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The Next BIG Thing In Wastewater

Also In This Issue:

Instrumentation In Activated Sludge: Past, Present, And Future

An Operator's Guide To Advanced Oxidation Processes

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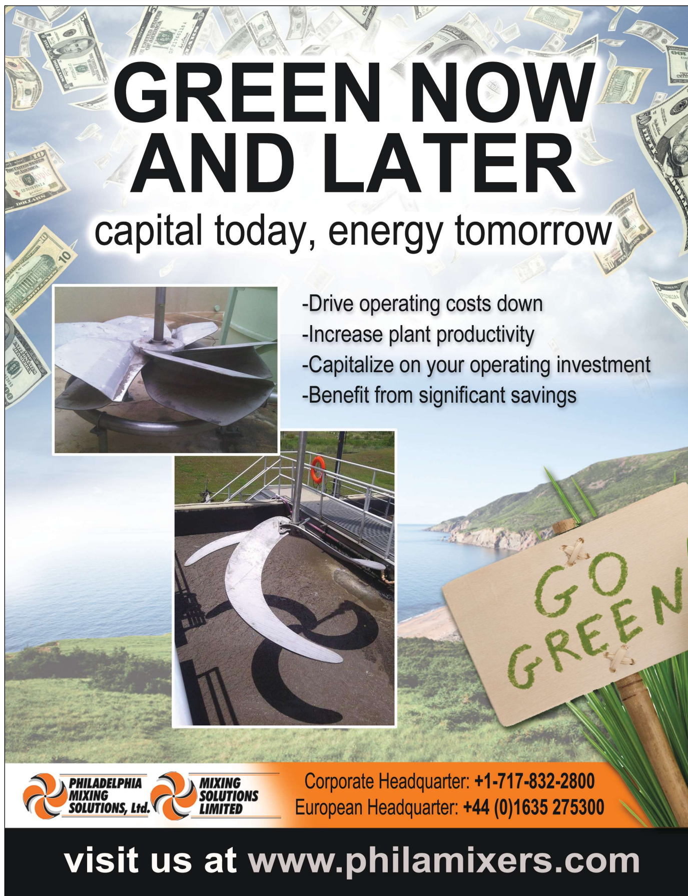

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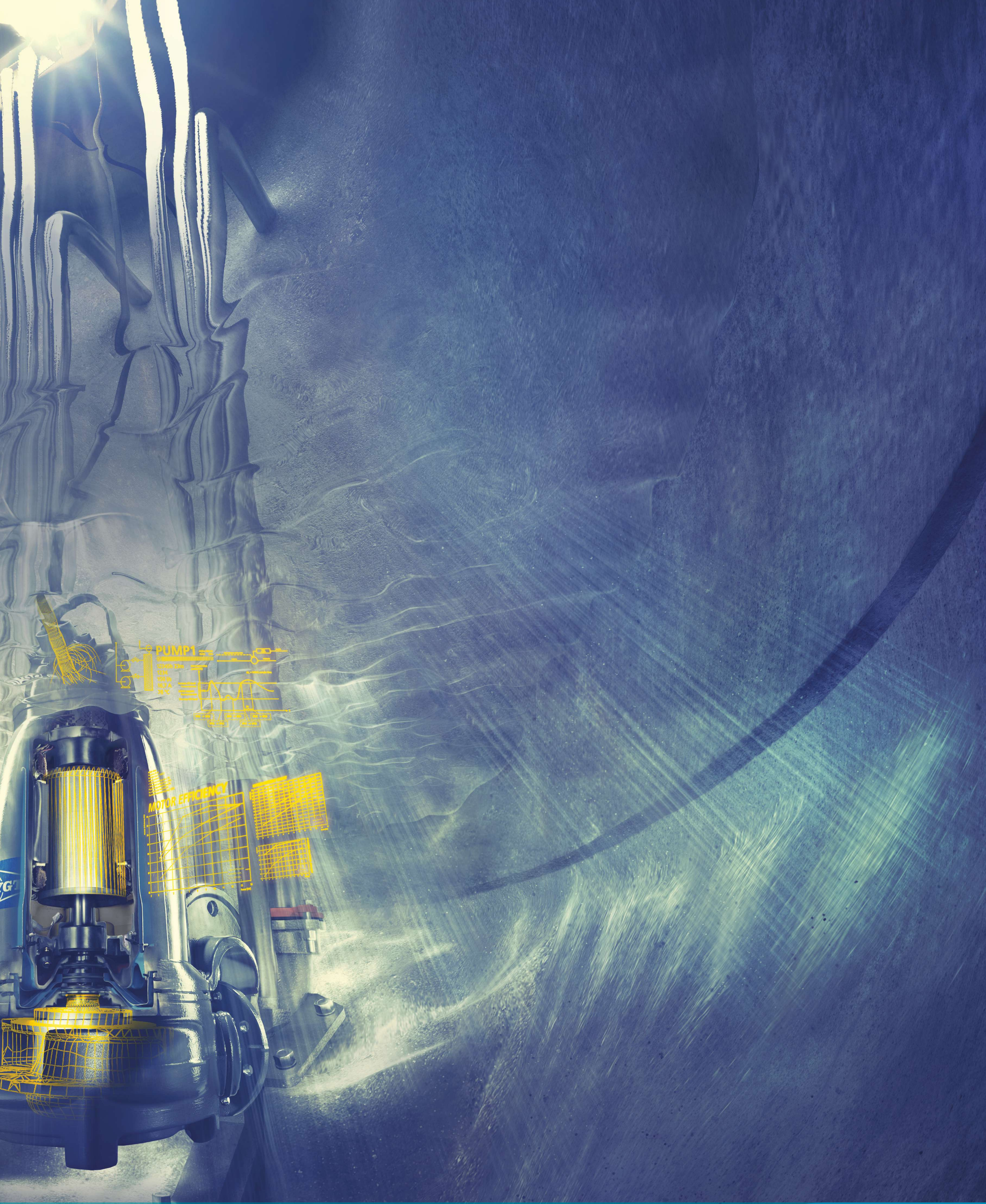

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Can Co-Locating Utilities Solve The Water-Energy Nexus?

Try explaining to your children, as I have with mine, that turning on a light is akin to running a faucet. You'll likely get a confused look, but this is perhaps the simplest example of the relationship between water and energy (the "nexus"). It's only one side of the coin, however. Water and wastewater operators experience the other side, chewing through electricity (and their budgets) to treat and transport water.

Resources being a scarce commodity, it's incumbent upon us to optimize the use of water and energy as best we can. While conservation is the prime course of action for the public, the best solution for utilities may be to work smarter — by having the water-energy nexus work for us instead of against us. One trending way to do this is by "co-locating" water/wastewater treatment and power generation at a single facility. Described below are two examples of co-location … and innovation.

Combined Heat And Power (CHP)

DC Water in Washington, D.C., is among the most forward-looking, innovative utilities in the U.S., proving it once again by constructing the world's largest combined heat and power (CHP) plant at its Blue Plains facility. CHP, also called cogeneration, uses a heat engine — a system that converts heat or thermal energy to mechanical energy — to simultaneously generate electricity and useful heat. Blue Plains will take heat from the 370 MGD of effluent it receives and turn it into 10 megawatts of off-grid electricity. The $450-million project relies on thermal hydrolysis, a process that pressure-cooks the waste before microbes convert it into methane in digesters. The methane powers turbines to generate electricity, while heat captured off the turbines is recycled into the thermal hydrolysis process. According to DC Water General Manager George Hawkins, the project will save the utility $10 million per year once completed (due this summer).

Combined Power And Desalination

Combined power and desalination plants, or hybrid desalination plants, produce drinking water and electricity by aligning the processes side by side; waste heat from the power plant is used as the heat source for desalination. Ideal for arid regions prone to drought (pay attention, California), it makes sense that the first such facility was built at Qidfa', Fujairah, in the United Arab Emirates, completed in 2004 for $1.2 billion. The Fujairah plant recently approved an upgrade that will further take advantage of the water-energy nexus by capturing residual energy from the reverse osmosis process, which pumps seawater through membranes at pressures as high as 70 bar. Special rotary devices will harness and return the energy to the pumps for more sustainable, cost-effective operation. Other hybrid desalination plants have been constructed throughout the Middle East, but Fujairah remains the leader. As the cost for the notoriously high energy-spend of desalination is improved, and as desalination becomes more of a necessity, this type of co-location is sure to become more common.

Nexus Gains Steam In The U.S.

Here in the U.S., we are voracious (but improving) consumers of both water and electricity, having been blessed for so long with a cheap, abundant supply of each. We have begun to feel the pinch, however, as population and demand grows. Some of our fastest-growing cities are also the driest, exacerbating the problems posed by water scarcity and the water-energy nexus. In response, California, Arizona, and Nevada have enacted statutes that specifically mention the appropriation of water for generating electricity, according to the National Conference of State Legislatures. Because citizens are being affected, politicians are reacting to a problem that utilities have seen for some time. By working together — with politicians and with each other — utilities can still be at the forefront of a solution. Some already are. Who's next?

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Shortcut Nitrogen Removal: The Next Big Thing In Wastewater

A vast improvement on conventional biological nutrient removal could save the wastewater treatment industry untold millions.

By Kevin Westerling, editor

If you're thinking about setting up your wastewater treatment plant (WWTP) for biological nutrient removal (BNR), hold that thought. There is a new process that heralds a radical departure in how BNR is performed, according to Lauren Fillmore, senior program director at the Water Environment Research Foundation (WERF), and it drastically reduces the amount of energy and O&M that current BNR methods require.

The breakthrough is known as shortcut nitrogen removal because it eliminates a step in the BNR process. Instead of nitrifying ammonia and then denitrifying later, this revolutionary advancement replaces nitrification and denitrification with single-step deammonification.

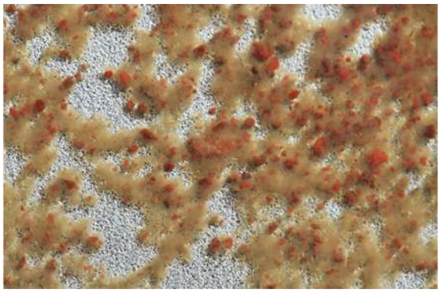
Used mainly for high-strength sidestream wastewater flows, shortcut nitrogen removal has been adopted at Hampton Roads Sanitation District (HRSD) in Virginia as a full-scale process — a first for North America — while DC Water is in the development phase of full-scale deammonification. Considering the savings potential involved (time, money, and carbon footprint), it's an option that should be investigated by any WWTP operator on the verge of BNR implementation.

"We're on the cusp of a major sea change in how people do nutrient removal in this country," said Fillmore. "If you're going to do a BNR upgrade, there's a lot you need to be aware of before you design and build something that has a 40- or 50-year life. You may be designing it based upon technology that's going to be outdated very quickly."

The Deammonification Difference

Conventional nitrogen removal is performed in multiple stages. Wastewater ammonia (NH_3) is oxidized to nitrite by autotrophic ammonia-oxidizing bacteria (AOB), and the nitrite is then oxidized to nitrate by nitrite-oxidizing bacteria (NOB) under aerobic conditions. Two additional steps are required to convert the nitrate into inert nitrogen gas (N_2). The overall process requires large amounts of dissolved oxygen (and energy) supplied by blowers, as well as a supplemental carbon source. It also produces high volumes of sludge that can be expensive to handle and discard.

With shortcut nitrogen removal, NOB are not used to convert nitrite to nitrate; instead, a different class of bacteria, labeled anammox (anaerobic ammonia oxidation), converts NH_3 into N_2 in two biological steps. The first step is called nitritation, in which AOB (the same used with conventional systems) convert about half of the ammonia into nitrite. This partial nitritation is common in wastewater treatment. The revelation comes with step two: anaerobic deammonification. The anammox bacteria, which use nitrite as an electron acceptor, convert about 89 percent of inorganic nitrogen (ammonia and nitrite) into N_2, with 11 percent left over as nitrate.



Anammox bacteria (red granules) promote floc formation.

Benefits Of Shortcut Nitrogen Removal

According to WERF, use of the above-described deammonication process "results in remarkable savings" in comparison to conventional nitrification/denitrification.[1] Cited benefits include:

- 55 to 60 percent reduction in aeration energy requirement
- No carbon requirement (or 90 percent reduction if carbon is used to eliminate leftover nitrate)
- Net consumption of carbon dioxide (CO_2) versus CO_2 release from carbon oxidation
- 45 percent reduction in alkalinity demand
- Reduced sludge production

Established Shortcut Technologies

Since the initial discovery of anammox bacteria in 1995, a number of variations on shortcut nitrogen removal have been developed to optimize performance and overcome inherent obstacles. The major shortcoming attributed to deammonification technologies is a long start-up period for slow-growing anammox bacteria (in comparison to AOB). Various commercial configurations include granular sludge reactors, suspended-growth sequencing batch reactors (SBRs), and moving-bed biofilm reactors (MBBRs) — all set out to better grow and retain the bacteria.

"We're on the cusp of a major sea change in how people do nutrient removal in this country."

— Lauren Fillmore, WERF senior program director

ANAMMOX® Granulated Sludge Reactor

Available as a single-step (one basin) or two-step arrangement, this process grows the anammox bacteria in gravity-separated granules. A high-rate clarifier is used to settle the granules in the reactor, which flushes out bacteria flocs while sustaining the sludge age required for existing bacteria.

DEMON® Sequencing Batch Reactor

The most widely employed of available shortcut nitrogen removal techniques, featuring 25-plus installations around the world, DEMON (DEamMONification) is also the first to be installed for full-scale use in North America. The process uses a hydrocyclone to separate floc from granular anammox bacteria under controlled dissolved oxygen (DO) and pH conditions to stabilize performance.

DEMON's performance at HRSD has been exceptional since going online in 2013, saving the plant an estimated $200,000/year in chemicals, sludge-handling costs, and energy, in addition to reducing its carbon footprint. HRSD installed the system at its York River facility, a 15-MGD plant under the care of manager Charles Bott.

"With a lot of these processes that are emerging in Europe, they seem almost too good to be true," said Bott. "But once you see them in action, you see that they are accomplishing exactly what they promise."

In recognition of the bold move, Bott and HRSD received the American Association of Environmental Engineers and Scientists (AAEES) Honor Award for Environmental Sustainability.

Moving-Bed Biofilm Reactors

Three companies are doing shortcut nitrogen removal with MBBRs: Purac/Läckeby AB offers the DeAmmon® process, AnoxKaldness/Veolia has ANITA™ Mox, and the Terra-N® process comes from Clariant/Süd-Chemie AG. These systems were developed to handle high-strength, ammonium-rich plant recycle streams. They vary in design and support media, but each works by establishing AOB and anammox bacteria within a biofilm that collects on the media.

Sidestream MBBRs supported by anammox have been shown to reduce inorganic nitrogen by as much as 90 percent. The long start-up times associated with shortcut nitrogen removal, typically eight to 10 months, can also be reduced with MBBRs to as little as four months.[1]

Biological Double-Efficiency Process

Returning to full-scale (mainstream) wastewater treatment, the U.S. EPA reported in August 2013 on a technology it singled out as innovative and emerging — the biological double-efficiency process (BDP)® — calling it "the world's first full-range simultaneous nitrification/denitrification (SND) process."[2]

According to the EPA, more than 20 full-scale operations in China utilize BDP, both for municipal sewage and industrial wastewater. The process achieves SND in a single bioreactor divided into aerobic and anoxic zones. Compared to conventional biological wastewater treatment, the EPA listed the following performance advantages for BDP:

- Increases efficiency by at least 100 percent for biological matter removal
- Reduces energy consumption by 50 percent or more
- Reduces carbon dioxide emissions by 50 percent or more
- Reduces sludge by at least 40 percent
- Reduces physical footprint by approximately 50 percent
- Reduces O&M costs by approximately 30 percent

BDP requires a carbon-to-nitrogen (C/N) ratio of just 0.17, which can be increased for higher nitrogen removal.

In China it has been implemented in new plant builds as well as retrofits, finding application in the petrochemical, oil refinery, textile, and pharmaceutical industries, to name a few. In short, BDP treats any waste stream with a high concentration of toxic chemicals.

The Path Forward

With agencies such as WERF and the U.S. EPA touting the benefits and potential of shortcut nitrogen removal practices, there is little doubt about the efficacy of simultaneous nitrification/denitrification. The true impact, however, is dependent on the rate of adoption. In an industry known to take the road *more* traveled, it remains to be seen if wastewater utilities will take advantage of this "shortcut" path that has been paved. ■

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Instrumentation In Activated Sludge: Past, Present, And Future

After a century of operation, the activated sludge process is still being fine-tuned to meet today's challenging treatment and efficiency targets.

By Oliver Grievson

This year, as many know, sees 100 years since the activated sludge process was first developed by Arden & Lockett in Manchester, United Kingdom. Since then, technological developments in the way the process is designed and operated have been governed by a number of different pressures including population growth and the need to intensify the process, the need to make the process more financially efficient, and, of course, the need to tighten consents in order to protect the environment. The use of instrumentation to monitor the process and feedback on how it is performing has been a necessary step.

As industry demands get tighter, activated sludge plants will be expected to do more.

Instrumentation and process automation in activated sludge have developed hand in hand. Initially, they were developed with variable speed drives for aeration blowers and PID (proportional-integral-derivative) loops to control the amount of dissolved oxygen in the process, and more recently with ammonia control systems and advanced process control.

This has evolved into the use of instrumentation and process models to control the activated sludge process. Mathematical models have been developed by the International Water Association (IWA) for the control of the process, and this has been fundamental in the evolution of modern advanced-process control systems.

A Short History Of Instrumentation In Activated Sludge

The development of dissolved oxygen probes was the first innovation within the activated sludge process initially with the advance of the Clark polarographic sensor in 1956 by Dr. Leland Clark (YSI, 2009), and then the first optical sensor in the late 1990s, developed by Environmental Instruments in the U.S. This was originally called the Fluorprobe and has evolved over the years into instruments such as the RDO by Partech.

The respirometer, a complement to the dissolved oxygen probe, was first developed in 1996 by Dr. John Watts, who was with Minworth Systems Limited at the time. The technology has been commercially available for many years with the advantage that it can be used for both online control of the dissolved oxygen requirement of the process and also for toxicity measurement allowing for interventions on the process to take place should a shock load be detected in the influent of the plant. The most notable systems that are available in the world today are those of Strathkelvin Instruments in the U.K. and Challenge Technologies in the U.S. The ASP-Con (activated sludge plant controller) is the most recent award-winning development by Strathkelvin Instruments, bringing respirometry to mainstream control.

The developments of suspended solids monitors in 1973 as a way of measuring the quantity of the biomass in the process and the ammonia monitor in the late 1990s have meant that the process has been able to run more and more efficiently over the years.

The key to instrumentation and its use within the activated sludge process is the development of activated sludge models. The first model was developed by the International Association of Water Quality (one of the groups that formed the IWA) in 1983. The first model, ASM1, covered chemical oxygen demand (COD) removal, oxygen demand, bacterial growth, and biomass degradation. This was extended further in 1995 to include biological and chemical phosphorus removal in ASM2 and was further developed in the late 1990s to ASM2d to include the aerobic uptake of phosphorus. The IWA models formed the basis of commercially available models such as BioWin, GPSX, and Stoat. These in turn form the basis of many of today's advanced-process control models.

The Modern Activated Sludge Plant And The Role Of Advanced Process Control (APC)

The state of instrumentation and process control in the modern activated sludge plant is very much dependent upon the size and the complexity of the plant itself. The vast majority of the smaller conventional activated sludge plants have only basic instrumentation including dissolved oxygen and flow, mainly for the control of the dissolved oxygen concentration to ensure that the plant is compliant and the energy consumption is kept in check.

The intelligence of instrumentation and process automation and control has been put in place at larger treatment plants. Water companies have done a variety of things, including:

- Dissolved oxygen control
- Organic load control
- Ammonia control
- Sludge age control
- Full advanced-process control

Larger plants generally rely on more instrumentation for activated sludge process control.

Dissolved oxygen control was one of the first initiatives to make the process more efficient with run and dwell systems on surface aeration systems and with PID loop control with fine bubble systems.

Organic load control of the carbonaceous load within the activated sludge plant and ammonia control was the next initiative that was brought to the activated sludge plant with the development of accurate instruments for ammonia analysis. This had led to mixed results with some water companies successfully implementing it and others less so.

Controlling the amount of biomass within the process became a possibility with the development of suspended solids monitors. This is key not only for energy reduction, but also for keeping the treatment plant compliant.

Within the past five to eight years, the principles of individual process control on the activated sludge plant have been gathered into integrated advanced-process control systems in the U.K. by two commercial organizations and one or two of the water and sewer companies. The water companies themselves have tried to do this with PID loop controls and in some cases with cascade loop control systems, some of which have had some success in Europe.

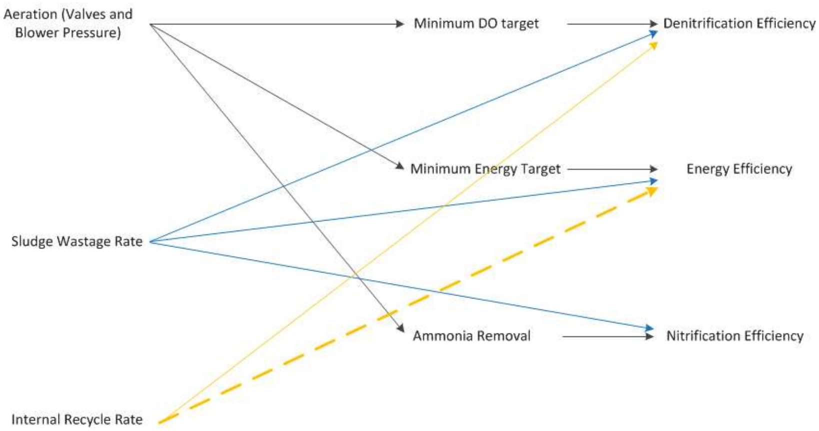
Hach Lange, in conjunction with MWH Global, developed the Water Treatment Optimization system (WTOS), which is very much an advanced-process control system based upon instrumentation. The WTOS system utilized Hach Lange instrumentation and a process model based upon the ASM1 activated sludge model (Thornton et al., 2010).

One of the first full-scale installations controlled with the WTOS system was a 250,000 population equivalent four-stage Bardenpho plant with methanol addition in the second anoxic zone. The system and controller that was developed for this treatment plant looked to monitor and automate the whole process including the nitrification and methanol dosing. This first installation conducted a trial over a 10-week period and managed to achieve a 20 percent reduction in the amount of aeration, control of the amount of ammonia that was discharged, and a 50 percent reduction in the amount of methanol that was consumed.

Since its first implementation in 2008, this technology has developed even further with other control modules including a nitrification module (which includes sludge age control) specifically designed for the activated sludge plant, as well as modules that are designed for other plant processes.

The second approach to advanced process control has again been based on model-based controllers but is less reliant on instrumentation and more reliant on the intelligence of the system as a whole; any failings in the implementation of APC have been due to poor data quality from the instruments. This approach put more intelligence into the control system to identify when an instrument becomes unreliable, and for the system as a whole to replace the unreliable data with an inferred value based upon the readings being received from other instruments within the system.

For example, the control model "knows" what each DO sensor should measure at any given time, given the influent flow, blower load, valve positions, manifold pressures, and treated water quality. If any probes report values that are significantly different from those that are expected, an alarm is raised, and the inferred value is used to exercise control of the process. Optimized control can be maintained even when real-time measurements become unreliable.



Typical interactions of a multivariate process control approach to advanced-process control (Credit: Perceptive Engineering)

The multivariate process approach has advantages of being a system based upon the control element and is much more widespread within the plant, taking into account the whole treatment facility rather than just the activated sludge plant on its own. Case studies of this approach in three U.K. water and sewage plants realized savings between 20 and 35 percent of the aeration costs while also reducing the risk of compliance failure as the treatment plant operates more efficiently under automated control.

It is clear that the advent of instrumentation within the wastewater industry has propelled the development of control systems that have given the industry significant savings in the way it operates (a) treatment processes and (b) activated sludge plants in particular.

Optimized control can be maintained even when real-time measurements become unreliable.

The Future Of Activated Sludge

So what is the next step in the next 100 years of the activated sludge plant?

As the demands on the wastewater industry get tighter and tighter, activated sludge plants will be expected to do more. We are seeing this with more and more treatment plants moving toward activated sludge and its different variants including the various forms of biological nutrient removal (BNR), enhanced biological phosphorus removal (EBNR), membrane bioreactors (MBRs), and integrated fixed-film activated sludge (IFAS) to realize these tighter demands.

For some of these variants, control systems have already evolved; for others, control systems will need to be developed.

There are also a number of different instruments that various suppliers within the industry have either developed or are in the process of doing so, including nitrous oxide sensors and a new generation of respirometers and biological monitoring systems to check on the health of the biological part of the process. Where these sensors will fit into the process remains to be seen.

What is clear, however, is that the activated sludge plant cannot be considered on its own, but rather as a much wider part of a larger system. The industry as a whole is starting to develop a philosophy of the treatment plant as a production facility and the production facility as part of the whole wastewater network, from the treatment system to the customer's discharge point, to the point of return to the environment. This could see the demands upon the treatment plant change again. The activated sludge control system will become part of a treatment plant control system ensuring a consistent product feed and knowledge of what a facility is expected to receive.

What challenges will the activated sludge plant of the future hold? To match the needs of the stakeholders — whether it's the customer or the environment as a whole — instrumentation, process automation, and control will need to play a major role. ■

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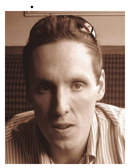

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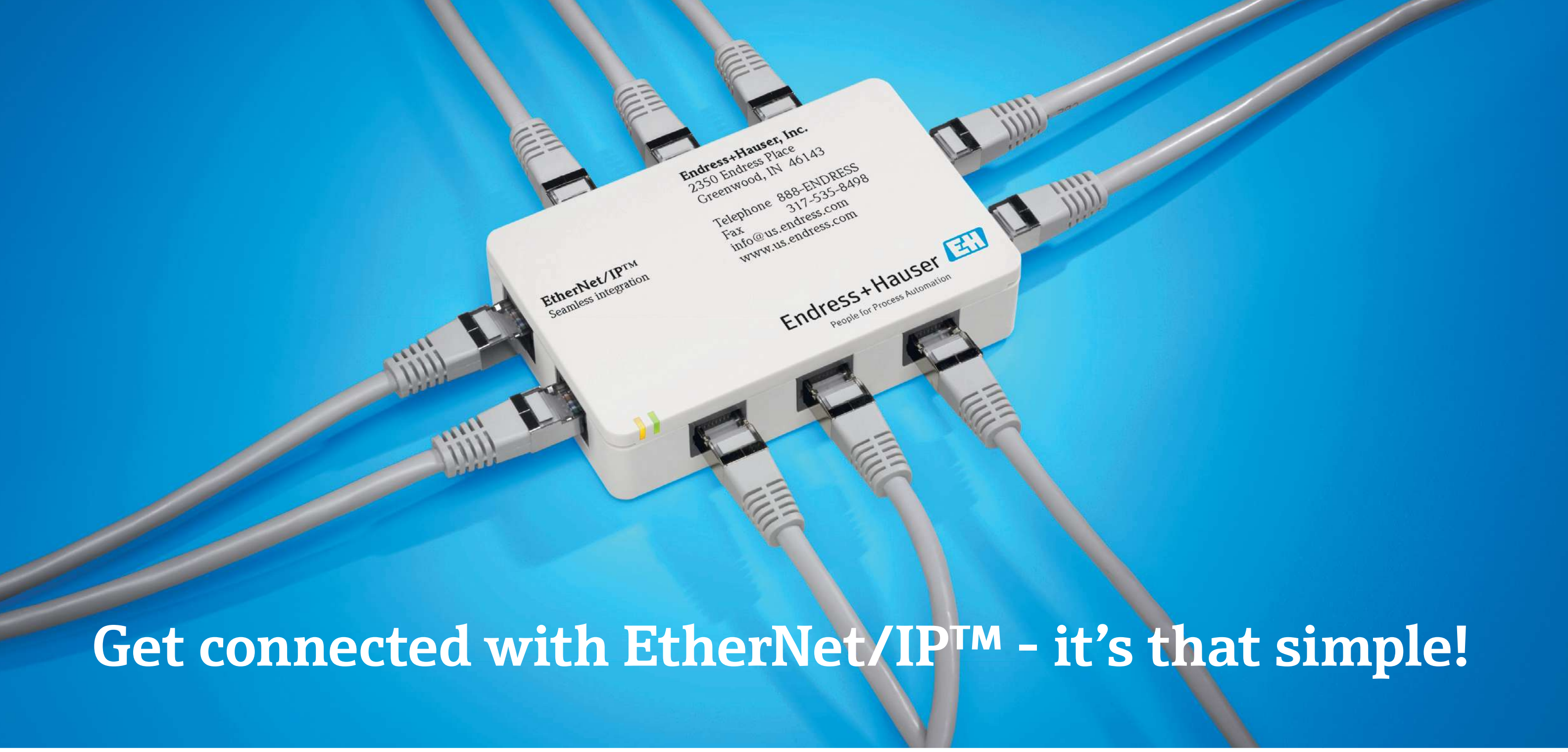

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The Benefits Of An Integrated Watershed Approach To Nutrient Management

How to look beyond the wastewater treatment plant for sustainable, holistic solutions to nutrient loading

By Jeff Herr

Surface waters including rivers, lakes, and estuaries have the natural ability to assimilate nutrients (phosphorus and nitrogen). In an undeveloped watershed, hydrologic and nutrient loads are commonly low, and surface water quality is very good. Some nutrients in a natural system are desirable and necessary to sustain aquatic life. As nutrient loads increase due to development and land use, surface waters become eutrophic (an increase in algal productivity, causing poorer water quality) and are commonly listed as "impaired" on state 303(d) lists. A surface water segment is listed as impaired when the measured water quality exceeds the state standard. The nutrient producing the impairment may be phosphorus, nitrogen, or both. The primary nutrient causing water quality impairment in a given water body is termed the "limiting" nutrient. Freshwaters are commonly phosphorus-limited, while brackish and salt waters are commonly nitrogen-limited. Certain types of algae present in surface waters can actually fix, or capture, nitrogen from the atmosphere.

The task of reducing the primary source of nutrients in a watershed is often complicated by regulatory authority and/or jurisdiction.

Wastewater facilities such as the Johns Creek Environmental Campus in Fulton County, GA, have adopted the integrated watershed approach.

Identifying The Issue

Eutrophic surface waters have a variety of undesirable aesthetic, chemical, biological, and human health characteristics. Impairment generally leads to the development of total maximum daily loads (TMDLs) and required nutrient load reductions by the regulatory community to improve surface water quality. There are currently almost 7,000 surface water segments impaired for nutrients in the U.S. with more than 5,700 completed TMDLs. States are currently in the process of transitioning surface water quality standards from "narrative" to "numeric" nutrient criteria, which will lead to additional nutrient TMDLs. In most cases, only the limiting nutrient needs to be reduced to improve surface water quality. In these economic times, it is essential to find cost-effective and sustainable solutions to reduce nutrient loads to nutrient-impaired waters.

There are commonly many potential sources of nutrients in a watershed, including municipal and industrial wastewater discharges, agricultural discharges, snow melt, stormwater runoff, septic systems, dry weather baseflow, groundwater seepage, internal recycling from surface water bottom sediments, atmospheric deposition (both wet and dry), and pets and wildlife. While most of these nutrient sources are direct sources, bottom sediments can release stored phosphorus into the water column under anoxic (low dissolved oxygen) conditions. Low dissolved oxygen is common at the sediment/water interface in eutrophic surface waters. In some cases, the less-recognized sources, such as bottom sediments or waterfowl, are the primary source of nutrients.

When attempting to improve surface water quality, it is extremely important to identify and quantify all sources and magnitudes of the nutrients of concern in a watershed. The primary sources of nutrients can then be identified, and cost-effective and sustainable solutions can be planned and implemented. If all nutrient loads are not properly quantified, millions of dollars may be spent to remove nutrient loads from an

unimportant source, resulting in minimal water quality improvement. For example, in a phosphorus-limited lake, if bottom sediments account for 70 percent of the annual phosphorus load, minimal water quality improvement would be realized by treating stormwater runoff inflows. Conversely, there would be little benefit from removing bottom sediments if stormwater runoff was the primary source of nutrients.

4-Step Approach

An integrated watershed approach to nutrient management is needed to develop and implement cost-effective and sustainable solutions. Step one, arguably the most important, involves quantifying all primary sources and magnitudes of nutrients in the watershed. This step requires a commitment of time and funding to perform the required field monitoring of nutrient sources. Field monitoring should be completed during different seasons throughout the year for stormwater runoff, dry weather baseflow, groundwater seepage, recycling from bottom sediment, and other sources. For nutrient sources with a hydrologic component, such as stormwater runoff and dry weather baseflow, both water quantity and water quality must be monitored to calculate nutrient loads. Monitoring of surface water quality is also recommended during this time to correlate watershed nutrient loads to receiving water quality. Vertical profiling of in situ parameters is also recommended throughout the water column depth in the monitoring period to assess stratification and internal processes. Although the monitoring cost can be substantial, it is most often very small compared to the cost of implementing nutrient reduction projects or the cost of implementing an ineffective solution.

Although modeling is often necessary to quantify watershed nutrient loads, models without field monitoring and calibration often overestimate nutrient loads by up to an order of magnitude. This can be a function of underestimated depressional storage and/or natural nutrient attenuation that occurs in the watershed and surface water system. Overestimation of nutrient loads leads to overestimating the required nutrient reduction and corresponding cost to achieve compliance and water quality improvement.

Step two involves evaluating potential point source solutions. This is only applicable if there are point source discharges containing nutrients in the watershed. Information about the point source discharge nutrient composition can be found in the National Pollutant Discharge Elimination System (NPDES) permit limits or monitoring reports. Examples of point source solutions to reduce effluent nutrient concentrations include biological and/or chemical treatment unit processes, membranes, and wetland treatment. Water volume reduction using infiltration basins or reuse may also be possible. Typical evaluation factors for all potential load reduction alternatives include nutrient load reduction, life cycle cost (capital plus ongoing operation and maintenance costs), life cycle cost per mass of nutrient removed, and greenhouse gas emissions. There may be other prioritization factors identified by the local entity for consideration, such as educational and recreational use, wildlife habitat, fisheries, and aesthetics.

Step three includes evaluating potential nonpoint source solutions. Examples of nonpoint source solutions include nonstructural practices (e.g., street sweeping, inlet inserts, end-of-pipe treatment for gross solids and sediment, and traditional treatment practices), wet ponds, dry basins, coagulant treatment, wetland treatment, and green stormwater infrastructure practices to reduce runoff volume (infiltration and reuse). Coagulant treatment, which involves precipitating phosphorus in an offline settling pond, is often the most cost-effective solution for phosphorus load reduction. Coagulant treatment also uses substantially less land than traditional wet ponds or dry basins. As an example, a 3-acre wet settling basin is used to treat stormwater runoff from a 1,200-acre urban watershed and achieve an 85 percent annual mass phosphorus reduction.

Stream restoration can reduce in-stream erosion and sediment/nutrient loads.

Step four involves evaluating in-water solutions to determine if they are feasible based on the type of water and primary nutrient sources. For lakes, examples include sediment removal, sediment phosphorus inactivation using a coagulant, recirculation treatment system, aeration/destratification, hypolimnetic oxygenation, and the treatment of surface water inflows using practices identified in step three for nonpoint sources. If bottom sediments are a primary source of phosphorus, and the existing water depth is acceptable, it is normally faster, much less disruptive, and much less expensive to complete a coagulant surface treatment rather than dredge and dispose of sediments off-site. For rivers and streams, example solutions are different and may include restoring creek natural hydrology, reconnecting creeks to wetlands/floodplains, improving creek riparian buffers, repairing or restoring degraded creek/tributary segments,

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removing sediment, aerating in-stream, containing or cleaning up point waste sources, and treating surface water inflows from tributaries.

The task of reducing the primary source of nutrients in a watershed is often complicated by regulatory authority and/or jurisdiction. As an example, assume the state environmental agency only has regulatory authority over point sources (wastewater and industrial discharges) in a nutrient TMDL watershed through the NPDES wastewater discharge permit. Although point source discharges may only be a minor source of nutrients, costly reductions to very low effluent concentrations may be required to meet the TMDL. Stormwater runoff may be the primary nutrient source, but it may not be regulated. This happens frequently and can be overcome using nutrient offsets or trading. Through the use of offsets and trading, the primary sources of nutrients in a watershed can be reduced in a more cost-effective manner.

Various options to cost-effectively reduce nutrient loads should be evaluated, including point source solutions, nonpoint source solutions, in-water solutions, and nutrient offsets and trading.

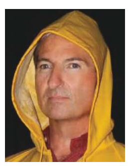
Proven Results

In Boise, ID, the city was required by the U.S. EPA to reduce the concentration of phosphorus in its wastewater facility effluent to 0.07 milligrams per liter (mg/L) to meet a phosphorus TMDL on the downstream Snake River. The wastewater facility discharges into the Boise River approximately 30 miles upstream of the TMDL water segment. Water from the Boise River is used for agricultural irrigation and returned to the Boise River. For this reason, much of the benefit of the upstream phosphorus reduction to a very low concentration would be lost through agricultural use.

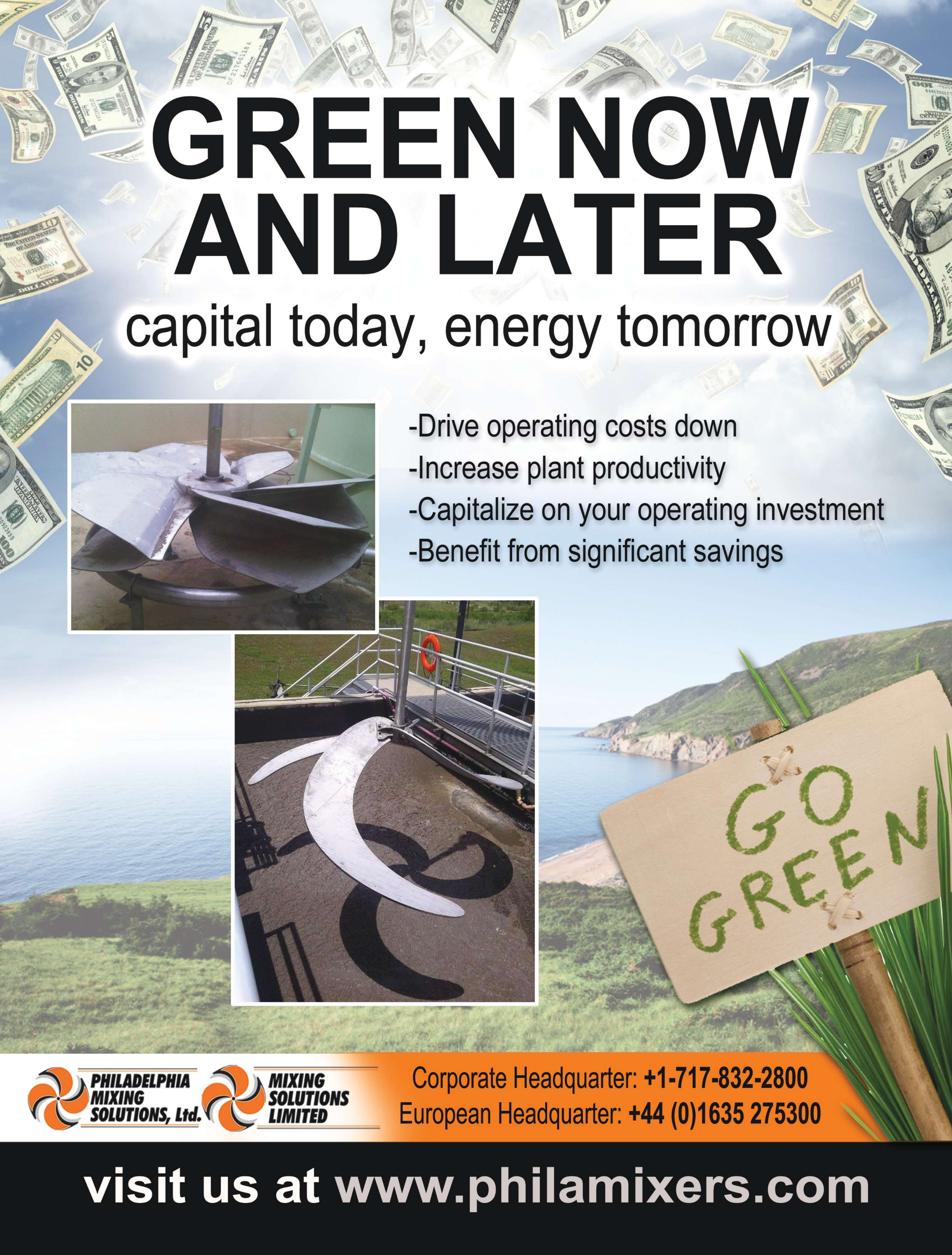
The city elected to partially reduce the phosphorus concentration in its wastewater effluent. The remaining required phosphorus load reduction (equivalent to an effluent of 0.07 mg/L phosphorus) will be achieved through a nutrient offset project. An offset project is typically owned and operated by the same entity responsible for NPDES permit compliance. The city purchased a parcel of land adjacent to an agricultural drain near the downstream end of the Boise River. A coagulant treatment project will be constructed to treat agricultural discharges from 40,000 acres of land. The capital cost for the coagulant treatment project is substantially less than the capital cost to achieve a phosphorus effluent concentration of 0.07 mg/L at the wastewater facilities. This treatment project will address a large agricultural drain, one of the primary sources of phosphorus in the watershed. In the absence of an offset project, this source would not have been treated in the watershed. In addition, the phosphorus reduction at the downstream end of the Boise River will result in lower phosphorus loads and additional environmental benefit for the Snake River. Requirements for both treatment facilities are included in the city's NPDES wastewater discharge permit issued by the EPA.

In north Georgia, the Coosa River drains into Lake Weiss in eastern Alabama. A phosphorus TMDL for Lake Weiss requires a 40 percent reduction of total phosphorus at the state line. There are a number of municipal and industrial discharges with NPDES wastewater discharge permits in the Coosa River Basin. There are no NPDES MS4 permits. For this reason, the state of Georgia only has the ability to regulate phosphorus discharges through the NPDES wastewater discharge permits. The state is requiring these point sources to reduce their effluent phosphorus concentrations. Chicken litter is generated in the watershed and commonly applied to agricultural fields in north Georgia for fertilizer. Primarily, the nitrogen is needed for its fertilizer value, but the phosphorus is not. The option of not using and exporting chicken litter from the basin is being considered in lieu of modifications at one or more of the wastewater facilities. This may provide an opportunity to achieve the required phosphorus load reduction at a lower cost. The details of this phosphorus trade would be incorporated into the NPDES wastewater discharge permit. In other locations in the U.S., formal nutrient trading programs have been established to assist local entities with satisfying TMDL nutrient reduction requirements. These include both point-to-point source and point-to-nonpoint source trading programs.

The overall objective of the watershed approach to nutrient management is to identify and implement cost-effective solutions that also maximize environmental benefits. This requires taking the time to develop a thorough understanding of the primary sources and magnitudes of nutrients in a watershed. Without this step, substantial funds may be spent with little or no environmental improvement. Various options to cost-effectively reduce nutrient loads should be evaluated, including point source solutions, nonpoint source solutions, in-water solutions, and nutrient offsets and trading. These options should focus on the primary sources of the nutrients of concern. The best solutions can then be planned and implemented based on total nutrient load reduction, cost-effectiveness, environmental benefit, and other factors established by the local entity. It is very important for local entities responsible for nutrient reductions to have a variety of options available to achieve compliance. Having options will lower the overall cost of nutrient solutions, increase total nutrient reductions, and result in greater surface water quality improvement. ■



Jeff Herr, P.E., D.WRE, is the national stormwater leader for Brown and Caldwell. He received B.S.E. and M.S.E. degrees in environmental engineering and has more than 30 years of professional experience in the areas of surface water quality assessment and restoration and watershed and stormwater management, working throughout the U.S.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Smarter Source Water: Could New Thinking Unite Industry And Environmentalists?

AMD can be a valuable resource for the oil and gas industry and result in cleaning up thousands of streams and rivers in the nation.

By Yves Pollart

Abandoned mine drainage (AMD) has long been a cause of concern in key geographies of the United States, namely, the Appalachian region of the Northeast and the Rocky Mountain region. In Pennsylvania alone, more than 300 million gallons of water are discharged from mines into the state's waterways each day. More than 5,500 miles of rivers and streams are affected by the toxic leakage.

Drainage from abandoned mine sites, often filled with high levels of metals, acidity, and sulfates, seeps or flows into nearby streams and rivers, killing all life in the water resources. While it takes significant time and effort to fix the widespread problem, local watershed groups and conservation organizations are making headway. In Pennsylvania, companies in the oil and gas industry can use such water in their operations and, with a recent change in regulatory guidance, can more effectively work with environmental groups to see this valuable resource brought back to life.

A completed abandoned mine drainage system

Industrial Use

In the past, industrial uses of AMD were not prevalent, mainly because of unclear liability issues after industries are finished using the resource, spurring energy industry possible users to find water resources elsewhere. However, as oil and gas companies continue to bolster economies in the U.S. and are continually in need of water resources, the tide is turning for AMD usage.

In the oil and gas industry, hydraulically stimulated wells require millions of gallons of water to extract natural gas from deep within the earth. This water supply has typically come from rivers, streams, and public water supplies. In states such as Pennsylvania, which is rich in nonpolluted water, energy industry giants have not traditionally explored the use of AMD. However, the Pennsylvania Department of Environmental Protection (PA DEP) released a white paper last year outlining a process to review AMD-use proposals from oil and gas operators. The document explores storage options for such water and describes possible solutions to long-term liability challenges. Because of this recent change, oil and gas companies could begin to install treatment systems, with the joint effect of cleaning up waterways while also using the treated AMD to continue hydraulic stimulation operations. The Pennsylvania Senate Appropriation Committee has already approved a bill (SB 411) shielding oil and gas developers from liability when using coal mine drainage.

Treatment Systems

A passive abandoned-mine treatment system uses little to no electricity to pass contaminated water from AMD discharges or contaminated streams through nearby aeration devices and settlement ponds, adding limestone along the way to increase the pH balance and alkalinity of the water. Aeration devices use gravity through step aeration, fountain aeration, or trompe aerators. This step provides oxygen needed for oxidation reactions, which are used to remove iron and acidity. The system adds limestone to create chemical reactions needed to start precipitating the metals, mostly aluminum and iron. As the pH increases, another chemical reaction occurs, and the metals take on a solid form. As the water comes to rest in a settling pond, the metals will slowly move to the bottom where they will be removed in a few years.

The water is then routed back into the nearby stream, still containing other nutrients, but with a high enough pH balance to cease the poisoning of the streams from the toxic metals. Aquatic life then begins to return to the surrounding waterways.

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Some treatment systems combine passive with an active component, such as using water power to constantly add lime to the water. In rare cases, an active treatment system is installed that mimics a traditional wastewater treatment plant; however, such systems are not often utilized because it is difficult to find ongoing funding to operate them.

Cost of a passive treatment system can range from about $300,000 to $1.5 million. Watersheds and local organizations often secure grant funding to install the systems, which then can operate for several years with very little maintenance other than adding chemicals on an as-needed basis. As more of these systems have come online in recent years, they are becoming more efficient and easier to operate. As the results and details are shared, treatment systems continue to become easier to install and maintain.

In regions of the U.S. lacking in pervasive water supplies, AMD can be an important consideration for the energy industry.

The Oil And Gas Industry

Because of the change in guidelines from the PA DEP, exploration and production companies are in the early stages of discussing options for using AMD in their operations in the Northeast.

One of the concerns oil and gas businesses have is sulfates in the water. Treatment systems described here generally aim to remove metals and acidity from AMD, rather than sulfates, because sulfates are necessary to spawn aquatic life in rejuvenated bodies of water.

But for oil and gas industry use, the sulfates remaining in traditionally treated mine water could pose a challenge. In the process of hydraulically stimulating a natural gas well, other metals are released from frissons hundreds of feet underground. One of those metals released in the Midwest is barium, which, if mixed with sulfate-rich water, combines to become barium sulfate. The result forms a thicker, sticky substance that can block the gas releasing from the underground fractures. This outcome is known as "scaling" and can reduce production of a well. Sulfates can be removed from AMD, though it requires a large-scale ecosystem involving wetlands and other components or a chemically heavy process.

However, in a peer-reviewed study recently released by researchers at Duke University, it was demonstrated that, when AMD was combined with wastewater from a hydraulically stimulated well, the chemicals in the drainage acted to neutralize radioactive material from the wastewater. The sulfates in AMD attached to radium and barium and created a solid, non-radioactive mineral known as strontium barite. With this knowledge, there could be a use for treated AMD in recycling wastewater from natural gas operations.

As more and more drills come online in the next few years in the Marcellus shale play, it's likely that natural gas operators will continue to explore options for AMD use. Stipulations include that operators must follow all applicable environmental laws and regulations when treating, using, storing, and moving the water.

In regions of the U.S. lacking in pervasive water supplies, AMD can be an important consideration for the energy industry. For instance, drought-stricken Colorado has 30,000 abandoned mines and more than 1,300 miles of affected streams. Water rights in that state differ from those in the Northeast, so AMD could be a viable source of water for natural gas drilling, reducing the need to source water from an already scarce supply so desperately needed for agricultural uses.

Using AMD has the potential to change operations for oil and gas companies. Operators could potentially partner with local watershed organizations to finance and construct the required treatment system. In these instances, the local community would operate the system, and the results would improve the environment and provide a necessary resource for operators. It becomes a win-win situation for all stakeholders.

Other effects of AMD use in the oil and gas industry include reduced truck traffic from having treated water potentially closer to well sites, rather than driven in from further afield, and consequently decreasing air pollution. This will also reduce the reliance on other sources of water by making a waste product — the treated AMD — now reusable and environmentally friendly.

Oil and gas companies utilizing AMD could also reduce their overall capital cost of developing a well and pass those savings on to consumers in the form of decreased gas prices.

As the oil and gas industry delves into using this valuable resource for its operations, streams throughout the country will come back to life and once again be a habitat for wildlife. Communities will work hand in hand with oil and gas companies to achieve environmental goals, leading to strong relationships as the industry continues to grow. ■

Yves Pollart, P.E., is the vice president of environmental engineering at RETTEW and is responsible for managing the group's studies, designs, and reviews of water treatment and storage facilities; abandoned mine drainage studies and remediation; and natural gas flowback treatment. He has more than 32 years of professional experience.

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An Operator's Guide To AOP

Here are principles and operational parameters to help today's wastewater plant operators figure out where AOP should and shouldn't be used.

By J.H. Wakefield

One of the current buzzwords in the waste treatment arena is AOP (advanced oxidation processes). It may have several different meanings depending on who is doing the talking, but it usually refers to enhanced methods of oxidizing wastestreams or components thereof. It should be used primarily in either the collection system or in the outgoing effluent in the final treatment phase of the wastewater treatment process. It may be used in the waste treatment plant as well, but it — like fire — is a faithful servant but a terrible master. Using enhanced oxidation processes within most treatment plants are ill-advised undertakings. So, in this introduction, I will confine my remarks to the collection system, the final "polishing" system, and a careful examination of the true nature of what AOP is.

There are four basic applications where AOP usage is of great benefit.

The most commonly used applications involve odor suppression, degradation of recalcitrant components of the wastestream, and control of microorganisms, usually pathogenic ones. How, when, and where these are affected will comprise the remainder of this introduction.

There are four basic applications where AOP usage is of great benefit:

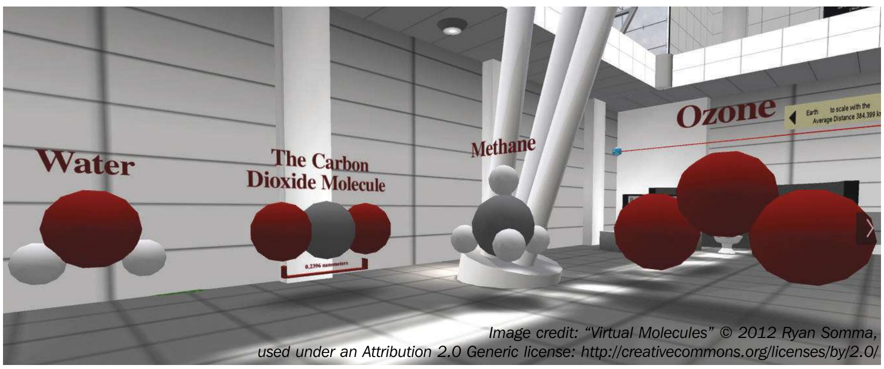
1. Where the presence of H_2S or other odoriferous compounds including 3-methylindole and a variety of mercaptans result in a big odor problem
2. Where the molecular disruption of selected problematical pharmaceuticals is necessitated to prevent a residual problem in water supplies and elsewhere
3. In the case of molecular disruption of recalcitrant compounds that could not otherwise be addressed
4. As an adjunct for dispersion/stabilization of microparticulates so that both suspended solids and emulsoids can be pumped from grease traps, lift stations, and other sites to prevent their "settling out" in the delivery lines

Let us concentrate our efforts with respect to ozone, especially with aerobic mixers, to three application areas: grease traps, selected lift stations, and downline treatment areas such as polishing ponds and effluvia of various sorts.

Ozone has usually been applied as an oxidizing agent and as a sterilant. The latter results from its oxidizing characteristics exclusively. We may utilize it to do both, though a primary use is for it to break down recalcitrant molecules encountered in FOG (fats, oils, and grease) deposits as well as to attack the unusually occurring compounds encountered in various wastestreams that are difficult to treat in other manners. Examples of these may include various hydrocarbons — heterocyclics, polyaromatic hydrocarbons, and other aromatic hydrocarbons that are difficult for bacteria to degrade and/or are toxic for specific microorganisms used in the degradation processes or for some other reason present aggravation in this manner.

In the cases where ozone treatment is effective, the resulting compounds formed are carbon dioxide, water, and various other oxides.

Another use found for ozone is to place an adsorbed charge on microparticulates engendered in aerobic mixers. This enables us to prevent them from settling out in the lines, to stabilize the suspensions formed so that they are pumpable, and to enable plant treatment



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The combination of ozone and hydroxyl radicals provides one of the most powerful oxidation products, which substantially reduces organic loading as well as microorganisms in wastewater.

operators to avoid "shear" problems in their clarifiers.

Another related application for aerobic mixers is the delivery of hybrid ozone to fluid streams containing metallic ions so that they precipitate or become complexed, making them more insoluble and easily removed.

The sizing of the delivered ozone depends on the actual problems encountered, the horsepower of the aerobic mixer's blower, the number of ozone tubes necessary to deliver whatever level of ozone we feel is adequate for the actual problems encountered, and taking into account any downline considerations such as impacting on microbial populations that are not targeted.

Grease traps require the highest ozone levels to effectuate grease management, to control odors (particularly H_2S), and to stabilize the suspension formed. The effect on the microbial community here is a relatively minor concern, as any buildup in microbial numbers would adversely affect any force main in the collection chain. Therefore, the sterilization effect of the ozone is a good thing in grease traps. Because of the relatively immediate reaction of the ozone we are using, dwell time and downline residuals can be safely ignored.

A more complex decision situation occurs where aerobic mixers are placed in lift stations. Here, we must consider several additional factors, mainly the distance from the waste treatment plant and, of course, the size of the lift station and where the situs of delivery is — that is, is it a force main, a secondary station, or a gravity-feed to the waste treatment plant? The reason that this must all be carefully considered is that we want to treat the wastestream and not adversely impact the treatment system by wantonly killing off essential microorganisms in the process.

At this point, the ozone generation becomes of interest as different ozones have different reaction characteristics, half-lives, and residual effects. We are discussing the use of a hybrid ozone that delivers an almost instantaneous reaction from both ozone itself and free-radical hydroxyl ions formed in this process of ozone generation. Residual moieties may be encountered, which are normally peroxide active-radicals. We have to be careful to limit these other moieties as they may be transported through the collection piping to affect the microorganisms in the waste treatment plant. Naturally, both the location and velocity of the wastestreams are taken into account. The sterilant effects of hybrid ozone come to the forefront in application to downstream effluvia, polishing ponds, and the use of various aerators to apply in most of these locales.

Let us examine the chemical nature of ozone so that we may better understand its effects.

Ozone is an allotrope of oxygen; that is to say, it is oxygen that manifests in a different atomic form. Normally, oxygen may exist in one of three allotropic forms — in the first, there is a single oxygen atom (O); in the second, there are two oxygen atoms (O_2); and in the third, there are three oxygen atoms (O_3). The first is known as monomolecular oxygen, the second is commonly encountered and called diatomic oxygen and more commonly referred to as molecular oxygen, and the third is called triatomic oxygen, more commonly referred to as ozone.

Chemically, oxygen is the second most active nonmetal. Metals are atoms that lose electrons and engender regions around the atom that are positively charged (+); conversely, nonmetals are atoms that gain electrons and engender regions around the atom that are negatively charged (-). All atoms in their native state consist of a neutral region caused by the balance of + and - charges, and these, in turn, are the result of the gain (or loss) of electrons. As an atomic nucleus has a + charge, the loss of an electron results in a net positive charge, and the gain of an electron conversely results in a net negative charge.

As these elemental atoms become larger, the tendency to become more active metals increases as the positive pull of the nucleus becomes weaker as a consequence of the outermost electrons being further removed from the nucleus. In nonmetals, this is just the opposite, as nonmetals are more active as the pull of the + nucleus affects the outermost electrons that are nearer to it, and nearer, in this case, relates to the decreased atomic size of the atoms.

As mentioned earlier, ozone is primarily used as an oxidant, and most of the other applications can be traced to this. To measure the activity of various oxidants, we can look at the oxidation-reduction potential of common oxidants comparatively.

The following are measured at 25°C (77.0°F) and are reported in volts:

- Ozone (O3): 2.87 [*gas*]
- Peroxide (H2O2): 1.76
Ozone is 63.1 percent greater [liquid/ionized form].
- Hypochlorite (HClO): 1.49
Ozone is 92.6 percent greater [hypochlorous acid].
- Chlorine (Cl2): 1.39
Ozone is 106.4 percent greater [gas].
- Bromine: 1.07
Ozone is 168.2 percent greater [liquid/gas].

Aerobic mixers polish a pond in Edmonton, Alberta.

Similar comparisons hold for various commonly used sterilants measured against ozone.

Hydroxyl radicals are generated by two means: (1) by breaking down hydrogen peroxide (H2O2) by irradiating the water with 254 nm UV or (2) combining ozone and water in the presence of 254 nm UV.

The AOP that we are discussing is employed in aerobic mixers by the second method of generating hydroxyl radicals in the presence of 254 nm UV. This system is compact and produces a concentrated and more effective oxidation process when applied using aerobic mixers from specific wastewater technology vendors.

Oxidation

When ozone reacts with BOD (biochemical oxygen demand) compounds, COD (chemical oxygen demand) compounds, FOG compounds, and combined halogens, it reduces (actually oxidizes) contaminants to nonproblematic compounds, even to carbon dioxide and water. Inert materials may be saline, silicon dioxide, or various other degraded compounds that are usually insoluble.

Ozone attacks many heavy metals in solution, e.g., iron, manganese, zinc, copper, and others. This advanced oxidation processing results in the breakdown of many pharmaceuticals as well as the killing of coliform bacteria and many viruses. Ozone may also oxidize hydrogen sulfide (H_2S) to (1) sulfur dioxide, SO_2, or (2) sulfite, SO_3=, or even (3) sulfate, SO_4=

This is the major reason AOP is so effective for air quality and odor control.

AOP (ozone combined with hydroxyl radicals) is 100 to 200 times more effective when properly injected directly into the water column where the hydrogen sulfide is produced. This hybrid ozone carries a half-life of up to 15 minutes. This half-life is variant depending on the wastestream treated; therefore, it is not to be confused with the "half-life" used as a designation for many radioisotopes, which are constant.

Usually ozone is applied as a fogging agent; this does not reach the source of the hydrogen sulfide. This method of fogging ozone is ineffective at destroying the source of the problem and often creates a more severe corrosion problem. The fogging approach reacts only with H_2S gas as it is released from the water column. To effectively eliminate H_2S, one must properly inject the ozone directly into the water column where the H_2S is originating.

The most efficient and, therefore, effective means of injecting ozone or concentrated oxygen into a fluid column requires a unique combination of coarse and fine bubble diffusion, released in a confined space or vessel under minimal pressure (<2.5 psi). Air under pressure generates heat, and heat can reduce oxygen transfer by as much as 80 percent. This may be achieved by means of a low-pressure, high-volume regenerative air blower.

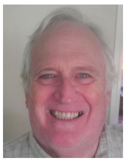
Ozone And Advanced Oxidation Combined

Hydroxyl radicals are an even more potent and powerful oxidizer than ozone alone. The combination of ozone and hydroxyl radicals provides one of the most powerful oxidation products, which substantially reduces organic loading as well as microorganisms in wastewater.

This hybrid ozone generation method allows one to:

1. Reduce the amount of ozone normally required
2. Improve the reaction time markedly (200X)
3. Address many complicated applications, particularly those prevalent in very large commercial, industrial, and municipal wastewater cleanup and remediation projects

AOP combined with an aerobic mixer delivery technology can now be used on varying scales to address a wide variety of difficult or previously impossible cleanup problems applying to wastewater treatment and environmental issues.■



Dr. J.H. Wakefield has been a consulting analytic chemist and a practicing chemical engineer (environmental/materials) for more than 30 years. He thanks DO2E for providing the AOP system and the aerobic mixers he discusses here.