'Neill, also includes focus on communicating the true value of water to the public, defining and developing the skills and attributes needed by water professionals of the future, and identifying highly practical short- and long-term solutions for resource recovery and holistic water management.

Shared Vision

Water Online, The Magazine shares WEF's goals of promoting ideas and solving problems. This issue offers articles on an innovative cryptosporidium detection, sewer rehabilitation lessons, the emergence of direct potable reuse, the practice of biological nutrient removal, and more.

As stewards of a precious resource, water and wastewater professionals are imbued with great power and responsibility — superheroes of public health and the environment, if you will — but part of that responsibility is to keep up with the latest technologies, techniques, and trends. The mission to continually learn conjures another enduring quote; it was Sir Francis Bacon, in 1587, who reminded us, "Knowledge is power."

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Texas Leads The Way With First Direct Potable Reuse Facilities In U.S.

Severe drought prompts both Big Spring and Wichita Falls to recycle wastewater effluent for drinking water use. Will others follow suit?

By Laura Martin, associate editor, Water Online

When John Grant and his team in Big Spring, TX, initially decided to build the first-ever direct potable reuse (DPR) facility in the U.S., they weren't trying to make history.

In fact, Grant, the general manager for the Colorado River Municipal Water District (CRMWD), wasn't even aware that there are only a handful of facilities worldwide that utilize DPR — the process of reusing treated wastewater as drinking water without an environmental buffer.

The CRMWD was simply looking to provide clean, safe water for the district's consumers in Odessa, Big Spring, Snyder, and Midland during the region's worst drought in decades.

"When we started our project back in 2002, we didn't even intend for it to be a DPR project. We were just looking for new water supplies in our area," said Grant. "We weren't able to build any more surface reservoirs because we physically had no more room, most of the fresh ground water had already been developed, and indirect potable reuse (IPR) wasn't an option because we get more than 60 inches a year of evaporation."

It took over a decade to research, test, and determine an alternative, but by May 2013 the CRMWD opened a DPR plant — which can treat up to 2 million gallons of wastewater effluent per day to drinking water standards.

The plant immediately gained national attention, and another Texas town took note. By June 2014, Wichita Falls — located 230 miles away from Big Spring — opened the second U.S. DPR plant, which can treat up to 10 million gallons of wastewater effluent per day.

Reverse osmosis equipment is used to disinfect the recycled water at the Big Springs DPR plant.

The Treatment Process

While both Wichita Falls and Big Spring use the DPR process, each plant's methods vary slightly.

The Big Spring plant treats the wastewater effluent at a new $14 million facility using microfiltration, reverse osmosis (RO), and ultraviolet disinfection (UV). That water is then added to a raw water pipeline that also sources water from an area lake. This mix (20 percent recycled water, 80 percent raw water) is then distributed to five drinking water facilities in the region (serving a total of about 250,000 people), where it is treated again using conventional drinking water treatment techniques.

Implementing DPR did not require much additional technical knowledge.

"This technology is not rocket science," said Grant. "This is all technology we already knew how to use."

In Wichita Falls, there was no need to build a new plant just for DPR. This is because one of the region's lakes is brackish, and so a microfiltration and RO plant already existed to treat that source water.

All that was needed for DPR was a 13-mile aboveground pipeline to connect the wastewater treatment facility to the drinking water plant. The pipeline cost around $13 million.

Like Big Spring, Wichita Falls mixes its treated effluent with raw water. Their mix is 50-50 and takes place at the same facility where it is treated again using conventional drinking water treatment techniques. The end result is distributed to roughly 150,000 people.

The long-term goals of each facility also differ. While the Big Spring plant is considered a pilot project with plans to expand, the Wichita Falls facility is only a temporary solution.

There are plans to transition Wichita Falls to an IPR facility (wastewater recycling using an environmental buffer) in the next two to four years depending on drought conditions. DPR was chosen as the first stage because the utility already had most of the technology in place. The aboveground pipeline created for DPR has been sized for IPR flow into a lake and will save the

utility $6 million when they start the IPR project.

"The DPR gives us a high volume of water at a very low cost, so we wanted to do it as quickly as possible," explained Daniel Nix, utilities operations manager for Wichita Falls. "But with DPR we have a 66 to 70 percent recovery rate because we lose some of the water in the treatment process. With IPR we will recoup almost 100 percent of the wastewater effluent, although it would be subject to evaporation for the hottest few months."

Educating The Public

In both Big Spring and Wichita Falls, gaining community support for DPR wasn't as difficult as some expected. Despite the "yuck factor" often associated with water recycling, both communities were mostly supportive of the projects from the beginning. It was the dire drought conditions that convinced people that DPR was necessary.

"In West Texas we have a better appreciation of water than other parts of the country," he said. "We still had some who were concerned, but most people were OK with it once we provided them with information. We held public meetings, we did news releases, we did television and radio, and we went around to civic clubs and did talks."

Education was also key in Wichita Falls. They created a video about the DPR project, which features utility representatives, doctors, and experts from local universities talking about the disinfection process and the safety of drinking recycled water.

"The video was met with quite a bit of success," said Nix. "We brought the media into the fold very early, we told them every step of the way what we were doing, and they've been getting the word out. Since we brought this treatment plant online, the feedback has been that the water tastes better than the lake water we were working with before."

Regulatory Challenges

Because there aren't any other examples of DPR in the U.S., permitting and regulating these new facilities presented a few challenges.

"The state of Texas, which is no different from any other state, does not have regulations and rules for DPR because no one has done it," explained Nix. "So we had to work with the Texas Commission of Environmental Quality (TCEQ) to develop guidelines from scratch, and that took some time."

For both Wichita Falls and Big Spring, extensive testing and verification was required and will continue to be required for the next several years. While there was little precedent in terms of recycled water regulations, the Clean Water Act did assist indirectly in making a DPR facility possible.

"The broad and far-reaching regulations from 40 years ago are what make this possible today," he said. "The Clean Water Act made changes to the way wastewater must be treated and turned into a very high quality water source. We sampled our wastewater effluent and compared it to 97 drinking water standards. With the exception of three components it was already up to drinking water standards before it was even treated."

The effluent missed the mark on levels of the disinfection byproduct trihalomethane (THM), which was rectified by changing the process at the wastewater treatment plant, and also nitrates and microbes, which were both corrected by the advanced treatment process at the wastewater recycling facility.

The Cypress Water Treatment Plant in Wichita Falls, TX, treats wastewater effluent to potable water quality. This is then mixed in with raw water and treated using conventional drinking water treatment.

What's Next For DPR?

With two DPR facilities now operating in the U.S., both Nix and Grant are confident that the verification and regulation process will get easier for their plants and other future DPR plants that may open. Already DPR is picking up steam throughout the Western U.S. The city of Brownwood, TX, has approved a DPR project with the TCEQ but has not started construction because of public backlash. El Paso, TX, which has had an IPR aquifer recharge project for many years, has also approached the TCEQ about the possibility of moving to DPR. In California, multiple IPR plants are in operation, and there are significant efforts under way to better understand and form regulations around DPR applications.

Nix has received calls from those interested in learning more about DPR from all over the world.

"We've had people call from other parts of the U.S., Israel, Australia, and the United Kingdom," he said. "Once Big Spring and Wichita Falls are up and running for a while, we are going to prove to the world that this is a viable water resource. DPR is just going to continue to grow." ■

Laura Martin is the associate editor for Water Online. She is responsible for creating and managing engaging and relevant content on a variety of water and wastewater industry topics. Her background is in print and digital journalism, and she has a bachelor's degree in journalism from Michigan State University. She can be reached at lmartin@wateronline.com.

What Everyone Should Know About Enhanced Biological Phosphorus Removal

As phosphorus effluent restrictions become more stringent, many utilities will need to step up their treatment. Black & Veatch advises on the potential of EBPR.

By Dave Bunch, Ed Kobylinski – lead author, Dave Koch, Tom Ratzki, and Mark Steichen

Regulatory activity in the Midwestern United States, as in other parts of the country, has spurred increased interest in nutrient management among utilities throughout the region. Discharges into the Great Lakes or water-quality-impaired streams, as defined by each state, will soon be required to meet nutrient discharge limits. This raises questions for utilities about how to cost-effectively and sustainably achieve compliance with new phosphorus discharge limits.

The Illinois Environmental Protection Agency (EPA) is considering a total phosphorus (TP) effluent limit — probably 1 mg/L TP — as the first step, and other state agencies are likely on a similar tack. Utilities that need to meet these lower limits will want to consider enhanced biological phosphorus removal (EBPR). Unfortunately, biological removal of phosphorus is frequently misunderstood; a solid understanding of the EBPR process and the needed wastewater characteristics that drive EBPR is essential for effective use of the technology.

Enter EBPR

The U.S. EPA's first major technical publication on phosphorus removal, which dates back to April 1976, addressed chemical precipitation of phosphorus. The discovery of biological phosphorus removal has since revolutionized the wastewater treatment industry with a lower operating cost and ability to produce a valuable end product with a high agronomic value. But understanding influent data analysis requirements, the role of fermentation, and how collection system practices affect the process is necessary for effective EBPR planning.

EBPR is simply the biological uptake of phosphorus by selected microorganisms called phosphorus-accumulating organisms (PAOs). While the actual uptake of phosphorus occurs under aerobic conditions, PAOs must first be conditioned by exposure to volatile fatty acids (VFA) under anaerobic conditions. PAOs store food under anaerobic conditions and then process the stored food once under aerobic conditions. The preferred foods for PAOs are VFA: acetic, propionic, and butyric acids.

PAOs expend energy to transform VFAs into a chemical form for storage, and they obtain energy for VFA storage by breaking phosphorus bonds within themselves. This results in the release of ortho-phosphate which is the conditioning step needed to trigger the aerobic "luxury phosphorus uptake." If PAOs are exposed to enough VFA, they will deplete their energy reserves and become stressed. This stress causes PAOs to overreact and accumulate more phosphorus in their chemical energy storage banks.

While good aeration is all that is needed for phosphorus uptake to occur, the aerobic uptake of phosphorus is dictated by the amount of VFA stored and energy/phosphorus released in the anaerobic zone. Therefore, EBPR process success is primarily determined by influent wastewater quality and the amount of VFA that is present in proportion to the amount of phosphorus to be removed.

Fermentation Can Help Fuel The Process

The recommended minimum ratio of chemical oxygen demand to phosphorous (COD:P) is 40:1. This influent COD:P ratio is correct but misleading. The authors have seen plants with a >40:1 COD:P ratio work great for phosphorus removal, while other plants with a similar ratio struggle. EBPR performance varies from plant to plant with similar influent wastewater COD:P ratios because not all COD is the same when it comes to EBPR.

Some wastewater treatment plants (WWTPs) have enough VFA in the influent to satisfy the EBPR needs for good phosphorus removal. If the VFA as COD:P ratio is over 8, EBPR will perform well. Good EBPR performance is defined as producing an effluent ortho-P concentration below 0.3 mg/L. Because effluent permits focus on TP, a 1 mg/L TP effluent permit can be easily met with a 0.3 mg/L ortho-P concentration and an effluent TSS less than 10 mg/L. Although having a sufficient supply of VFA in a WWTP influent is ideal, some plants have little VFA in their influent and still achieve effective EBPR


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How can an EBPR system consistently remove phosphorus to a very low concentration with a low or variable supply of influent VFA? The anaerobic zone needed for EBPR performs multiple functions. The primary function is the uptake of VFA by PAOs, but PAOs constitute only a small subset of the bacterial population in the mixed liquor suspended solids (MLSS) in the anaerobic zone. The rest of the bacteria are switching gears to ferment organic compounds to obtain food and energy (Figure 1). These facultative bacteria do not consume VFA; they break down complex soluble organic chemicals to form VFA, allowing the PAOs to take up VFA and release phosphorus. Therefore, the anaerobic zone in an EBPR plant simultaneously conditions PAOs and provides an environment for additional fermentation of soluble organics to VFA.

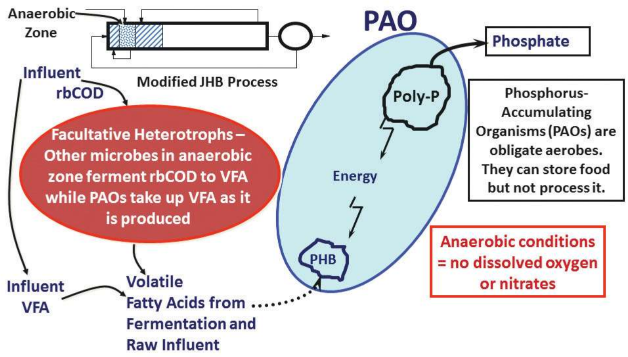

Figure 1. PAO Phosphorus Release in Anaerobic Zone

The analytical tool used to predict the amount of VFA that can be formed is the soluble readily biodegradable COD fraction or rbCOD. The rbCOD concentration is derived from a special flocculation and filtration treatment procedure — called filtered flocculated COD (ffCOD) — to pretreat the sample prior to COD analysis. Subtracting the effluent ffCOD (nonbiodegradable COD) from the influent ffCOD (total soluble COD) results in the rbCOD concentration. The ratio of rbCOD to P is a better indication of the performance of the EBPR process than the total COD:P ratio referenced in textbooks because only the soluble rbCOD will be fermented into VFA in the anaerobic zone. There is not enough time for suspended COD to be fermented to VFA in the anaerobic zone.

Figure 2 illustrates the variable relationship of rbCOD to P. As the fraction of influent rbCOD that is VFA decreases, the necessary rbCOD:P ratio for successful EBPR increases. If fermentation occurs in the collection system due to anaerobic activity in the collection system (odor issues at the WWTP headworks is good indication of this), the anaerobic zone does not have to

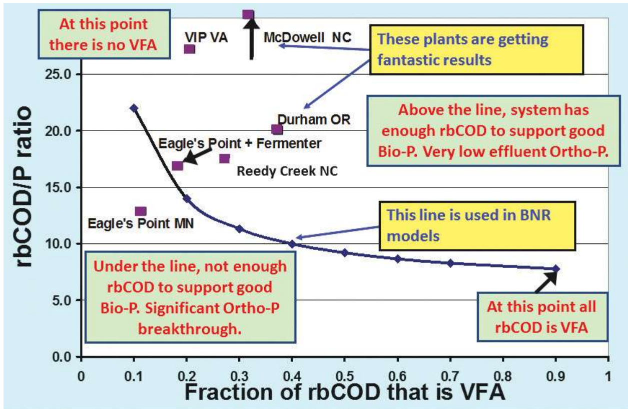

Figure 2. Relationship of Wastewater-Soluble Carbon to Good Bio-P Performance

provide much additional fermentation for EBPR to work well. Conversely, if fermentation does not occur in the collection system, it has to occur in the anaerobic zone for EBPR to work well.

The discussion thus far has focused mainly on the phosphorus release portion of the EBPR process because phosphorus uptake is covered through good aeration design. Keeping >2 mg/L DO residual at the head end of the plug flow aeration basin is the goal. The phosphorus release depletes the PAO of energy, which stresses the microbe. This stress causes the PAO to take up excess phosphorus in the oxic zone; if DO is limited at the front end of the oxic zone, the PAOs fail to uptake as much excess phosphorus.

Fermentation at a WWTP can take many forms. A dedicated primary sludge fermenter is common for plants that have primary clarifiers. Primary clarifiers can also be "activated" to enhance fermentation. In two-stage anaerobic digestion the acid digestion phase is essentially fermentation and can be used as a VFA source.

MLSS fermentation is another viable option for carbon augmentation and PAO conditioning. If the influent is short on rbCOD, a simple strategy of cycling mixers on and off in the anaerobic zone allows MLSS to settle and increase the solids retention time in that zone, which results in formation of additional rbCOD/VFA. If more soluble material is needed, a separate return activated sludge (RAS) or MLSS fermenter will provide more efficient fermentation. Compared with RAS fermentation, MLSS fermentation ferments a higher fraction of primary effluent volatile solids and colloidal material absorbed by the mixed liquor, which increases carbon available for fermentation.

Fermentation in the collection system is desirable for operation of an EBPR system, but can present problems for collection system staff due to undesirable side

effects such as odor complaints and sulfide-induced corrosion. Chemical addition and physical modifications to the collection system can be implemented to reduce sulfide production, although such changes also reduce fermentation to make rbCOD.

Odor and sulfide-corrosion control methods include addition of oxidants (e.g., chlorine, hydrogen peroxide) to destroy hydrogen sulfide or injection of oxygen or addition of nitrate to modify the sewer environment from anaerobic to anoxic or oxic and stop formation of hydrogen sulfide (Kobylinski, et al. 2008). Such chemical additions are intended to stop fermentation and reduce sulfide concentration in the sewer, but they also result in the loss of rbCOD, thereby hurting EBPR performance. The only proven sulfide control approach that will not significantly impact EBPR performance is the addition of iron. Iron specifically reacts with hydrogen sulfide but does not impact rbCOD concentrations and has no impact on microbial activity to produce VFA.

Where To Start

If you're now wondering whether you have to choose between fermentation in the collection system (risking infrastructure damage and odor complaints) or chemical addition to remove phosphorus, it's time to step back. Utilities that are considering implementation of EBPR to meet new or lower phosphorus limits should begin with a comprehensive/coordinated plan for the collection system and WWTP improvements.

Comprehensive influent wastewater characterization can help you determine the quantity and reliability/consistency of the influent carbon source (rbCOD) to support EBPR. Knowing the incoming wastewater quality will help determine if the level of hydrogen sulfide control needed to protect a collection system from excessive corrosion will interfere with or stop collection system fermentation, making it necessary to add a fermentation process for reliable EBPR at the WWTP site.

To make sure utility investments culminate in facilities that meet future capacity needs and comply with anticipated permit requirements, WWTP designers tend to make relatively conservative assumptions. Such assumptions help address unknowns such as how much VFA or rbCOD is available in the influent throughout seasonal fluctuations but tend to increase project costs. Availability of historical data reduces the need for assumptions, which in turn reduces capital costs.

Additionally, arbitrarily reducing VFA in collection systems to control odors may be counterproductive. The best approach in planning is to understand the balance between odor generation in the collection system and the cost of VFA production at the WWTP. Ultimately, sampling today to generate a good historical database of these different influent wastewater characteristics will reduce the need for assumptions and allow better definition of the facilities necessary for plant upgrades to meet new phosphorus effluent limits. Good influent characterization builds confidence that the new facilities will achieve permit compliance. It also allows for optimized design and operations to reduce capital investment. Good sampling data provides a reasonable basis to defend the plant upgrade design to regulatory review, especially when phosphorus removal is new to a state.

MLSS fermentation was included in a nutrient management project at a wastewater treatment plant in the Midwestern U.S. to help improve EBPR performance. *(Credit: Black & Veatch)*

We all know the value of starting with the end in mind. If phosphorus removal is your goal, enhanced biological phosphorus removal may be your best direction. Careful consideration of process needs and related side effects, combined with maximum knowledge about your influent characteristics and system needs, can smooth potential bumps on the road to compliance. Planning and influent sampling today can save you money in the future. ■

Reference

Kobylinski, E., Van Durme, G., Barnard, J., Massart, N., Koh, SH; "How to overcome hydrogen sulfide problems while preserving biological phosphorus removal," WE&T Operations Forum, October 2008.

Ed Kobylinski is a senior treatment process engineer and Mark Steichen is director of wastewater process in the Kansas City, MO, office of Black & Veatch. Dave Koch leads Black & Veatch's Chicago office. Dave Bunch has been an engineer/project manager for numerous EBPR projects in the Midwest, and Tom Ratzki is the Midwest client relations director in the St. Louis, MO, office of Black & Veatch. All have considerable experience with nutrient management.

Kobylinski

Steichen

Koch

Bunch

Ratzki

Can Nitrogen Removal And Enhanced Biological Phosphorus Removal Coexist?

Enhanced biological phosphorus removal (EBPR) is considered the most economical and sustainable way to remove phosphorus from municipal wastewaters, but its integration with nitrogen removal puts EBPR at risk for failure. Recent research helps resolve the conflict.

By Dr. Juan A. Baeza, Dr. Javier Guerrero, Dr. Albert Guisasola

EBPR is performed by polyphosphate-accumulating organisms (PAO) in a two-step process. During the first anaerobic stage (lack of oxygen, nitrate, and nitrite), PAO are able to accumulate volatile fatty acids (VFA) as internal reserve polymers (poly-hydroxyalkanoates [PHA]). The energy required is obtained through the hydrolysis of intracellular polyphosphate reserves, thereby releasing phosphate to the medium. Anaerobic organic matter uptake by PAO is a competitive advantage over other microorganisms unable to perform this uptake in the absence of an electron acceptor (oxygen, nitrate, or nitrite).

Subsequently, under aerobic (oxygen) or anoxic conditions (presence of nitrate and/or nitrite), PAO degrade the accumulated PHA, obtaining enough energy for growth and cell maintenance. Part of the energy obtained is used to uptake and accumulate phosphate in the form of polyphosphate chains, which are used as energy sources (i.e., which may be used under posterior anaerobic conditions).

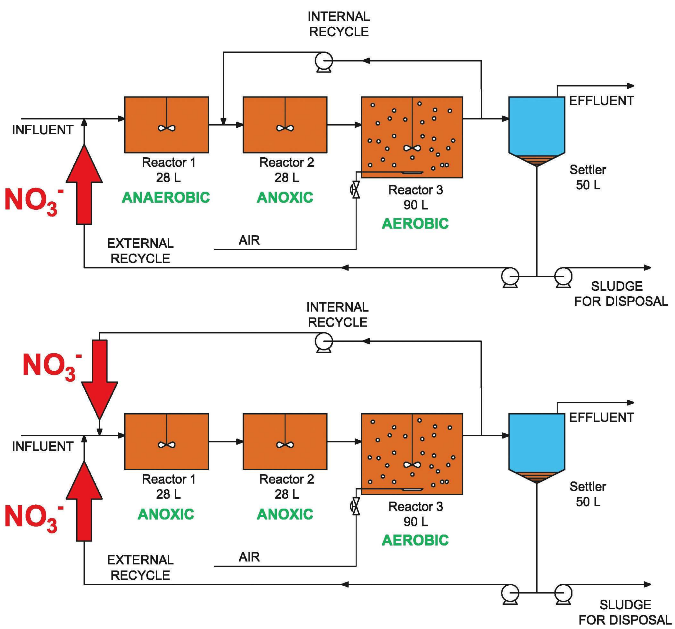

Figure 1. Scheme of WWTP configurations under study (top: anaerobic/anoxic/aerobic (A_2/O) configuration; bottom: MLE anoxic/aerobic configuration). Red arrows show the main nitrate inlets to the anaerobic phase.

The net result of this process is the uptake of phosphorus (P) from wastewater, since the P taken up under aerobic and/or anoxic conditions is higher than the previously released under anaerobic conditions. P-removal is achieved due to the purge of these microorganisms after the aerobic phase, when the intracellular P levels are maximal. When the electron acceptor is nitrate or nitrite instead of oxygen, a fraction of PAO called denitrifying PAO (DPAO) is able to uptake P linked to denitrification.

PAO are now classified into two types according to their different denitrifying capabilities (Flowers et al, 2009). One type (named IA or nitrate-DPAO) is able to couple nitrate and nitrite reduction with P uptake, while the other (named IIA or nitrite-DPAO) can only use nitrite instead of oxygen. Most of the research conducted on DPAO metabolism was initially focused on using nitrate as an electron acceptor, while the use of nitrite as a potential electron acceptor has been a recurrent research topic in recent years.

The Nitrogen Issue

The implementation of simultaneous biological removal of organic matter (chemical oxygen demand [COD]), nitrogen, and phosphorus in wastewater treatment plants (WWTPs) allows a sustainable and economic removal of nutrients from wastewater. However, over the years, it has been observed that the combination of these processes as in the conventional anaerobic/anoxic/aerobic (A^2/O) configuration (see Figure 1) results, sometimes, in the failure of EBPR due to interactions occurring between the metabolism of PAO and nitrate recycle from the settler to the anaerobic reactor through the external recycle.

The presence of nitrate in the reactor that should theoretically be anaerobic is one of the most widely reported causes of EBPR failure in WWTPs (Henze et al, 2008) and, despite its importance, the real reasons for this failure were not fully understood yet. The prevailing hypothesis assumed that, in the presence of nitrate or other intermediate species of denitrification, organic matter was

preferentially consumed by ordinary denitrifying organisms, which reduce nitrate/nitrite to N_2 gas. Thus, PAO lose the competition for the carbon source, resulting in EBPR deterioration (Cho and Molof, 2004). Other authors (van Niel et al, 1998; Saito et al, 2004) have hypothesized that nitrate, nitrite, or other denitrification intermediates can cause inhibition of PAO, which ends up with a loss of EBPR activity.

Piloting A Cure

In a recent research project, we studied the loss of activity of EBPR observed in municipal WWTPs due to nitrate recycle with the objective of understanding this failure and providing solutions to minimize its detrimental effect. A pilot plant (see Figure 1 on the previous page) was initially operated with A^2/O configuration to obtain simultaneous removal of COD/N/P. After four months of working under stable conditions, a steady state with high nutrient removal capacity was achieved with a 70 percent of PAO (quantified by FISH [fluorescence in situ hybridization] microbial identification).

The plant was moved to a modified Ludzack-Ettinger (MLE) anoxic/aerobic configuration to study the effect of the presence of nitrate in the anaerobic phase by placing both internal and external recycles to the anaerobic reactor, thus maximizing the nitrate load to the theoretically anaerobic reactor. The pilot plant was first fed with wastewater containing a high percentage of VFA (75 percent of 400 mg COD/L). The internal recycle was progressively increased up to an internal recycle ratio of 10, resulting in a high nitrate load to the anaerobic reactor and nitrate concentration in the anaerobic reactor higher than 7 mg NO_3^- - N/L. Even under these unfavorable operational conditions, the system was able to maintain a high P-removal efficiency above 85 percent. These results showed that carbon source was preferentially consumed in the EBPR process rather than ordinary heterotrophic denitrification, which is in disagreement with literature to date (Henze et al, 2008).

In the next step of this study, the inlet carbon source was reduced to 200 mg COD/L, testing two types of substrate: VFA and sucrose. For the wastewater with high VFA content, the reduction in COD did not affect the P-removal process despite the nitrate concentration in the effluent increasing. Conversely, when the main substrate was a more complex carbon source (sucrose), most of the COD was used for heterotrophic denitrification, which resulted in a drastic decrease of P-removal capacity. Thus, the major role of the nature of carbon source in EBPR deterioration by the nitrate presence in the anaerobic reactor was demonstrated (Guerrero et al., 2011).

The results can be explained considering the processes usually assigned to denitrifying microorganisms. Under anaerobic conditions, denitrifiers ferment complex carbon sources to produce VFA which are used by the PAO. The presence of nitrate prevents fermentation of complex carbon sources to VFA since this carbon source is directly denitrified, which is energetically more favorable. The experimental results show that nitrate input to the anaerobic reactor is not per se the direct cause of the loss of EBPR activity in urban WWTPs, but it is a key element that reduces VFA production — certainly having a negative effect. Therefore, WWTPs would be able to maintain biological P-removal despite the introduction of nitrate in the anaerobic reactor, provided that the presence of VFA is guaranteed. These results also allow rejecting the hypothesis of a possible inhibitory effect of nitrate or denitrification intermediates as suggested in the literature, since the pilot plant was able to maintain EBPR activity despite the high amount of recycled nitrate to the anaerobic reactor.

Figure 2: Different strategies to apply EBPR were studied at this WWTP in Manresa, Spain.

Potential Solutions

The results demonstrate that the presence of VFA ensures EBPR operation process despite the presence of nitrate in the anaerobic reactor. Thus, VFA addition as an external carbon source would also minimize the competition between PAO and denitrifiers in the scenario of low organic load wastewaters. However, the high cost associated with this addition makes it a difficult alternative to apply. One possible solution is the use of anaerobic fermentation of primary sludge (Moser-Engeler et al, 1998; Chanona et al, 2006) to generate a VFA-rich effluent.

Another alternative is the addition of other low-cost external carbon sources to improve EBPR for COD-deficient wastewaters. We obtained promising results using the byproduct generated in biodiesel production (i.e., crude glycerol). The addition of this byproduct provides a carbon source for the denitrification of nitrate recycled and allows the in situ generation of VFA in the anaerobic reactor. The utilization of this carbon source requires the development of a proper microbial community able to degrade/ferment complex substrates as glycerol to produce VFA.

A direct replacement strategy of the carbon source was successfully applied for glycerol, starting from the original microbial community developed in the pilot WWTP. EBPR was maintained using glycerol as the sole carbon source, with a proper selection of the fraction of anaerobic, anoxic, and aerobic phases. The anaerobic phase has to be long enough to facilitate fermentation of complex substrate to VFA and consumption of VFA by PAO. In addition, the aerobic phase should allow net P uptake.

Regarding the initial distribution of the biomass, the initial microbial consortium requires the presence of a fraction of organisms capable of fermenting the complex substrate to VFA, but these microorganisms are usually present in activated sludge of any WWTP. Another important operational condition that needs to be considered is avoiding the excessive dosage of the external substrate, ensuring that it is consumed during the anaerobic phase to maximize its effect, minimizing the overall costs. The controlled addition of glycerol for achieving a stable effluent concentration has been tested recently in our A^2/O pilot plant, obtaining very good results for keeping a proper controlled P concentration in the effluent, despite several disturbances applied to increase anaerobic nitrate inlet (Guerrero, 2014).

The experimental results demonstrate that glycerol could be used as an external carbon source for the biological removal of P in wastewater with low organic content. This process can be performed whenever the duration of the anaerobic phase or anaerobic residence time in a continuous reactor is sufficiently high to allow glycerol fermentation and VFA uptake. Additionally, the added organic material can also be used by denitrifying microorganisms to remove nitrate recycled to the anaerobic reactor. This dual effect provides improved stability of the EBPR process. ■

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Dr. Javier Guerrero is a postdoc researcher in the department of chemical engineering at Universitat Autònoma de Barcelona. He is also a member of the GENOCOV research group, and his main research topics are the improvement of biological nutrient removal in WWTPs by the implementation of novel and optimized control strategies.

Dr. Albert Guisasola is a chemical engineer and Ph.D. in environmental engineering. His main research interest is not only to optimize wastewater treatment processes, but to convert wastewater into a resource of energy, nutrients, and bioplastics. Guisasola is studying advanced biological and bioelectrochemical systems for wastewater treatment.


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How Does Anammox Technology Perform On Industrial Waste Streams?

An innovative, single-stage deammonification technique to treat high-strength waste is tested on landfill leachate. Find out if it makes the grade.

By Ting Lu, Biju George, and Hong Zhao

In recent years, single-stage deammonification technology combining partial nitritation and anammox has rapidly become an emerging technology for cost-effective autotrophic nitrogen removal in sidestream centrate. The sidestream has high ammonia concentration, low C:N ratio, and warm temperatures that provide the ideal conditions for anammox bacteria to convert ammonia under anoxic condition (with nitrite) to nitrogen gas. The benefit of this technology in comparison with conventional nitrification/denitrification includes reducing aeration energy, eliminating carbon dependency, reducing alkalinity consumption, and reducing sludge production — all of which have the potential to significantly reduce operational costs for nitrogen removal.

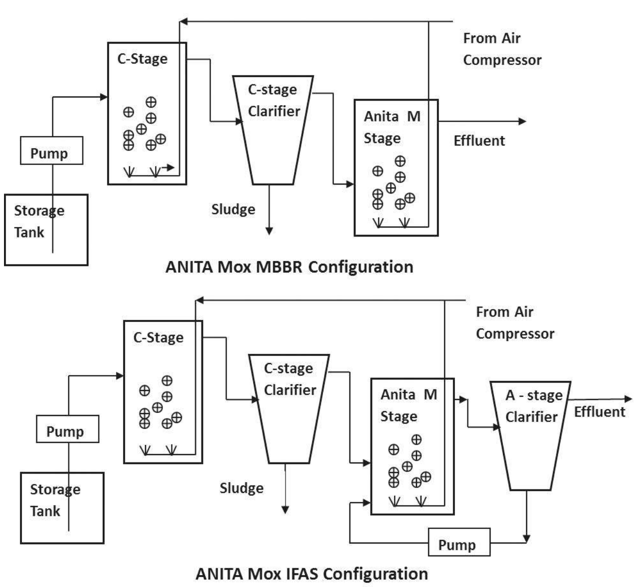
At the Metropolitan Sewer Department of Greater Cincinnati (MSDGC), there are more than 200 significant industrial users that discharge industrial wastes into the treatment plant. In order to save energy and operation cost, MSDGC initiated many innovative technologies to treat high-strength wastes more cost-effectively. This paper details the case study of integrating innovative deammonification technology to treat landfill leachate.

The regular-strength leachate (old leachate) is characterized by its low ratio of biochemical oxygen demand/chemical oxygen demand (BOD/COD) and fairly high NH_4-N (i.e., low biodegradable COD to N ratio). Nitrogen removal from old leachate usually involves autotrophic nitrification and heterotrophic denitrification. There are very few studies reporting the use of a deammonification process to treat landfill leachates, especially in the United States. The objective of this study is to conduct an eight-month pilot project to study the feasibility of nitrogen removal of old leachate using ANITA Mox, a single-stage deammonification process. The outcome of this study is significant because it indicates whether the deammonification process is a viable alternative for treating leachate, and it provides some criteria for full-scale design. In addition, it provides significant understanding of what chemicals would inhibit anammox bacteria and how to optimize its performance. The project also offers valuable information for alternative landfill leachate pretreatment processes.

Materials And Methods

ANITA Mox grows biofilms on moving carriers in a mixed reactor and can be designed in two configurations — moving bed biofilm reactor (MBBR) and integrated fixed-film activated sludge (IFAS). The biofilm on the MBBR carrier consists of multilayers, where anammox bacteria grow on inner layers and ammonia oxidizing bacteria (AOB) grow on the outer layers to achieve single-step deammonification. In the IFAS configuration, AOB is grown as suspended mixed liquor, where anammox bacteria is the dominant species on the biofilm carriers. Studies of the IFAS system have shown that effectively integrating return sludge that includes AOB will improve single-stage biofilm deammonification process performance due to less mass transfer resistance.

Figure 1. Flow diagrams of bench-scale reactor system – MBBR and IFAS phases



The feasibility study consisted of three phases — start-up (May 20 to June 16, 2013), MBBR (June 17 to Aug. 4), and IFAS (Aug. 5 to Oct. 21). As shown in Figure 1, the flow diagram of the bench-scale reactor system, a carbon removal stage (an MBBR reactor with clarifier) was added before the ANITA Mox stage to ensure influent with a low biodegradable COD concentration coming to the ANITA Mox stage. Both C-stage and ANITA Mox reactors were started with 100-percent-seeded carriers (AnoxKaldnes K5 plastic media carriers), which were obtained from the ANITA Mox pilot plant in Denver. Figure 2 on the next page shows the actual system layout in the plant. The C-stage reactor was located on the shelf, and the ANITA Mox reactors were located on the table.

Process control (DO, pH, temperature, and free ammonia) is key to maintaining the right microbial population and structure to maximize performance.

Table 1 on the next page summarizes the reactor volumes, media volumes, and media surface areas in the bench-scale reactor system. The feed was the old leachate that was delivered from the Rumpke Sanitary Landfill on a weekly basis. Table 2 on the next page summarizes the feed characteristics during the testing period. The characteristics indicate a variation of a factor of 10 between the maximum and minimum values on COD, total suspended solids (TSS), and ammonia with a pH range from 7.6 to 10.6. For both the MBBR and IFAS phases, the influent flow rate was adjusted to achieve relatively stable performance. Nitrogen components (ammonia, nitrate, and nitrite), COD, TSS, and alkalinity were measured daily in each reactor for influent and effluent. The operating conditions (e.g., dissolved oxygen [DO], temperature, pH, and intermittent aeration cycles) were monitored by online probes, and DO was controlled manually with adjustment of airflow.

Results And Discussion

Figure 3 on page 28 presents the COD removal performance for both the MBBR and IFAS phases. During the MBBR phase, the C-stage was capable of removing a majority of the influent COD, and not much COD was left to the ANITA Mox stage. On

Table 1. Reactor volumes, media volume, and media surface areas

	C-stage Reactor	*C-stage Clarifier*	ANITA Mox Reactor	*ANITA Mox Clarifier (IFAS Phase Only)*
Reactor Volume, Liter	5.0	5.0	7.0	5.0
Media Volume, Liter	2.0	NA	3.0	NA
Media surface area, m^2	1.6	NA	2.4	NA
Return sludge flow	NA	No RAS	NA	100% to 500% of influent

Table 2. Characteristics of old leachate during the testing period

	TCOD	*SCOD*	TSS	*VSS*	NH_4-N	NO_3-N	PO_4-P	pH	T (° C)
Average, mg/L	4,226	1,988	580	267	650	7.0	10.1	8.5	24.8
Min, mg/L	1,290	1,110	110	75	140	3.8	2.9	7.6	14.5
Max, mg/L	20,600	4,900	1,180	460	1,460	10.2	19.5	10.6	29.4

average, the influent COD was about 4,000 mg/L, and the effluent of the C-stage was less than about 1,000 mg/L. A COD surface removal rate (SRR) was estimated to be about 15 g/m²/d at 26˚C based on a feed flow rate of 8 L/d. During the IFAS phase, the COD removal in the C-stage was not complete, and about 500 to 1,000 mg/L of COD was removed in the ANITA Mox stage. The incomplete COD removal was probably due to a lack of mixing, which resulted in media settling in the C-stage reactor. Figures 4 and 5 on page 28 present the ammonia and total inorganic nitrogen (TIN) profiles in each reactor for both the MBBR and IFAS phases. At the beginning of the MBBR phase (Figure 4), the C-stage converted most of the influent ammonia to nitrite because the seeded media in C-stage contained AOBs. After about 20 days of operation (July 7), the nitritation capability in C-stage was decreased, and most of the influent ammonia was removed in the ANITA Mox stage. As shown in Figure 5, the majority of influent TIN was removed in the ANITA Mox stage after July 9. Since there was not much COD removal in the ANITA Mox stage during this same period, the TIN removal was attributed to the activity of anammox. Based on the influent flow rate of 8 L/d and average feed and effluent TINs of 483 mg/L and 158 mg/L, the average nitrogen SRR was estimated to be about 1.1 g/m²/d at 27˚C.

During the IFAS phase, stable ammonia and TIN removals were not achieved, which may have been caused by the large variation of influent ammonia load, lack of aeration control, incomplete COD removal in the C-stage, and inability to build up mixed liquor suspended solids (MLSS) in the process. Although the performance was not stable, significant ammonia and TIN removals (200 mg/L to 500 mg/L) were observed in the ANITA Mox stage for this phase. The above ammonia and TIN removals were much higher than the nutrient requirement for heterotrophic growth and were therefore attributed to AOB and anammox activities. At an average flow rate of 7.0 L/d and an average TIN removal of 300 mg/L, the TIN SRR was estimated to be about 0.9 g/m²/d at roughly 25˚C.

Summary And Conclusions

This bench-scale feasibility study has clearly demonstrated that the two ANITA Mox configurations (MBBR and IFAS) were capable of removing COD and nitrogen from old leachate at SRRs of 15 g/m²/d for COD and 1.0 g/m²/d for nitrogen. The COD removal from C-stage is 75 percent, and the TIN removal rate from the MBBR system is 74 percent. The MBBR test has been very successful and meets the design criteria from the vendor perspective. The relatively unstable performance from IFAS was caused by many factors as discussed above, which opened the door for more mechanical optimization and future pilot work. There is no noticeable inhibition from the old leachate that inhibit the anammox activity.

In summary, deammonification is now an established and acceptable process used by many state agencies to treat sidestream

Figure 2. ANITA Mox system layout at Cincinnati's Mill Creek WWTP

centrate to reduce nitrogen load. Process control (DO, pH, temperature, and free ammonia) is key to maintaining the right microbial population and structure to maximize performance. For an industrial waste stream, the deammonification process still requires a pilot to validate the effectiveness of the technology. In the pilot study at MSDGC, the ANITA Mox technology was capable of removing COD and nitrogen from landfill leachate. The deammonification process provides a cost-effective alternative to the landfill leachate pretreatment processes. This is valuable information for MSDGC during their process in evaluating the construction of a new wastewater treatment plant. On another deammonification pilot project, significant inhibition on bacterial activity was found when treating combined wastewater from a tannery and a pig slaughter house. ■

Figure 3. COD profiles in each reactor during MBBR and IFAS phases

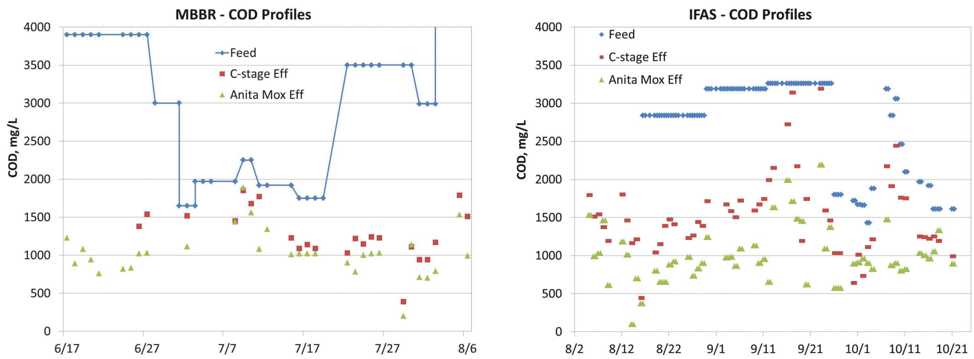


Figure 4. Ammonia profiles in each reactor during MBBR and IFAS phases

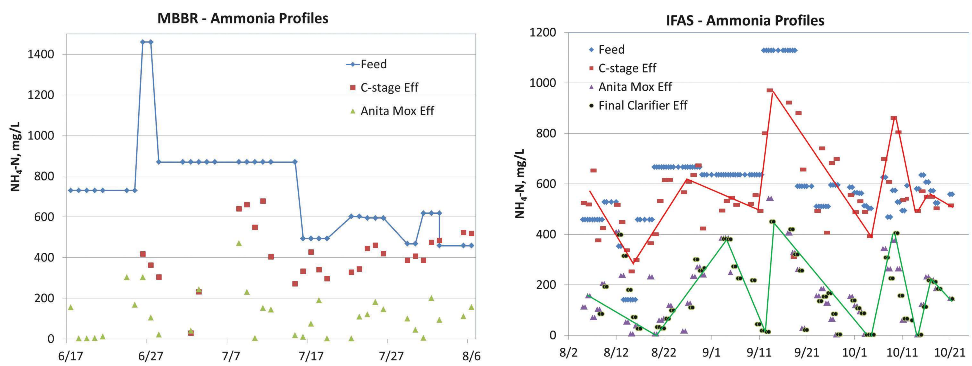
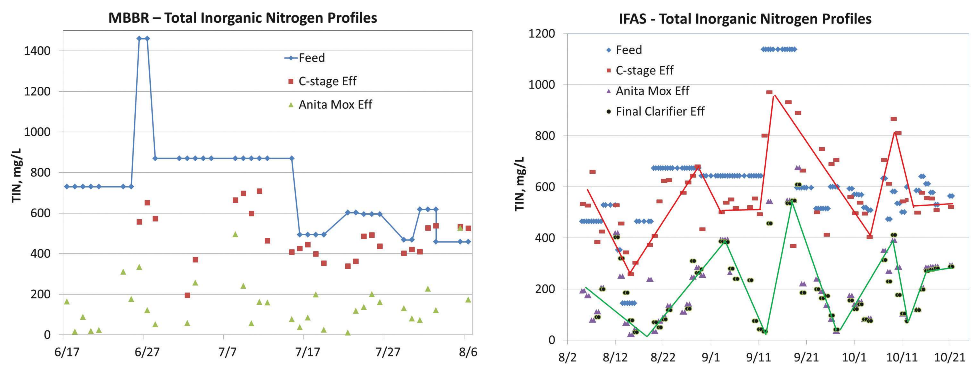


Figure 5. TIN profiles in each reactor during MBBR and IFAS phases



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__Hong Zhao__ graduated with a Ph.D. in environmental engineering from the University of British Columbia. Zhao has been a process engineer at Kruger, a Veolia Water Technologies company, for more than 15 years.

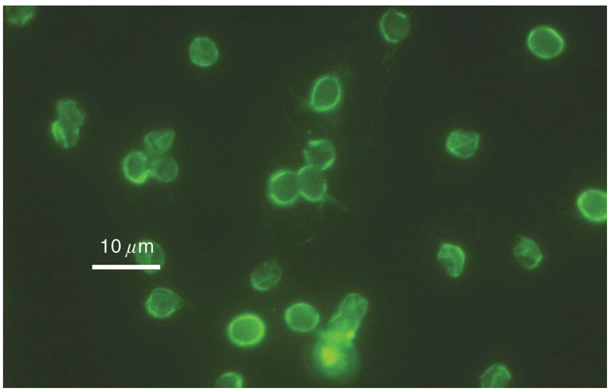
Do-It-Yourself Crypto Detection

Learn how to construct a simple and inexpensive tool for detecting cryptosporidium in your watershed – and why it's important.

By Kevin Westerling, chief editor, Water Online

As advanced as monitoring has become, cryptosporidium (crypto) has seemingly slipped through the cracks. The accepted U.S. EPA method of detection, mandated by the Long Term 2 Enhanced Surface Water Treatment Rule (LT2), is to catch oocysts (the infectious dormant form of crypto) in capsule filters. It is neither simple nor cheap — and not terribly accurate, considering its cost. So what if you could build a better crypto trap?

A new, do-it-yourself crypto detection system has been developed by researchers at Lehigh University through a project funded by the Philadelphia Water Department (PWD) and tested in Philadelphia area waters, with promising results. So far, the "homemade" alternative to the current standard (EPA Method 1623) has provided very comparable detection results, but at a fraction of the cost. This allows for more units to be deployed throughout the watershed, possibly providing utilities an additional tool for detecting cryptosporidium.



Oocysts have an intense apple green color under immunofluorescence imaging and measure four to six microns in diameter. (Credit: H.D.A. Lindquist, U.S. EPA)

Researcher Kristen Jellison, associate professor at Lehigh's Department of Civil & Environmental Engineering, calls the device a "biofilm sampler." It is simply a box containing microscope sample slides — at a cost of roughly $3 each — that is placed in a body of water at the location of interest. Jellison, who holds a Ph.D. from MIT and a B.S. from Cornell University, had done past work, along with others, in proving that biofilms are good receptors of oocysts, but the PWD pilot study marks the first time biofilms (which grow on the slides) have been used to monitor crypto in a watershed.

"It's a very easy way to see if crypto are present in your watershed and where, without spending hundreds of dollars on the filters," said Jellison.

Standard Filter Performance Problems

As the next round of LT2 approaches — monitoring for large facilities (serving at least 100,000 people) begins in April 2015 — utilities of all sizes may recollect the pain points from using EPA Method 1623 in the initial round. The capsule filters are prone to clogging in turbid conditions, which often necessitates a second filter to collect the required 10 liters of water for a valid sample. At $100 or more per filter, per sample, anything beyond the bare minimum gets expensive.

"It racks up really quickly," stated Jellison. "A utility with a smaller budget is limited as to how often and how many different locations they can sample."

Furthermore, the results of the EPA method are quite variable. In one study (McCuin and Clancy, 2003), oocysts were seeded in both clean tap water and raw source water, then repeatedly tested using EPA Method 1623. The range of recoveries — or how many oocysts were detected compared to the known quantity put in — was 23.5 to 71.2 percent for the tap water, and 19.5 to 54.5 percent for the raw water. The high incidence of undetected oocysts means that crypto presence could be greater than tests indicate.

"With recoveries so variable, it becomes questionable if you don't detect anything," Jellison noted. "Is it because it really wasn't there, or because you only had a 30 percent recovery? You may or may not catch it."

The method can also be misleading in that it only provides a "snapshot" of place and time. The oocysts you gather in 10 liters of water at a single collection point, over the course of time it takes to collect a sample (perhaps 30 minutes), is almost coincidental. As Jellison pointed out, "You could have had an oocyst in there the day before or the hour after you leave, or even while you were there, but not in your 10-liter sample."

The biofilm sampler improves on at least two of these pain points, creating the opportunity for better understanding of crypto occurrence in a waterbody.

Biofilm Sampler Vs. Filter

The first advantage is cost. Because the biofilm sampler's materials are so much cheaper than the filters required under LT2 guidelines, many samplers can be constructed and used for monitoring throughout the watershed.

A second advantage is that the biofilm samplers can stay in the watershed for any length of time, which is a matter of convenience, opportunity (to catch more oocysts), and local factors. There is no optimal duration period established for the biofilm samplers; it may be variable according to

location, weather, and source water. At PWD, Jellison and colleagues replaced the biofilm sampler every two weeks simply to coincide with the EPA-approved filter sampling.

As both the biofilm samplers and the filters were drawn from the watershed at the same time, results of the samples were compared. Samples were routinely taken in the source water prior to entering the intake of the PWD water treatment plant (WTP) and from a location farther upstream. Over the course of a full year (July 2013 to July 2014), the frequency of detection was remarkably similar (see Table 1).

Table 1. The biofilm sampler and EPA-approved filter method returned a similar frequency of oocyst detection at two collection points.

	Water Source
Biofilm Sampler	46% positive (18/39)
Filter (EPA) Method	43% positive (17/40)

This comparison study suggests that, with regard to oocyst detection, the biofilm method is on par with the EPA-approved filter method. The pilot project did not include the seeding of oocysts and therefore does not speak to the variability of recovery — an established flaw with the filter method, but a complete unknown with the biofilm method. Volume concentrations of the water passing through the biofilm sampler are another unknown.

It's because of the many as-yet unknowns that Jellison calls biofilm sampling a "long way" from becoming EPA-approved. Outside of LT2 testing, however, biofilm samplers can have significant impact.

"It's cheaper, so you can sample in more locations at a higher frequency, over longer spans of time, and really understand where the sources of crypto are in your watershed," summarized Jellison.

In other words, instead of the snapshot image, water quality managers can now get the big picture. By obtaining relative data on oocyst concentrations — where and when they appear — mitigating actions such as source water protection plans or the installation of best management practices (BMPs) can be developed in areas where they will be most effective.

How To Build A Biofilm Sampler

To start monitoring oocysts and the threat of cryptosporidium in your own watershed, you need only a sturdy container and standard microscope slides. The container will need two open sides to permit water flow, as well as slots

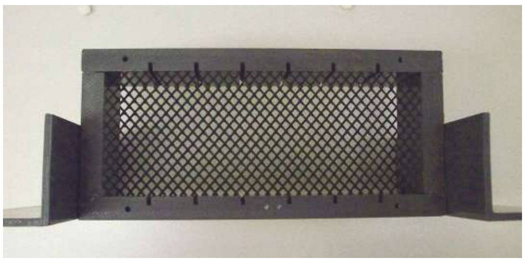


Figure 1. The simple construction of the PWD biofilm sampler includes slots for six slides and protective mesh siding.

to hold the slides in place; mesh or a similar material should also be used to cover the open sides and prevent large debris from breaking the slides (see Figure 1).

The PWD team utilized two weighted PVC pipes to keep the units submerged in the watershed (see Figure 2), but they collected samples from the source water just prior to the WTP intake by hanging the biofilm sampler from a rope off a dock.

Figure 2. Weighted PVC pipes help keep the biofilm samplers in place.

Once the biofilm sampler is retrieved, the slides are simply scraped to remove the biofilms; by contrast, the second step of the standard method requires the filtered content to be eluted. The remaining steps are exactly the same as with the filter method under EPA Method 1623: immunomagnetic separation (IMS) followed by immunofluorescent microscopy (IFA) — steps familiar to any utility that has done previous crypto/LT2 monitoring.

The Future Of Crypto Detection

The next step on the road toward validation for the biofilm filter is to have more utilities try it out in the field to help gather information, work out the kinks, and develop best practices. A sticking point, so to speak, is how biofilms behave in different areas.

"Is any biofilm going to be equally sticky for cryptosporidium, or are there specific things about the biofilm that make crypto more or less likely to attach? That's what we need to figure out," Jellison explained.

She has already made some inroads, finding that "rough" biofilms catch more oocysts than smooth ones, as they tend to get caught in the crevices. Ultimately, she hopes to develop a synthetic surface that can be used anywhere, with a known attachment efficiency. Until then, she welcomes the participation of others and is optimistic that there will be benefit for other "do-it-yourselfers."

"I think it's absolutely worth trying," she said. "And based on what we see here [in Philadelphia], I think it will give good information. If other people want to use it in their watersheds and share their findings, I see that as a really useful collaboration on both ends."

For more information (or collaboration), contact Kristen Jellison at kjellison@lehigh.edu. ■

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Shear Power: How To Defeat FOG Once And For All

Overcome the problem of fats, oils, and grease (FOG) by understanding it and choosing the right equipment.

By Dr. J.H. Wakefield

Fats, oils, and grease (FOG) from municipal wastestreams are widely variant from each other, as municipal wastestreams tend to be. It is also maddeningly difficult to obtain meaningful data for FOG, partly due to this variance and partly because FOG are natural products. What will or won't work for the removal of FOG is never universal, but there are parameters for success.

All FOG wastestreams contain hydrophobic components, meaning they contain "water-hating" parts that are insoluble in water. These hydrophobic components are usually less dense (lighter) than water and float on the surface. This results in clogging masses interfering with the physical and chemical functioning of the treatment process — both the collection and the actual treatment of the wastestream at the wastewater plant. This floating mass entrains other floating debris, making it even more difficult to remove. In short, this is probably the biggest and most aggravating problem that those working with collection systems and treatment systems encounter.

Keys To Overcoming FOG

The successful removal, alleviation, and control of FOG deposits in wet wells, lift stations, and grease traps will involve both physical and chemical considerations. The key parameters are:

1. providing oxidation potential to the deposits, and
2. providing a means to increase the surface area (and thereby the reactivity) by decreasing the size of components of the deposits into microparticulates.

FOG microparticulates are defined in wastestreams as very small hydrophobic organic particles (either solid or liquid, as in the case of emulsoids) that are stable within the wastestream. The solid's structure on a macromolecular level may be lamellar (as in a composite or crystalline material, such as graphite) or branched (as in steel wool). The surface of these solid microparticulates is generally referred

FOG composition is varied, but often thick and sedentary.

Great balls of FOG: Balls of grease clog the collection system.

Milk fat deposits wash ashore at a dairy plant treatment lagoon.

to as rugose, which means heavily wrinkled. Their decomposition depends on the microorganisms present and the enzymes that they provide. Upon microscopic examination of these particulates, one can readily observe the rugose surface areas of the solid microparticulates, which results in their increased rate of degradation by the microbial enzymes.

Physical And Chemical Catalysts

The production of these microparticulates is accomplished by devices that provide a shearing environment and also deliver a charge of oxygen that can be assimilated into the various wastestreams and deposits encountered. Some devices are designed to engender an extreme shear on FOG deposits and transform them into reactive microparticulates. By actually increasing the availability of oxygen to resident microorganisms, as well as to enzymatic action on the FOG particulates as they are pulverized, a radical result on the deposits is achieved.

Note that shear and turbulence are the critical factors. The provision of oxygenation is, of course, a desirable feature, but some decomposition regimens occur under anaerobic conditions. No matter how the metabolic degradation of the wastestream is affected, these smaller particulates (with radically increased surface area) will be more efficiently degraded by the appropriate microorganisms and their enzymatic "packages." This is a consequence of surface area and collision probabilities from the turbulence.

A small amount of ozone or other "charge carrier" molecule may also be injected to establish a charge on the formed particulates. This stabilizes the particulates in the liquid stream so that they don't settle out in the collection lines as they are pumped into the wastewater treatment plant (WWTP). Depending on the size of the particulates engendered, ozone charging may not be necessary, as sufficiently small particulates will carry sufficient charge (colloidal particles) to remain in suspension. Of course, all this time, enzymatic action will be "working" on them from the plethora of microorganisms that are inherent in most collection systems and wastestreams.

There are several principles that enable FOG deposits to be degraded. We have seen that shear, turbulence, and enzymatic action are the "ball game" in this regard. Shear and turbulence are physical in nature, while enzymatic action is chemical. Three entirely different methods may be used to resolve FOG at the WWTP.

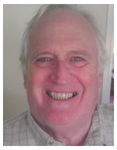
FOG Removal Systems: Choose Wisely

In some devices, the principle is to use a Venturi draw (by means of air lift bubbles or otherwise) to impact the wastestream solids against a sharp edge or other immovable object to generate microparticulates. As a circulation is developed, the wastestream becomes less viscous, thereby increasing the velocity at which the particulates are slammed into the immovable (and sharp) edge. The particulates are constantly reduced in size by this action, and it is relatively easy to provide oxygenation from the airlift bubbles used to engender the Venturi draw, as well as smaller diameter bubbles specifically tailored to create this outcome.

In other devices, the principle is to use a propeller-type mixing blade to reduce the size of the particulates. By judiciously choosing the type of mixing blade used, one can also entrain oxygen into the process from either a pure oxygen source or an atmospheric one.

In yet other devices, the wastestream is pressurized and then injected into a lower pressure zone, resulting in the destruction of the solid particulates into even smaller ones. These devices are more effective where the suspended solid levels are very low and are usually dedicated to these applications. However, ordinary wastestream systems rarely, if ever, deploy this method.

As is the case so many times, the method chosen is the one that is the simplest to set up, install, and is economical with respect to power usage. In short, cheap is not only good, but essential. We have come a very long way in a relatively short time in addressing the FOG issue, and we can now control the situation expeditiously and economically. ■



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Lessons Learned During Sewer Rehabilitation On Public And Private Property

Four distinct sewer rehabilitation projects, each with its own set of challenges, offer guidance to others in the field.

By Scott Belz, Bob Kelly, and Jim Smolik

The City of Westlake, OH, is located in the northeastern part of the state. The city is mostly residential with light industry and a population of 34,000.

In 1992, the city implemented an inflow/infiltration (I/I) program based on flooding problems. Since 1992, four areas have been investigated. Each area used similar rehabilitation techniques; however, certain lessons were learned from the testing to the construction phase.

The four areas are King James Subdivision, Salem-Radcliffe Subdivision, Berkeley Estates, and Canterbury. All of the areas were built between the 1950s and the 1970s, with separate storm and sanitary sewers.

Methodology

Prior to any sewer rehabilitation or repairs, a sewer investigation must be conducted to identify the types and locations of defects in the sewer system. These investigations utilize different testing techniques that focus on both public and private property. Both of these areas have different sewer components that are susceptible to deterioration and malfunction.

For all of the projects undertaken by the city, either contractors or consultants conducted the testing as part of the sewer investigation. Testing for all of the project areas included some or all of the following testing methods: flow monitoring, mainline dye testing, residential dye testing, manhole inspection, and CCTV.

Once the testing was complete, a detailed report was submitted to the city with recommendations for rehabilitation to the system based on the best engineering judgment at the time of the report. These reports included recommendations for mainline sewer lining, lateral lining, manhole sealing, and grouting.

Results

King James Subdivision

The King James Subdivision was the first area to be investigated and rehabilitated by the city. The investigation for this area was conducted by a contractor, and data was provided to the city as data with no engineering recommendations. While engineering was completed internally, the contractor data report lacked the backup and details of the testing commonly provided by a consultant.

Testing in this area was focused on public property only. No flow monitoring was conducted for either post- or pre-rehabilitation monitoring. Testing consisted of mainline dye testing, which included adding dyed water to the storm sewer system and looking for leaks in the sanitary sewer, then using a CCTV camera to identify the leak and its location. From the testing results, a rehabilitation plan was developed and included the sealing of manholes and lining the sanitary sewer with a cured-in-place (CIP) sewer liner.

The city revisited investigating the area since the flooding problems were not solved. The city felt that the problems


Residential dye-testing manifold


Residential dye testing with GIS data


Sanitary lateral branch connection reinstatement

Prior to any sewer rehabilitation or repairs, a sewer investigation must be conducted to identify the types and locations of defects in the sewer system.

may lie on private property as well as public property, and all 50 houses in the area were dye tested by adding dye to each downspout. Wherever dye transferred from the downspout of a house to the sanitary sewer, rehabilitation was performed.

The city was faced with the issue of who should pay for the new repairs, which included work on private property. The city council agreed that residents should pay for structural repairs outside the right-of-way (ROW), and the city would pay for all work in the ROW and lateral grouting outside the ROW. The result was that only $5,000 of the total of $338,000 for rehabilitation costs fell under the homeowner's responsibility (approximately 1.5 percent of the contract).

Lessons Learned

Lessons learned from the King James Subdivision showed that both public and private sides need to be addressed when completing sewer system rehabilitation. The city also decided that all of the future rehabilitation work for these types of projects shall be 100 percent funded by the city.

Salem-Radcliffe Subdivision

The next area to be investigated was the Salem-Radcliffe Subdivision. The sewer investigation for this area was also conducted by a contractor, and data was provided to the city as data with no engineering recommendations. For this area, CIP sanitary lateral lining was utilized from the mainline sewer to the house. The CIP method used consisted of a felt liner with a polyester resin and steam curing. A pit was used to expose both storm and sanitary laterals for cleaning and televising, sanitary lateral lining, and installation of new cleanouts. Manhole sealing was conducted using a spray-applied polyurethane liner.

Lessons Learned

Lessons learned from the Salem-Radcliffe Subdivision showed that the liner was installed short of the mainline with the work not addressing the mainline sewer/lateral interface. This allowed groundwater to migrate down the lateral to the path of least resistance at the mainline/lateral connection. In manholes that had the spray liner applied, the grade ring area was not sealed with a flexible product. This allowed groundwater to enter and led to the product cracking at the grade interface.

Berkeley Estates

Berkeley Estates was the first area to be tested by a consultant. Both mainline and residential dye testing was completed in this area showing that both public and private property sewers were contributing to I/I in the system.

The same type of lateral lining CIP process from the mainline sewer to the house was used for this area. The CIP method used consisted of a felt liner with a polyester resin and ambient curing instead of hot water. A pressure launching vessel was used for the inversion and the lateral/main interface was grouted with a lateral packer.

Manhole sealing was conducted using a cementitious product with a flexible urethane product at the grade ring. This was an improvement from the last project, which did not use a flexible material. Prefabricated rubber membranes with expansive straps were also used in several manholes.

Lessons Learned

Lessons learned from the Berkeley Estates project showed that liner failures, possibly due to ambient curing or the resin introduction process, impacted the ability to grout the mainline/lateral connection. This area was previously serviced with septic systems, and records were not available on how they were tied into the mainline when they were converted. This resulted in the contractor sometimes needing to excavate two pits to expose both the storm and sanitary laterals, which was not in the bid document. Storm laterals were difficult to locate due to the lack of data from not televising the storm sewer prior to the repair work.

The city found that testing requirements need to be established to verify that the liner met the performance strength requirements that were specified in the contract documents. Vacuum testing for manhole products also needs to be implemented on future projects. This project also showed that more research needs to be conducted during the design stage of the project, especially in identifying the pipe layout in septic tank conversions.

Storm lateral root blockage

Canterbury Area

The Canterbury Area was the most recent area investigated with a rehabilitation of the mainline sewers and laterals based on the recommendations of the investigation. Like Berkeley Estates, a consultant conducted the exact type of testing and provided an engineering report.

Again, sanitary lateral lining utilized a CIP process from the mainline to the house. The original CIP installation utilized a felt liner with a polyester resin and ambient cur-

ing. However, the resin was changed to epoxy because it was available domestically. The method of curing the CIP was also changed to recirculating hot water to meet the performance specification of the product. Similarly, a pit was used to expose both storm and sanitary laterals, lateral lining, and install cleanouts during the lining procedure.

Mainline grouting was completed in areas identified from the mainline dye-testing results. Grouting of interface was also completed between the sanitary lateral and the mainline sewer.


Storm lateral compromised by roots

Manhole sealing utilized a cementitious product with a flexible urethane product at the frame/wall interface. This product seemed to work the best in comparison with previous products used.

Testing that was implemented on this project included pre- and postflow monitoring, pre- and postdye testing, vacuum testing of the manholes, air testing from the cleanout to the mainline sewer, and physical testing of the CIP liner to verify strength parameters (flexural modulus and flexural strength).

Lessons Learned

Lessons learned during the Canterbury Area focused on complications due to the houses being septic tank conversions. Many had branch connections and could not be lined, and some liners had to stop short of the house due to a 4" diameter reducer at the interface of the lateral and the house. Some laterals failed due to workmanship. For example, resin was not cured properly, not measured correctly due to faulty equipment, calibration bladders pulled prior to curing, or installed too short. In some instances, the liner was installed too short from the pit to the main.

Conclusions

Throughout all four of the rehabilitation projects, lessons were learned in each one and at different phases of the project, from testing during the investigation, to bid and specification items, to product specification and testing, to construction methods and installation. Key items for each segment of the project are discussed below.

Testing techniques

During the residential testing, locating the exact source or potential location of the leak will assist the engineering judgment of recommending lateral lining or spot repair at a specific house. Altering the testing procedures to spend more time searching for the leak on private property rather than discerning if it was positive or negative may possibly eliminate the lining and associated costs.

Bid and specification items

By conducting rehabilitation on several projects, the overall bid and specification document improved at each project. Important items that protected both the city and the contractor were eventually included in the package. Specifically, number of cleanout pits, length of the lateral liners, how to deal with lateral branches, type of product, and quality assurance testing requirements were all things that made important decision-making points at various times of construction during the project and provided insight for future improvements. It is important to include the proper testing procedures and requirements and hold the contractors and manufacturers to those requirements.

Product recommendations

While several products were used on these projects, overall success was based on the cumulative effort of the product, installation, and workmanship. Products that were successful were CIP liners, which were felt liners with an epoxy resin with hot-water curing. Chemical grouting was also successful on the mainline sewer joints; however, long-term exposure of the product has not been endured, as this was only installed within the last five years. Manhole liners worked much better with a flexible urethane grade ring than the rubber liners with straps.

Construction methods

One of the key lessons learned during these projects was the ability to find a contractor that has extensive experience in installing, testing, and overall knowledge of the product limitations. Throughout these projects, different contractors were used and each with varying degrees of knowledge and competence, which wasn't identified until the project was ongoing or had ended. With the advances in technology and new products being introduced to the market every year, it is important to find a contractor that has experience with a specific product. ■


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Bob Kelly is director of engineering for the City of Westlake since 1992. He is responsible for 300 miles of sewers systems and has over 30 years in municipal sewer maintenance and design.


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