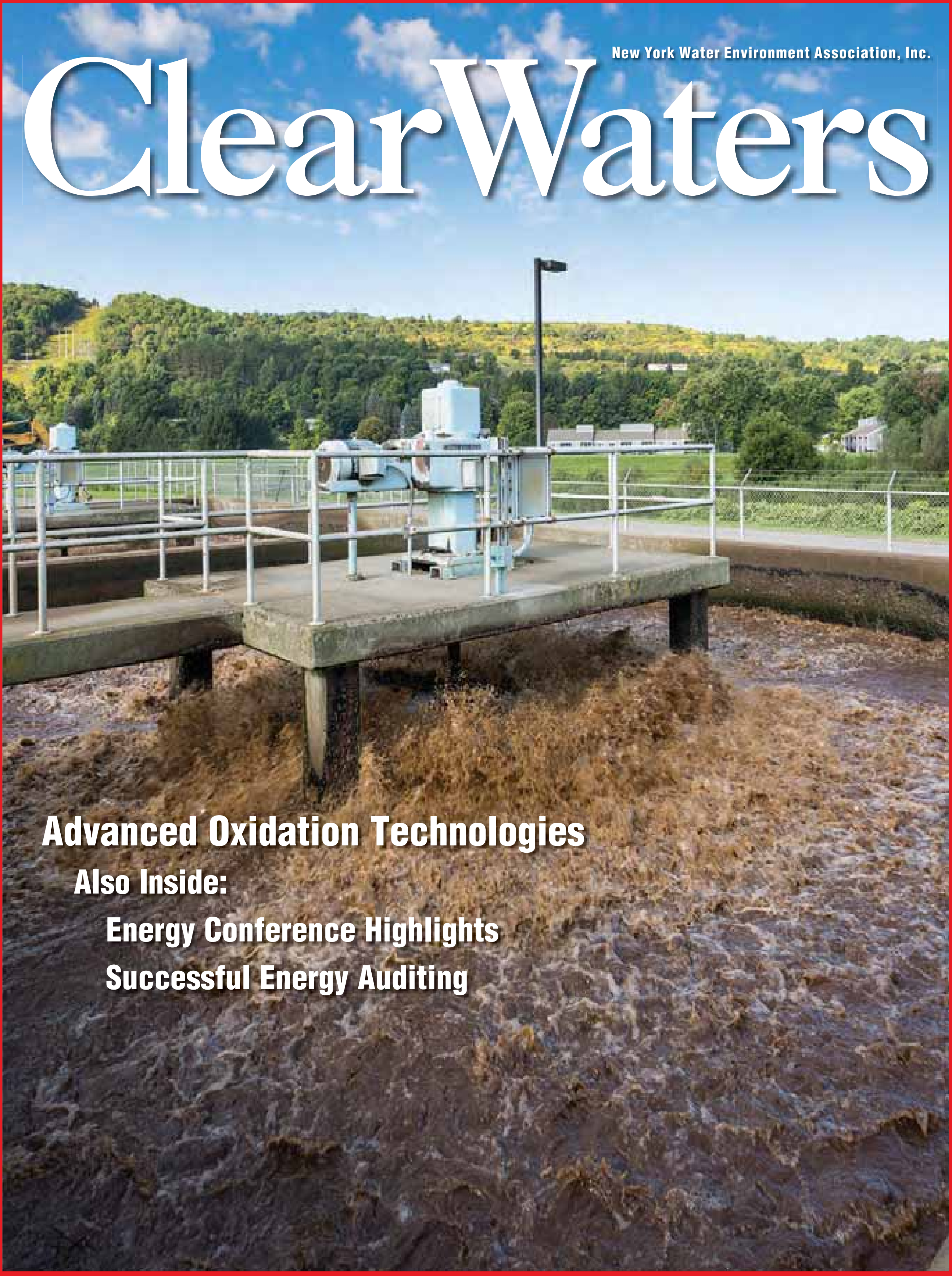
Winter 2014, Vol. 44, No. 4

New York Water Environment Association, Inc.

Clear Waters



Advanced Oxidation Technologies

Also Inside:

Energy Conference Highlights

Successful Energy Auditing

Winter 2014, Vol. 44, No. 4

Clear Waters

New York Water Environment Association, Inc.

Cover Image: The existing surface aerators shown here at the Hornell Water Pollution Control Plant (story inside) are being replaced with a more energy efficient system.

Image by Johnson Controls – Gary Hodges Photography

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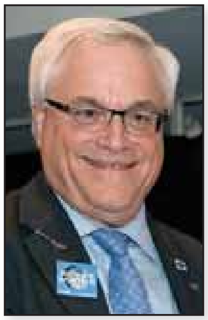
♻ **Clear Waters** ***is printed on recycled paper, using soy-based ink.***

President's Message | Winter 2014



87th Annual Meeting

The New York Water Environment Association's (NYWEA) 87th Annual Meeting will celebrate the 50th anniversary of New York's Pure Waters Program. Today's NYWEA members have little idea of what this program was, but many of our members remember it as the program that preceded the Clean Water Act and led the way to the improvements in water quality that we enjoy today in New York State. The Annual Meeting will return to New York City at the Marriott Marquis Hotel in the heart of Times Square, running from Monday–Wednesday, February 2 through February 4, 2015. Please join with all NYWEA members in the largest water quality technical conference and exhibition in New York.

The 26 technical sessions include wet weather issues, energy resiliency and green infrastructure, to name a few. The Technical Exhibition runs noon February 2 through all day February 3.

The Opening Session titled, "Sustainable Water Resource Management in the 21st Century," will include a discussion on the original New York Pure Waters Program and issues regarding water quality today and future goals, including refocusing sewage treatment plants to water resource recovery facilities.

Additionally, we honor the "Best of NYWEA" at the Wednesday Awards Luncheon and there are events for students and our "Young Professionals" as well. All this will be completed in a jam-packed three days.

Whether you need professional or operator's credits, want to find out the latest technological advances from vendors in the exhibit areas or would just like to network with NYWEA members, the 87th Annual Meeting is the place to be. Join us in New York City!

NYWEA Moving Forward in 2014

When I accepted the gavel from Past President Mark Koester at last February's annual meeting, I reflected on Mark's accomplishments and the goals for the coming year. Throughout this past year, our NYWEA members did not disappoint. As I previously reported, the Joint WEFMAX (Water Environment Federation Member Association Exchange) meeting held with our friends from the New Jersey Water Environment Association was a great success. We look forward to attending NJWEA's 100th Anniversary Celebration in Atlantic City in May 2015.

In April, NYWEA built on a history of previous Fly-In's to Washington, DC and it has strengthened our presence and voice on Capitol Hill. Also, we continued to bring NYWEA's voice to Albany through the Government Affairs Committee which coordinated the Legislative Dialogue program. Educating political and local leaders on environmental quality issues in New York through forums is a key NYWEA mission goal.

New at the Spring Technical Meeting the past year was the first Operations Challenge Regional Competition wherein NJWEA again participated with its nationally ranked Division I team, the New Jersey Devils. Using our home field advantage, the Metropolitan Chapter took top honors as New York State and Regional Champion.

Another first came in August with the first NYWEA CHAPEX (Chapter Exchange). The information exchange between chapters was enlightening, and planning will begin soon on the second CHAPEX in 2015. The Watershed Conference in September was successfully built on the partnerships developed with the New York City Environmental Protection Department, the Watershed Protection and Partnership Council and NY State Department of State. Finally, the Energy Conference held in Albany was a highly successful meeting with our partners from NYSERDA. The WEF president, Ed McCormick, gave the keynote luncheon address on the recent Energy Roadmap WEF publication, which he championed.

At WEFTEC in New Orleans in the fall, NYWEA continued its many partnerships by presenting on its successful Joint Meeting with NJWEA and participating in a leaders meeting with other Member Associations and WEF representatives. We also continued issues outreach with WEF and the National Association of Clean Water Agencies.

Our association's partnering efforts were demonstrated and our voice in water quality was heard also at the New York Conference of Mayors, the Hudson Valley Watershed Alliance, and Long Island Water Conference's Surface and Groundwater Quality meetings, to name a few. The Utility Executives Committee continued its voice on issues involving utility members from around the state.

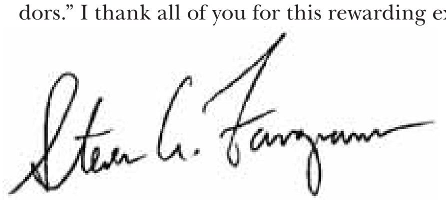
As you can tell, an overall theme of 2014 has been partnering and advocacy, efforts which have led NYWEA to being heard loud and clear on water quality in New York State and beyond.

Some Words of Thanks

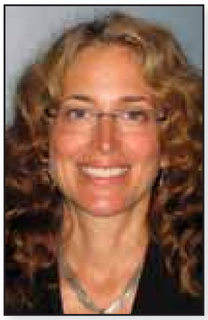
All of what is accomplished by NYWEA in any given year is a credit to our talented membership and the excellent executive office in Syracuse. As I visited or attended meetings in most of the seven chapters throughout the state, I recognized the diversity of our members and the events held. I cannot possibly summarize everything that I saw and heard. All I can say is that I was impressed by all of the talented members who I met and the enthusiasm expressed by so many for the work that was performed and the goals of clean water that all embraced.

I thank the volunteers throughout our organization, from the friends I worked with on the Executive Board and Board of Directors, to the many committees that perform the work of the Association and chapter-level leaders and members who drive all of us forward. I cannot forget Patricia Cerro Reehil, our executive director, and all of our executive office staff for the excellent work completed day in and day out.

I look forward to the Annual Meeting and to passing the gavel to Mike Garland, our next president in a long line of "water ambassadors." I thank all of you for this rewarding experience.



Steven A. Fangmann



NYWEA Experiences Strong Fiscal Year-End

NYWEA's fiscal year-end financial performance was better than anticipated with income over expenses coming in at $77,835. This is contrasted with budget expectations of $22,313. There are several items attributable for this positive financial picture that runs from 9/1–8/31, and includes the successful 86th Annual Meeting last year, the Spring Technical Conference held in Hauppauge in June, as well as the 2013 Joint NYSAWWA Watershed Tifft Science and Technical Symposium in September at West Point.

I'm also pleased to report that since taking on the administration of the State Wastewater Operator Certification Program three years ago, we landed solidly in the black for 2014. This, after two years of deficits and not meeting budget expectations. One-hundred-and sixty-five new operators became certified from September 1, 2013 to August 31, 2014 and 451 operators renewed their licenses. The number of renewing operators increased significantly over the previous two years (250 in 2013 and 214 in 2012) and is directly correlated to the five-year renewal cycle. NYWEA's Publications account that includes the finances for *Clear Waters* magazine continues to be a successful program and has met or exceeded budget expectations for the past eight years. Other successful programs include the Member Education Committee's operator training series that brought 18 training classes to 655 members. To learn more about NYWEA's successful programs carried out in 2014, look for the Administrative Dashboard that will be posted on the website in January.

Prudent financial planning by NYWEA's Board of Directors and the Investment Committee, has resulted in the association being able to transfer surplus monies into investments at this successful year's end. Reserves are being built up in good times to assist the organization if/when tough times occur. To more clearly focus our financial lens, the Board of Directors recently approved revisions to the Accounting and Financial Procedures Manual which includes a series of financial policies to help guide the efficient operation of how the association and its seven chapters manage their budgets. Included in the manual is an investment policy, officer and operations travel policies, as well as expense payment and committee budget request forms. It is my hope that this document will assist staff, the finance committee, chapter officers and the NYWEA board on taking the appropriate actions regarding the organization's finances.

We are working to continually improve the programs that NYWEA carries out. As we embark on a new Strategic Planning session in 2015, we welcome your input, ideas and energy to help us advance the noteworthy mission of the New York Water Environment Association.

NYSDEC's Water Management Advisory Committee (WMAC)

NYWEA is a member of the NYSDEC Water Management Advisory Committee and attending these meetings helps staff and officers to learn about policy changes and updates that affect members. At the November 6 meeting, members of NYSDEC's Division of Water team discussed the Sewage Pollution Right to Know Law and introduced the NY-Alert online program for reporting. NYWEA members Tim Taber and Yoon Choi serve on WMAC's Wastewater Infrastructure Sub-committee focusing on asset management. Involvement on such committees gives NYWEA a voice on important polices and allows a forum for exchange of information.

On the Horizon

Members Only Area of Website: As an action identified in the Strategic Plan, and in response to members' needs and feedback received on meeting evaluations, a "members only" area of the website is being developed and will be rolled out in early 2015. Stay tuned for directions on how to access unique information that will enhance and add value to your membership.

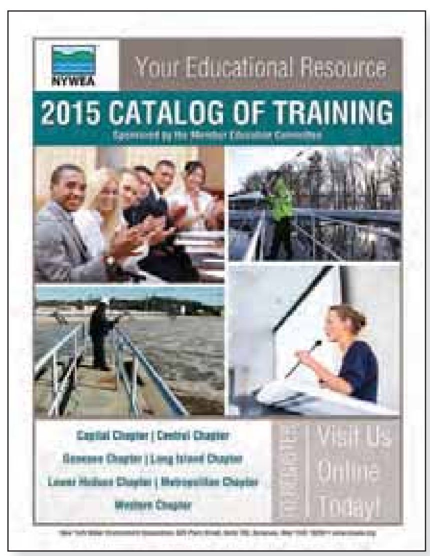
Gratitude and Appreciation

As I reflect on our programs, it is important to recognize that our success is in large part due to the generosity of our exhibitors, sponsors, advertisers, new and renewing members, and all of the many volunteer hours hundreds of members spend to help us further NYWEA's mission. With the end-of-year holiday season, it is fitting to share our gratitude to all that made this past year so successful. On behalf of the association, many thanks to each one of you and I wish you all the very best in the coming year!

Patricia Cerro-Reehil
pcr@nywea.org

The 2015 Training Catalog has Arrived!

NYWEA exists to enrich the lives of its members through educational training opportunities that include the added benefit of networking with peers and others interested in the profession. The 2015 Training Catalog includes 19 events scheduled throughout the year. To view the catalog, visit the NYWEA website today at www.nywea.org.



Desmond Hotel, Albany, NY

Highlights of Energy Specialty Conference

"Utilities of the Future" (UotF) is not just some buzz phrase for those in the wastewater treatment industry. Reclaiming and reusing water while saving money and energy is nothing but smart and necessary, both for the industry's success and the public health, and for the foreseeable future. With UotF the focus of discussion at the NYWEA and NYSERDA-sponsored Energy Specialty Conference held November 20, over 120 utility managers, environmental consultants and other water quality experts convened in Albany to share the newest in projects and ideas.

The four main topic sessions: Anaerobic Digestion, Resource Recovery and Net Neutrality; Innovative Low Energy Treatment/Resource Recovery Technologies/Strategies; Energy Efficiency; and, Innovative On-Site Power Generation Technologies and Financing Mechanisms, hosted 20 panels with over 30 experts coming from around the state and Northeast. Impressive and comprehensive, each power discussion delved deep into the details of such issues as net zero energy to power exporting, facilitating public/private partnerships for nutrient resource recovery, using algae to create biofuel, the utilization of biogas and the effects of energy efficiency on wastewater rate structures, and so much more!

The Opening Plenary Session was introduced by NYWEA President Steven Fangmann, executive vice president of Dvirka and Bartilucci, and included three presentations: the current energy positions of New York State's water resource recovery facilities as reported by the Water Environment Research Foundation; a case study at the Ithaca WWTF on energy production and reduction; and integrated resource management in New England by USEPA Region I.

Another highlight of the conference was having the Water Environment Federation President, Ed McCormick, as the featured luncheon speaker, whose topic was: "Directions to the Utility of the Future."

Many thanks also go to the several exhibitors who participated: ClearCove Systems, Demand Response Partners, G.P. Jager & Associates, Inc., GEM Energy, Koester Associates, Inc., MICROrganic Technologies, Milton CAT, Natural Systems Utilities (NSU) and Unison Solutions.

Kathleen O'Connor, conference coordinator, introduces Jason Turgeon from USEPA, Region I.

Joe Brilling, Washington County Sewer District Executive Director, served as a moderator on Energy Efficiency.

NYWEA President Steve Fangmann and WEF President Ed McCormick welcome participants.

Laura Bendernagel of Hazen & Sawyer speaks on use of algae to clean wastewater and create biofuel in New York City.

Dan Ramer from the Ithaca Water Resource Recovery Facility talks about how the City of Ithaca focused on taking advantage of local waste streams to increase energy production.

Ian Diamond of Solar City speaks on the state of solar energy in New York.

Peter May of Biohabitats Inc. discusses a pilot project using algae to clean wastewater and create biofuel.

Peter Radosta of Koester Associates talks about Ogdensburg's energy optimization using high speed blowers, fine bubble aeration and digester gas conditioning.

Ed Weinberg of ESSRE Consulting reports on wastewater resource recovery to produce biogas and enhance nutrient reduction.

Tyler Masick is a wastewater engineer at Gloversville-Johnstown Water Resource Recovery Facility.

George Bevington speaks on the experience of Gloversville-Johnstown moving from net zero to power exporter.

Nate Carr of the Quasar Energy Group talks about a renewable energy project using anaerobic digestion upgrades to create savings.

Kun (Arthur) Xiang from SUNY Binghamton talks about clean energy from wastes using sustainable harvesting.

Mark Greene from O'Brien & Gere describes enhanced primary treatment technology.

Lauren Ray of GEM Energy talks about the funding and design process for microturbine systems.

Right: Scott Hutchins from the US Department of Energy

Silvia Marpicati of ARCADIS discusses optimizing an aeration system.

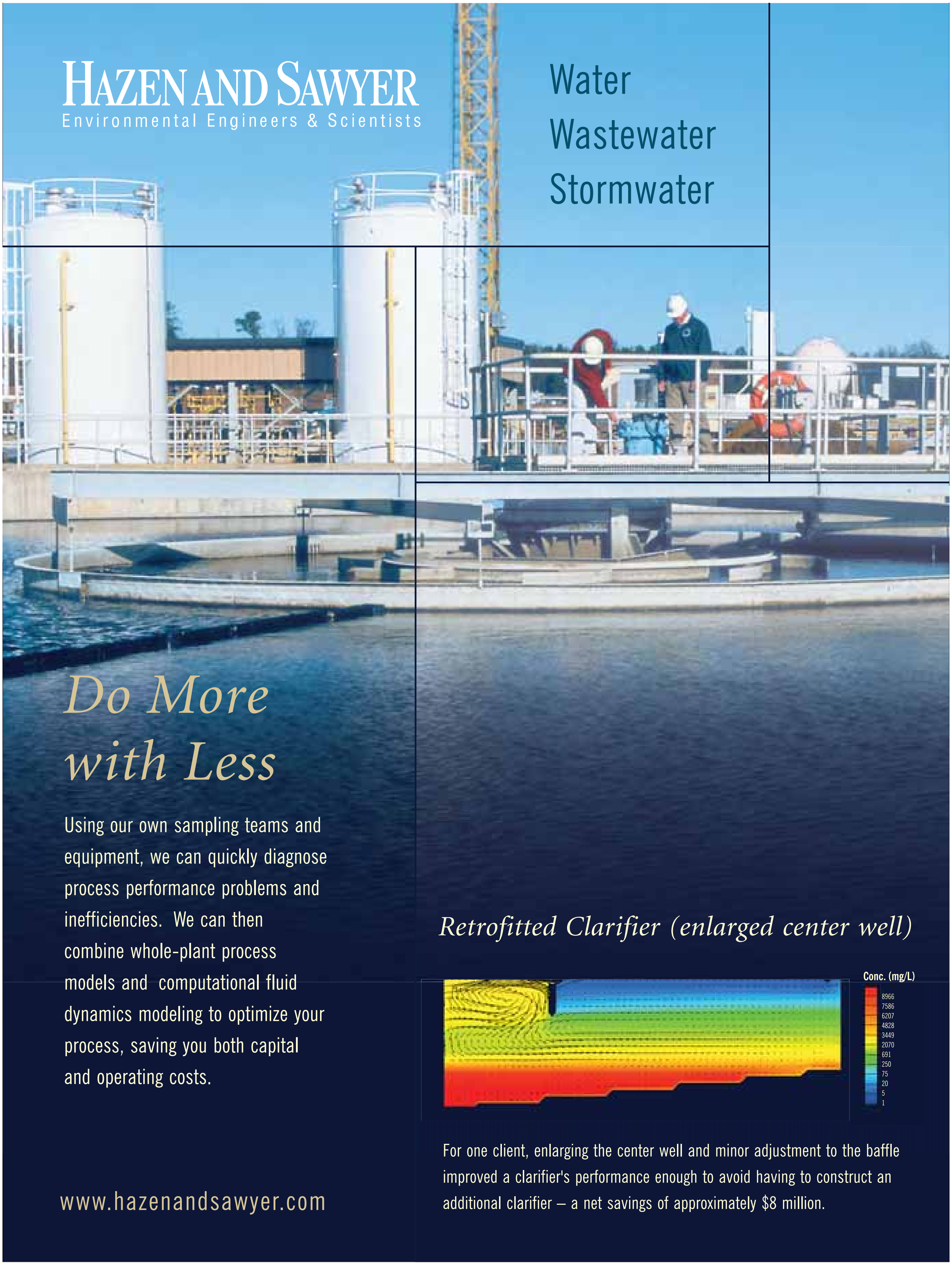
Luigi Tiberi of Ovivo USA discusses linear motion mixing technology.

Nancy Andrews from Brown and Caldwell speaks on the WERF barriers to energy efficiency.

Jason Turgeon, USEPA Region I, chats with Brent Solina from MicrOrganic Technologies.

Those in attendance listened, took notes and provided input.

Conference photos continued on page 60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For one client, enlarging the center well and minor adjustment to the baffle improved a clarifier's performance enough to avoid having to construct an additional clarifier – a net savings of approximately $8 million.

Water Views | Winter 2014

Building on Resiliency

Superstorm Sandy, Hurricane Irene, Tropical Storm Lee and other extreme weather events have triggered deeper thinking about ways to be resilient. A key approach that New York is pursuing through an array of programs is sometimes referred to as the "multiple-barrier" approach. Multiple layers of resilient systems can "add up" to provide much higher levels of overall protection; it also makes sense from the vantage point of not putting all of your eggs in one basket. We are also finding that some proposed resiliency solutions have multiple co-benefits.

Let me share an example. Long Island's south shore is clearly vulnerable to storm damage. Many projects are completed and more are being designed to restore dunes and other coastal protections, purchase or elevate homes, improve "natural infrastructure" and rebuild public infrastructure along the coast with increased resiliency. As part of this effort, an interesting connection has been made: high levels of nutrient nitrogen in water surrounding Long Island are degrading and damaging the marshlands that provide a significant level of wave and tidal surge attenuation during storms. The NYSDEC has published reports discussing this problem and recommending solutions.

We know that excess nitrogen fuels an array of algae blooms – harming swimming, fishing and boating, and the tourist economy. The hard clam industry that once thrived on the south shore of Long Island is mostly gone. The extent of ecologically important eel grass beds is dramatically diminished. I could go on.

To preserve and restore marshlands and to improve water quality we need to reduce nitrogen pollution. Indeed, NYSDEC now views reducing nitrogen pollution in Long Island as a fundamental element of efforts to promote coastal resiliency. Without reducing nitrogen pollution we will lose the existing marshlands, and many efforts to expand marshes or otherwise restore protective natural marshland infrastructure are likely to fail.

In the Western Bays of Nassau County, most of the excess nitrogen comes from sewage effluent, specifically the Bay Park Wastewater Treatment Plant. To protect the Western Bays and their extensive marshlands, New York has supported the creation of a discharge pipe from the Bay Park facility well out into the Atlantic Ocean. The ocean can assimilate the nitrogen far better than the shallow, warmer back-bay. New York is also supporting the installation of a mid-stage level of nitrogen treatment at the Bay Park facility. Interestingly, this is a resiliency proposal, one that New York hopes to accomplish with $700 million in FEMA Public Assistance dollars.

In Suffolk County, the main source of nitrogen pollution is the 360,000 structures that employ septic systems or cesspools that are not designed to remove nitrogen. A key proposal is to jump start efforts to extend sewers in four "hot-spot" coastal areas and to upgrade nitrogen treatment in various septic systems. Suffolk County has shown great leadership in this regard. Yes, this is a critically important water quality issue. But here too, New York is proposing to use a significant allotment of federal resiliency funds to address nitrogen pollution to increase resiliency.

In the face of climate change, we all need to think harder and see the connections.

– James Tierney, Assistant Commissioner for Water Resources
NYS Department of Environmental Conservation

Focus on Safety | Winter 2014

Hierarchy of Risk Controls

Usually, safety professionals are idealistic enough to want everything to be easy and safe. However, most are sufficiently pragmatic to realize that if a situation is improving, we will claim that as a win. Suffice it to say, total zero risk is often an elusive target. A hierarchy of controls outlines the various steps that will reduce the risk of a hazardous process. The steps are: *Elimination, Substitution, Engineering, Administrative,* and *Personal Protective Equipment (PPE).*

The most effective techniques are *elimination* of a hazard and *substitution* with a lower risk profile. In advanced oxidation processes (AOPs), heavy duty industrial chemicals may be eliminated and replaced by more innocuous methods. In one case, perhaps chlorine is eliminated and replaced by ultraviolet (UV) light, ozone, hydrogen peroxide or a combination thereof. With *Engineering* advances (or simplification) the task is redesigned to a safer level. Again, UV light and ozone are already in place for water disinfection in many plants and could be used in the wastewater treatment process. Rather than having to construct an elaborate new facility to house common AOP technologies, some portions of the process may already exist. The familiarity of UV and ozone is an added advantage as such technology is readily understood by most technicians.

Less effective, but still important, is the *administration* of the process to control the risk. Administrative control is considered a less effective means of risk control because it depends on personal compliance and behaviors. This involves policies, procedures and training for the staff to follow when working with any hazard. For instance, even though hydrogen peroxide is a great substitute for chlorine, the industrial version is still much stronger than the bottle on the drugstore shelf. Hydrogen peroxide needs to be treated with the respect it deserves since it remains an industrial chemical, but its risk profile is significantly less than that of chlorine. Thus, specific procedures and training must be developed as the more employees are familiar with the benefits and risks of a process, the safer for them and for the public. Training remains one of the most important aspects of any industrial process. While providing the appropriate *personal protective equipment* is also important, one must realize that this is the last line of defense for the individual. If the PPE is lacking or inadequate, there is no fallback position.

Often, hazards are inherent to the industrial processes in our plants. It is incumbent on us as managers, supervisors and involved individuals to make our work environments as safe as possible given the different settings and parameters with which we're faced.

– Eileen M. Reynolds, Certified Safety Professional
Owner, Coracle Safety Management

Oxidation of Sludge – Options to Consider

by Kristin Waller and Mark Greene

Oxidation is a chemical reaction where an oxidizing agent or oxidant loses an electron. These reactions are coupled with a simultaneous reduction reaction, where a compound accepts or gains the electron lost through oxidation. Through the combined process of these reactions, chemical compounds can be broken down and transformed. When these reactions are used to treat sludge, they can cause microbial cells to rupture or breakdown.

Sludge oxidation can be performed through the addition of strong oxidants, like ozone, or using thermal combustion. Oxidation using strong oxidants has been shown to improve the biodegradability of the sludge, allowing microorganisms to process sludge more efficiently. Whereas, thermal combustion uses extreme heat to incinerate sludge and minimize overall sludge production.

Two emerging sludge oxidation technologies, Praxair's sludge ozonation process and Infilco's Thermylis™ high temperature fluid bed system (HTFB), were reviewed as a part of a larger sludge minimization and stabilization literature study for a municipal wastewater treatment plant (WWTP) in Perrysburg, Ohio. The process, benefits and setbacks of these sludge oxidation technologies are summarized here.

Ozonation

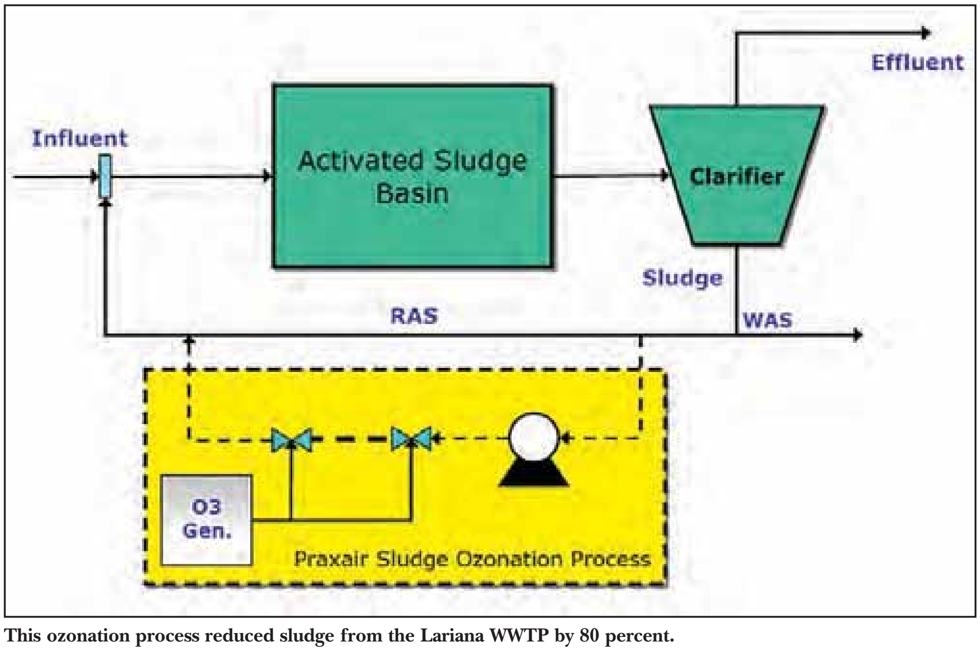
Oxidation using ozone, or ozonation, is a process that uses the strong oxidizing action of ozone to cause cell lysis in sludge. Ozonation is typically used to treat return activated sludge (RAS) from secondary treatment reactors in order to minimize excess sludge generation through the secondary treatment process *(Fabiyi 2008)*.

Traditional secondary treatment processes encourage the growth of biomass in order to treat chemical oxygen demand (COD), or more specifically, biochemical oxygen demand (BOD_5) in the waste stream. While this process is effective, the excess biomass generated can be large in volume and costly to dispose. In the Praxair process, a portion of a WWTP's RAS stream is passed through a plug flow ozone contact system before it is returned to the secondary treatment reactors. The ozonation process breaks open biomass in the RAS stream, releasing the contents of the cells. The ozonation process converts excess biomass into substrates readily available for the microbial growth in the secondary treatment reactors.

The application of ozone to sludge is carefully controlled and applied (using multiple injection loops to maximize the sludge-ozone in contact) in order to optimize the effectiveness of ozone to break open cells and minimize wasteful ozone consumption. Furthermore, the Praxair contact process allows excess oxygen, typically seen as a waste gas in other ozonation systems, to be dissolved into the RAS stream, providing supplementary dissolved oxygen (DO) to secondary treatment *(Fabiyi 2008)*. This additional DO may be beneficial to WWTPs with aerated activated sludge systems (e.g., blowers may be turned down). However, at plants where advanced nutrient removal schemes are used, the additional DO in the RAS stream may be detrimental to anaerobic or anoxic zones to where RAS may be returned.

The Praxair process has been tested in the US at laboratory scale (Illinois) and in Italy at pilot scale (Lariana WWTP, Como, Italy). Bench testing of the process was first conducted in the US to measure the biodegradability of lysis products generated through the Praxair process and to confirm the products would not inhibit COD removal in secondary treatment. The initial testing reported an average COD removal efficiency of 80 percent, suggesting the cell lysis products from the process could be efficiently removed when returned to aerobic secondary treatment. This conclusion was also confirmed by pilot testing, as the COD removal efficiency at the Lariana WWTP remained at 80 percent (average value) through the pilot testing period *(Fabiyi 2008)*.

At the Lariana WWTP, the Praxair process reduced sludge generation for the plant by 80 percent (from 2 dry tons/day to 0.4 dry tons/day) using ozone dosages between 0.05 and 0.10 kg O_3/kg suspended solids (SS) removed. In addition, the DO level in the secondary aeration basin was increased (from 1 mg/L to 2–3 mg/L) and a previous foaming issue (a persistent 20 cm foam layer at the top of the aeration basin) was quickly eliminated when the pilot system was put online *(Fabiyi 2008)*. Improvements in overall process stability, settling, dewatering and effluent quality (de-colorization) were also reported from the pilot testing *(Fabiyi 2008 and Praxair)*.

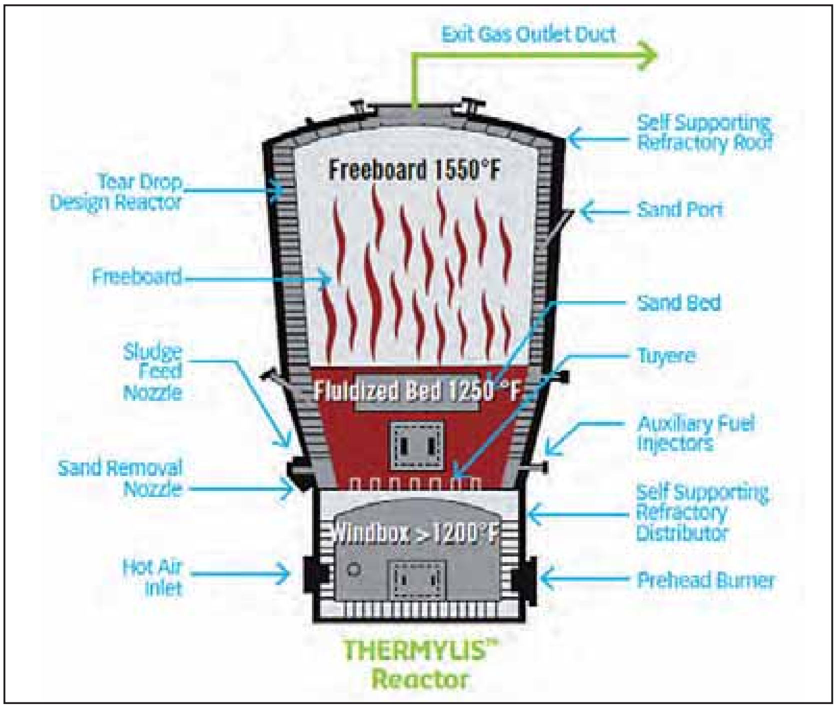


This ozonation process reduced sludge from the Lariana WWTP by 80 percent.

Thermal Oxidation

In a thermal oxidation process, extreme heat (>649˚C) is applied to a sludge in order to oxidize or combust organic materials and evaporate off water, reducing the overall volume of sludge *(Infilco)*. In the past, multiple hearth furnaces were the predominant wastewater treatment thermal oxidation technology; however, in recent years, more efficient fluidized bed reactors have become more prevalent in newly designed systems *(Lundberg 2004)*.

The Thermylis™ system (a trademark of Infilco) is a fluid bed incinerator that uses time, temperature and turbulence to reduce the overall volume of sludge. Heat and turbulence are distributed in the system by the action of a "fluidized bed," which is created by blowing hot air up through a bed of sand, causing the sand to fluidize (i.e., boil violently). The delivery of air through the sand bed is regulated using a refractory-lined windbox and refractory arch distributor, which ensure that air is distributed evenly through the sand bed. When dewatered sludge is introduced into the hot fluidized sand bed, the high heat and turbulence of the bed instantly combust organic materials in the sludge and evaporate off excess water, reducing the sludge to a much smaller volume of inert ash. If needed, auxiliary fuel may also be added into the fluidized bed reactor; however, the process is reportedly autothermic, requiring no additional fuel, assuming a typical undigested sludge at 26 to 28 percent total solids (TS) is used. Combustion gases and steam produced by the incineration process flow upward into a teardrop-shaped freeboard. The higher heat (1,550°F) and additional gas retention time (6.5 seconds) provided by the freeboard ensures complete combustion of process gases. Remaining heat in the exhaust gas is then used to pre-heat fluidizing air (to above 1,200°F), which minimizes auxiliary fuel needed for the process. If required by local regulations, the Thermylis™ system can also include a scrubbing system for emission control, which can be designed to meet or exceed the most stringent air emission standards.



This fluid bed incinerator is applied to oxidize organic intervals, reducing the overall volume of sludge.

When the Thermylis™ system is used to incinerate sludge, the process is reported to eliminate odors and destroy all combustibles and pathogens, producing an inert ash material. The ash material produced from the process can be as low as 7 percent of the influent sludge material by weight, reducing the overall weight of sludge in need of disposal by 93 percent. While the Thermylis™ system has been marketed as a stand-alone sludge reduction technology, additional studies suggest that when a fluidized bed reactor is used as a pre- or post-treatment to anaerobic digestion, the efficiency of sludge treatment can increase. Specifically, when incineration is coupled with a digestion process, energies from each technology can be used to supplement one another, or produce a surplus of energy to be used in other areas of the plant. Excess heat from incineration can be further used in a heated anaerobic digestion process and methane produced in digestion can be used to pre-heat fluidized bed air if needed *(Lundberg 2004)*.

Oxidizing Sludge Options

Strong oxidants and extreme heat can be effectively used to oxidize sludge. Adding strong oxidants like ozone has been shown to improve the biodegradability of sludge, where adding extreme heat has been shown to minimize the overall volume of sludge produced.

Praxair's ozonation technology has been successfully used to treat RAS, minimizing sludge generation in a secondary aeration plant up to 80 percent. In addition to the sludge minimization benefits, the ozonation process also gives off excess oxygen, which can be beneficial to aerated treatment systems (in basin DO increased from 1 mg/L to 2–3 mg/L in full scale testing, without blower increases). Additionally, improvements in stability, settling, foam-management and dewatering may also be realized.

Infilco's Thermylis™ system not only oxidizes sludge, but also evaporates off water from the system, reducing the overall volume of sludge produced up to 93 percent (by weight) and significantly reducing odors. The system may be used as a stand-alone technology to produce Class A biosolids, or may be used pre- or post-anaerobic digestion for additional efficiency improvements.

Kristen Waller (kristen.waller@obg.com) is a Wastewater Project Engineer at O'Brien and Gere in Syracuse, NY. Mark Greene is Technical Director for Wastewater, also at O'Brien and Gere.

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Ozone Pretreatment for Membranes Improves Performance and Lowers Cost

by Louis LeBrun

Until recently, ozone has seen limited use for pretreatment of hollow-fiber ultra filtration (UF) and micro filtration (MF) projects. This is unfortunate since ozone provides approximately 53 percent more oxidative capacity than sodium hypochlorite (NaOCl) or other chlorine derivative compounds. The main aversions to ozone treatment have been both its cost and complexity to implement, as well as a fear of adequate process control to prevent chemical attack to the membrane filter elements themselves. Fortunately, recent developments in ozone technology can adequately address these issues. Results from two facilities employing ozone pretreatment to membranes illustrate the advantages of this new process.

Ozone has been effectively used for disinfection in municipal water treatment applications since the early 1900s. More recently, a growing body of evidence shows that ozone oxidation is very efficient at removing a whole class of organic compounds related to disinfection by-products (DBPs), trihalomethanes (THMs), and a new class of contaminants such as trace pharmaceuticals and other organics collectively called endocrine disrupting compounds (EDCs). Despite the treatment benefits, limitations of conventional ozone technology have restricted its use to mostly the larger (>40 mgd) treatment plants. Over the years, smaller systems have explored ozone treatment to find its process engineering, maintenance, and complexity limitations too costly and difficult to justify. Ironically, given today's operating challenges, these same small to medium-sized facilities are the ones that might benefit the most from ozone treatment.

Over the past 10 years, advances in process instrumentation, control and automation have made their way into almost every facet of life, and ozone technology is no exception. Recently, a new class of modular ozone generators and "smart" controls technology are revolutionizing the way ozone is generated, applied and maintained in the field. As a result, the engineering complexity, maintenance and operating cost of newer systems are significantly reduced. Together, these new technologies are a good fit for small to medium-sized water and wastewater treatment facilities looking to improve performance while also reducing the cost and complexity of treatment.

Photo by Louis LeBrun, Pinnacle Ozone

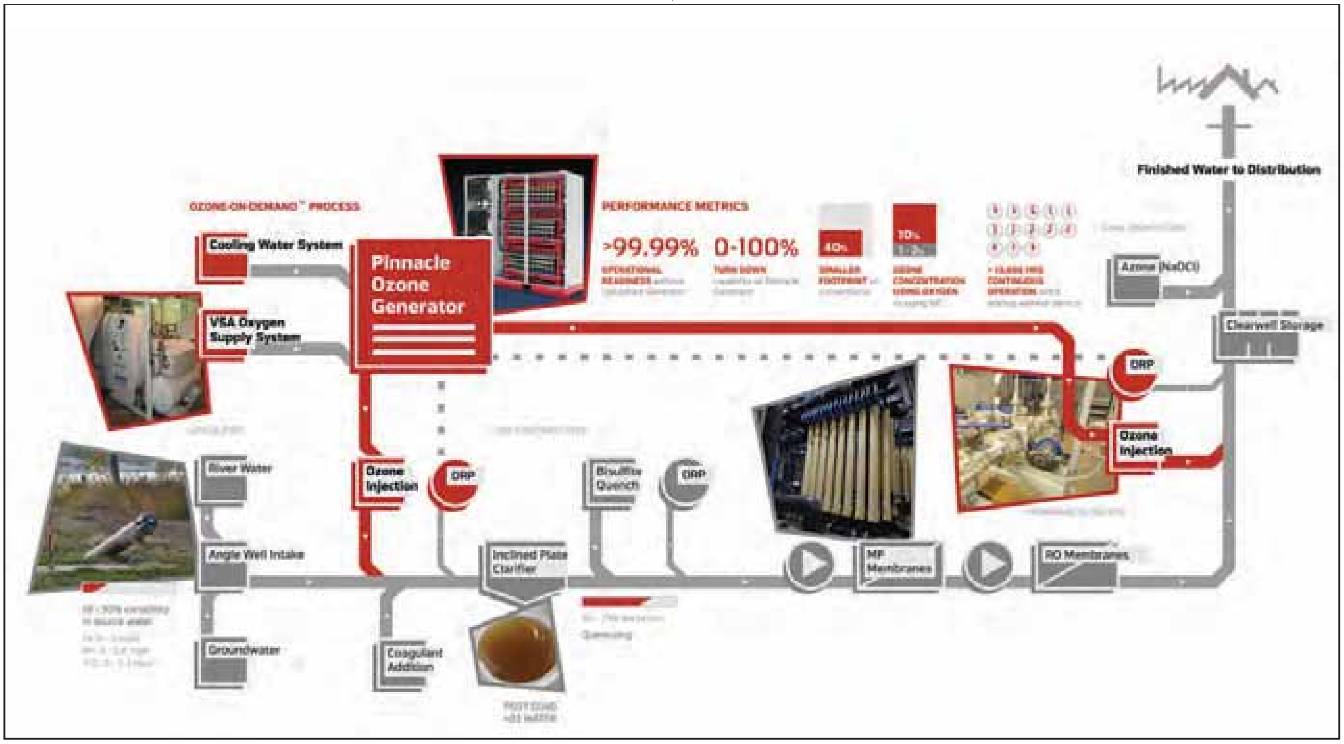
Installed Pinnacle system at Emmons, ND, water treatment plant

The North Burleigh Water Treatment Plant (WTP) near Bismarck, ND is unique in that it draws source water from a series of horizontal wells drilled into a shallow sand layer beneath the nearby Missouri River. The configuration of the intake results in the plant receiving a continuously variable mix of surface and groundwater with raw water concentrations of dissolved iron (Fe), manganese (Mn), and total organic carbon (TOC) which can fluctuate by more than 30 percent in a given day. Seasonal water quality fluctuations and water temperature extremes compound these issues making control of the microfiltration and reverse osmosis treatment process extremely challenging. To address these issues, the WTP uses ozone for pretreatment before the MF membranes, and again for final disinfection of treated water.

From August 2009 through March 2010, the Burleigh plant completed an expansion and upgrade to 2.5 million gallons per day (mgd), which more than doubled the size of the facility. Another important aspect of project improvements involved the existing ozone system to increase output and enhance process control. The new system is based on modular ozone generator technology, which allows for complete integration of all ozone process controls. The complete system includes onsite oxygen generation, dual ozone injection skids and complete dissolved ozone process controls for both pretreatment and finished water disinfection. A key to system performance is its ability to provide constant ozone concentration (8 percent by-weight) across a wide (0–100 percent) efficient operating range, or turn-down. Automatic process control allows the facility to continuously adjust ozone dosing based on real-time water quality conditions with minimal operator input. As a result, the system continuously provides "just enough" ozone to meet treatment conditions without the danger of overdosing, and this alleviates concerns about damage to the membrane system.

Another project specific challenge at the Burleigh site was space. In order to keep total project costs within the available budget, all of the new ozone equipment needed to fit within existing building footprint. This was a particularly difficult challenge since only approximately 300 square feet was available to accommodate the new ozone equipment. Fortunately, modular ozone technology is approximately 50 percent smaller than comparably-sized conventional systems. By designing around a modular system, the Burleigh plant was able to double its ozone capacity within the available space while also leaving the existing ozone equipment in place to serve as emergency backup.

The benefits of the new ozone system were immediately clear on startup of the expanded plant in March 2010. Beyond more than doubling ozone capacity to 120 lb/d, the new ozone system



Courtesy of Pinnacle Ozone

A diagram of the ozone-on-demand process used at the described treatment plants

seamlessly and automatically manages ozone dosing for both pre-treatment and disinfection. Evaluation of performance data before and after the upgrade shows a remarkable improvement in performance and operating cost. The new system has delivered 64 percent more treated water at approximately 44 percent *lower* unit operating cost. Most significant in the operating cost savings are the approximately 67 percent lower maintenance cost and 8 percent lower chemical cost. Moreover, the new plant successfully ran for over 40,000 hours (approximately 4.5 years) with no maintenance to the ozone system. When maintenance was recently completed, the work consisted mainly of recalibrating process instrumentation and providing refresher training to the operations staff at the plant. Based on this success, in 2012 the owner constructed a nearly identical treatment facility in Emmons, ND that has demonstrated very similar results.

Ozone System Cost Savings, North Burleigh, WTP, Bismarck, ND 2010–2012

The results from the Burleigh and Emmons treatment plants represent an exciting development trend for membrane treatment facilities looking for higher levels of pretreatment. Modular ozone generator technology can offer significantly enhanced pre-treatment for iron, manganese, organics, disinfection byproducts (DBP)/ trihalomethanes (THMs), and emerging endocrine-disrupting compounds issues, that are a major challenge at many facilities. Integrated controls, constant ozone concentration, and 0–100 percent turn-down make new ozone an excellent fit for many facilities looking to improve treatment performance while also lowering their treatment costs.

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Net OPEX (operating expenses) Savings 2010–2012. North Burleigh, WTP, Bismarck, ND

Month	Power $/kGal	Chem $/kGal	Supply $/kGal	Maintenance $/kGal	Labor $/kGal	Source Maint $/kGal	Testing $/kGal	Unit OPEX $/kGal
January	23%	5%	-70%	-63%	-68%	109%	-59%	-37%
February	-4%	-18%	-76%	-71%	-75%	64%	-68%	-51%
March	6%	-9%	-74%	-68%	-72%	81%	-65%	-46%
April	11%	-5%	-73%	-67%	-71%	88%	-63%	-43%
May	10%	-6%	-73%	-67%	-71%	87%	-64%	-44%
June	12%	-4%	-72%	-66%	-71%	91%	-63%	-43%
July	6%	-9%	-74%	-68%	-72%	80%	-65%	-46%
Annual Avg:	**9%**	**-7%**	**-73%**	**-67%**	**-72%**	**86%**	**-64%**	**-44%**

Peracetic Acid as an Alternative Disinfectant

by Jacquelyn N. Wilson

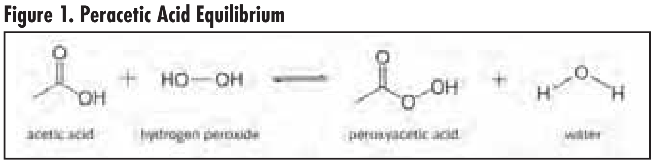
Throughout the world, the most commonly utilized wastewater disinfectant is chlorine, usually added as sodium or calcium hypochlorite, with use of a dechlorination method. Chlorine is a persistent disinfectant, which does not degrade in the environment and so must be quenched, typically with sodium bisulfite, in order to meet effluent permit requirements. The wide span use of this product is primarily due to its inexpensiveness and accessibility. However, recent health concerns have emerged regarding the harmful by-products produced by chlorination. In surface waters pretreated with high doses of chlorine, formation of total organic halides are produced which show long-term toxic risks.

In order to reduce disinfection by-products (DBPs) formation, alternatives to disinfection treatment have gained momentous traction in the water and wastewater industries. Combinations of commonly used disinfectants, such as ultraviolet (UV) and chlorine, have been pursued as viable options for reducing total organic halide concentrations. Additional research has been performed to find an alternative disinfectant similar to chlorine that does not produce harmful by-products – in other words, peracetic acid.

Background of PAA

Peracetic acid, or peroxyacetic acid (PAA), is an aqueous equilibrium solution of acetic acid, hydrogen peroxide and water. The equilibrium is represented in ***Figure 1***. PAA has been used in the food and beverage and paper industries for many years and has been studied in wastewater disinfection since the 1980s. Peracetic acid's direct oxidation and destruction of the cell wall of microbial pathogens allows for its prime candidacy as a disinfectant in wastewater treatment.

Figure 1. Peracetic Acid Equilibrium



Peracetic acid (peroxyacetic acid) exists in an equilibrium between acetic acid, hydrogen peroxide and water. *Courtesy of PERAGreen Solutions, LLC*

Peracetic acid has a diverse repertoire of uses including: disinfection of secondary systems, disinfection of combined sewer overflow (CSO) and sanitary sewer overflow (SSO) systems, filter cleaning, algal and snail fouling, and bypass/redirect/blend system disinfection. The product is dependent upon contact time, mixing and starting dose. Peracetic acid has been seen to be relatively insensitive toward suspended solids when provided enough contact time, thus making it a prime candidate for CSO disinfection. However, the best results for PAA disinfection can be seen after filtered tertiary effluents.

Properties

The PAA product is a colorless, clear liquid with no foaming capabilities. A strong vinegar odor is observed due to the acetic acid concentration, and the odor is more pungent with increasing concentration strength. The pH is less than 2 with a specific gravity of 1.10 to 1.11, depending on temperature. The freezing point of the product is 40.3°C. The product is produced by reacting acetic acid and hydrogen peroxide over a few days in order to achieve high yields. Commercially, this product is available in concentrations from 2 to 15 percent weight/weight. Though peroxide is also a commonly recognized disinfectant, the active disinfecting agent within this equilibrium – PAA – is highly active at low concentrations across a wide range of microorganisms.

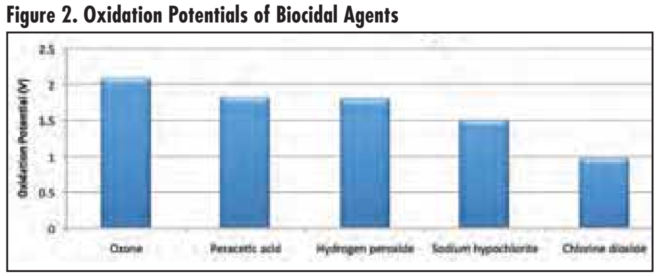
The germicidal properties of PAA are found to be bactericidal at 0.001 percent; fungicidal at 0.003 percent; and, sporicidal at 0.3 percent. The disinfection efficacy of PAA on microorganisms can be ranked as: bacteria>viruses>bacterial spores>protozoan cysts. Its bactericidal effectiveness is dependent upon the organism. A specific fecal coliform bacterium, *E. coli*, has been found to show low resistance to the PAA mechanism, and similarly fecal coliform in general. Following in susceptibility to PAA disinfection are enterococcus (fecal bacterium), giardia (protozoan parasite) and cryptosporidium (microscopic parasite).

Disinfection by-product formation during PAA disinfection has been studied and found that no brominated or chlorinated phenols are formed. The peracetic acid decomposition products are acetic acid, hydrogen peroxide, oxygen and water. Peracetic acid can be consumed in an aqueous solution in three ways: spontaneous decomposition, hydrolysis and transition-metal-catalyzed decomposition. High levels of solids in the water system can also consume PAA, so adequate dosage and contact time is required for disinfection. Within the pH range of 5.5 to 8.2, spontaneous decomposition of PAA to acetic acid and oxygen occurs. Peracetic acid produces little to no toxic or mutagenic by-products after reaction with organic material in wastewater effluents or surface waters. By-products produced are mainly carboxylic acids, which are not recognized as mutagenic. No halogen disinfection by-products have been observed.

Mechanism

Similar to chlorine, PAA is an oxidizing agent. It oxidizes the outer cell membrane of bacterial cells by disrupting the function of the lipoprotein cytoplasmic membrane and the transport through cell walls. Oxidations occur by the transfer of electrons – the stronger the oxidizer, the faster the electrons are transferred to the microorganism and the faster the microorganism is inactivated or killed. Peracetic acid has the second highest oxidation potential, next to ozone, among common disinfectants as shown in ***Figure 2***.

Figure 2. Oxidation Potentials of Biocidal Agents



(Source: Lorecheim, 2010)

Common disinfectants utilize oxidation methods for pathogen inactivation. The stronger the oxidant, the faster the inactivation.

Peracetic acid reacts with organic matter in sewage water systems. The greater the amount of organics, the longer the reaction time required for disinfection. In systems with little organic

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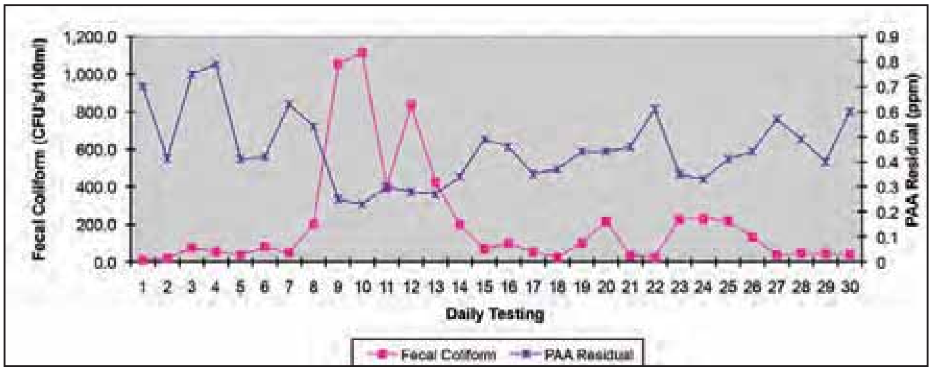
matter, holding times of less than 10 minutes are functional for disinfection. Highly organic systems require up to 30 minutes or greater, depending on the system.

Figure 4. Fecal Coliform vs. PAA Outfall Residual



Courtesy of PERAGreen Solutions, LLC

Peracetic acid exhibits a residual floor that must be maintained in order to achieve permitted pathogen levels. If a residual of 0.3–0.4 ppm is not maintained, pathogen levels will spike.

Applications

Peracetic acid is commonly used as a disinfectant in the food, beverage and paper industries and has begun gaining traction in wastewater and water treatment. Studies of PAA have been performed globally and are cropping up in North America at an increasing rate. North America now has several active PAA applications at wastewater facilities. The product is being used as a tertiary disinfectant, CSO disinfectant, blend/bypass/redirect disinfectant, enhancing UV disinfection, and lagoon disinfectant ***(Figure 3)***.

In secondary systems, PAA has been seen to outperform chlorine and bisulfite applications in pathogen reduction as well as cost. Research had previously suggested that PAA was too expensive to produce due to limited production globally, however, studies show that product feed is so low to achieve kill that a 26 percent cost reduction is possible when compared with chlorination/dechlorination. Typical feed rates for secondary systems are found to be below 1.0 ppm. In order to achieve maximum pathogen reduction, a residual floor of 0.35-0.40 ppm must be maintained as seen in ***Figure 4***. A hand-held DPD test using a total chlorine colorimeter can be used to monitor residual and establish control.

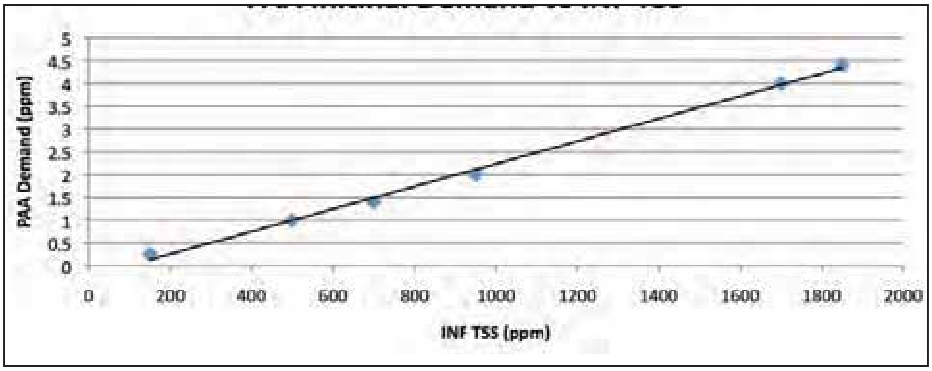
Courtesy of Largo WWTP, FL

Figure 3. Largo Wastewater Treatment Plant in Florida. A peracetic acid pilot study was performed at the Largo WWTP in Florida. The facility looks to use PAA as a disinfectant in the future.

Systems feeding PAA have seen tremendous success and versatility in the use of the product. Peracetic acid has been shown to bring plants into compliance within a half-hour of feeding, reduce pathogen levels by 25 percent within five seconds and handle pathogen spikes up to 290,000 CFU/100 mL without changing dosage. To increase pathogen kill, a combination of UV and PAA disinfectants can be utilized. This is known as an advanced oxidation process that occurs as the UV light enhances the formation of radicals such as hydroxyl groups, found in PAA, making the environment unfavorable to the survivability of the microbes. Peracetic acid naturally decomposes and at effluent discharges, PAA residuals decrease in concentration by 94 percent eight feet into the receiving stream from the outfall point from 0.39 ppm in the effluent overflow to 0.02 ppm.

In CSO and lagoon applications, the increase organic material and solids levels can increase the starting dosage required as well as the contact time needed for treatment. Solids levels and PAA dosage can be seen to follow a straight line curve as shown in ***Figure 5***. As the total suspended solids and volatile suspended solids (TSS/VSS) levels increase, so too does the feeding dose of PAA increase. The product requires increased time to penetrate the solids membrane and fully kill the pathogens inside, therefore, a longer holding time after injection is desirable. The increase in dose required for solids can be seen to influence the "initial demand" on the product, after which achieved the PAA uptake drops and begins to degrade naturally ***(Figure 6)***.

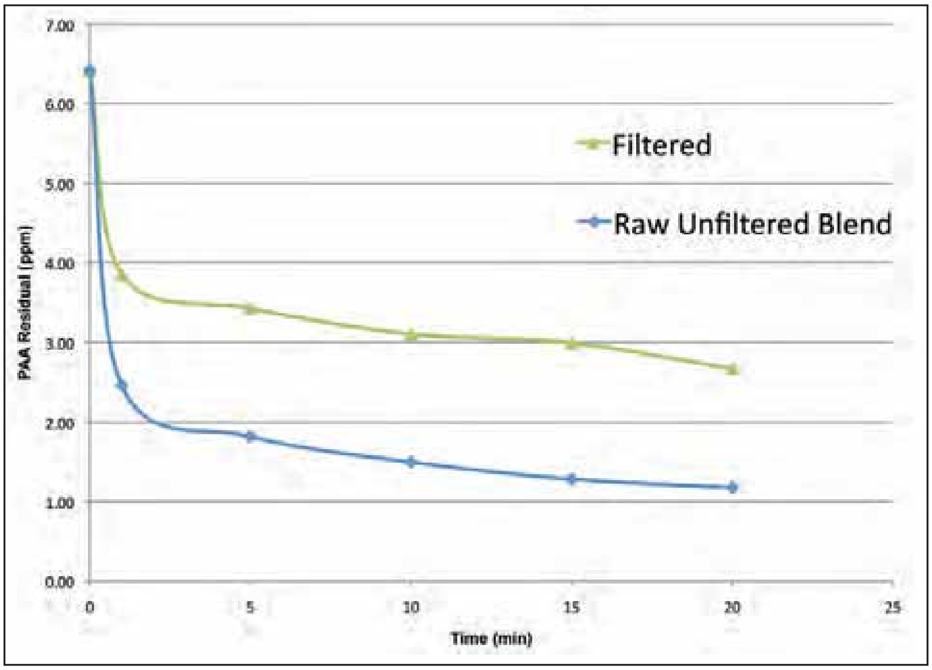
Figure 5. SPAA Initinal Demand vs INF TSS



Courtesy of PERAGreen Solutions, LLC

The direct correlation between solids levels and PAA dose shows the higher the solids, the greater the required dose of PAA.

Figure 6. PAA Uptake Curve



Courtesy of PERAGreen Solutions, LLC

Solids removal elevates some of the "initial" demand on PAA, allowing for a faster kill.

PAA Viable Alternative Disinfectant

Pilot studies, virus testing and water treatment studies are being conducted throughout the United States and the use of peracetic acid is becoming increasingly common in municipalities. Peracetic acid is a viable alternative disinfectant that produces no harmful by-products, achieves pathogen reduction, and is cost effective. Further work must be conducted with regulatory agencies involved in permitting in order to ensure full understanding of the product and to accurately monitor it.

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Ultraviolet Advanced Oxidation Processes – Application Considerations

by Steven Day

Advanced oxidation processes (AOPs) are capable of treating a broad range of contaminants in water reuse, industrial wastewater and groundwater treatment applications. Ultraviolet advanced oxidation (UV AOP) uses ultraviolet light in conjunction with standard oxidants, such as hydrogen peroxide (H_2O_2) and ozone, to achieve greatly increased treatment performance over that obtained with either hydrogen peroxide or ozone alone.

The most common UV AOP process is the use of UV with hydrogen peroxide. Ultraviolet light is used to split the hydrogen peroxide molecule, producing very reactive hydroxyl radicals (•OH). These hydroxyl radicals then quickly react with organic contaminants in the water, and can completely break down (mineralize) toxic compounds into carbon dioxide and water. In most applications, this level of treatment is not necessary, as when the treatment objective for the target contaminant is reached, the oxidation products (typically low molecular weight aldehydes or carboxylic acids) are not problematic from a regulatory or toxicity viewpoint and are readily biodegradable.

The key advantage of UV AOP is its inherent destructive nature; a wide range of contaminants are destroyed onsite with no requirement for disposal of secondary product. There is no transfer of contaminants from one medium to another. Furthermore, UV systems in combination with hydrogen peroxide have no vapor emissions; hence, no air permit is required. The equipment is quiet, compact and unobtrusive, and preventative maintenance and operating requirements are low in a carefully designed system.

UV AOP Principles

The UV AOP provides two distinct mechanisms for treatment of organic contaminants: direct photolysis and oxidation via hydroxyl radicals. Additionally, the disinfection of pathogens occurs as the UV dose required for AOP generally exceeds that for required disinfection.

Photolysis involves the interaction of light with molecules to bring about their dissociation into fragments. For the absorption of a photon by a molecule to cause photolysis (dissociation), the photon energy must exceed the energy of the bond to be broken. This requires that the wavelength be in the ultraviolet region of the spectrum for most photolytic reactions. Compounds that absorb UV light and have high quantum yields of photolysis arc good candidates for photo degradation. Examples of these classes of compounds include N-Nitrosodimethylamine (NDMA) and various chlorinated alkenes and aromatics (i.e., TCE and PCP).

Oxidation is the chemical conversion of a contaminant to more oxygenated forms by means of reactions with oxidizing agents. In UV AOP, a known concentration of hydrogen peroxide is injected upstream of the UV reactor, which is activated by the UV light to form oxidizing hydroxyl radicals. A typical UV AOP system is shown in ***Figure 1***.

Application Design

The UV AOP is increasingly considered and applied to indirect and potable reuse applications for recalcitrant compounds not effectively removed by other processes in the treatment train. A typical treatment train could include microfiltration, reverse osmosis or activated carbon followed by UV AOP. Additionally, UV AOP has been successfully applied to groundwater remediation for over two decades.

Treatment requirements and favorable economics versus alternate technologies should be carefully considered when looking at UV AOP. Experience and economic analysis has shown that in some instances where concentrations of target contaminants are greater than 10 ppm, a hybrid approach with activated carbon may be the most cost effective solution.

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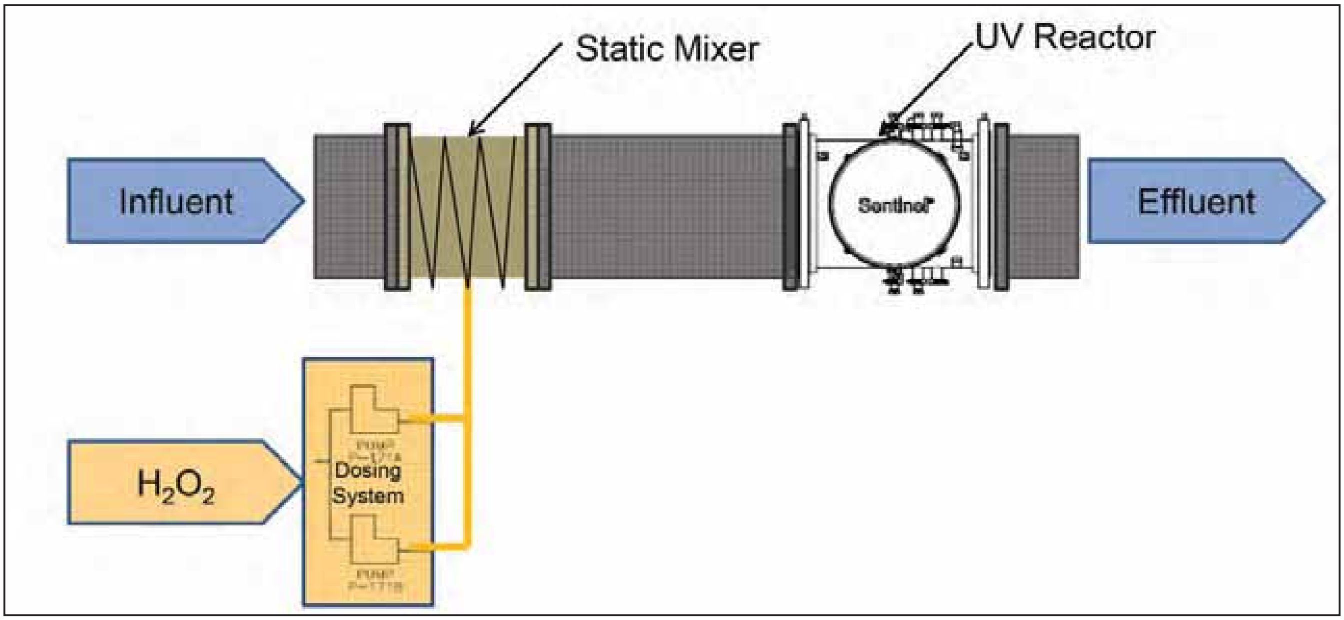

Courtesy of Calgon Carbon Corp.

Figure 1. Typical UV AOP System

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Suppliers of UV AOP solutions can initially design and provide cost estimates with a good characterization of the water and treatment objectives using computational models. Flow rate, contaminant concentration and UV absorbance are the most critical design parameters. The chemical oxygen demand (COD), alkalinity, hardness, concentration of certain metal ions (e.g., iron), and the total suspended solids are also important.

Compounds that have a fast or moderate reaction rate with the hydroxyl radical will be treated more efficiently and economically. Fast reaction rates include compounds such as vinyl chloride, PCE, TCE, atrazine, 1,4-dioxane, NDMA, and the taste and odor compounds, 2-methylisoborneol (MIB) and geosmin (algal metabolites). Efficiency will be limited for some compounds with slow reaction rates, such as chlorinated alkanes, nitrobenzene and derivatives, and freons.

Other factors that reduce UV AOP efficiency include:

- Presence of radical scavengers (i.e., carbonate and bicarbonate ions, chloride ion and natural organic matter)
- Substances that absorb UV photons (i.e., nitrate, dyes)
- High strength waters with organics in excess of 100 to 1,000 mg/L

Often a design test is appropriate to empirically confirm the initial design and cost estimates made by the UV AOP supplier. This test is typically carried out on a representative sample of the water to be treated and is used to optimize the UV dose and hydrogen peroxide concentration and to confirm the rate of target destruction and scavenging potential of background water constituents. Design tests can be performed at different scales, ranging from testing six gallon batches in a batch reactor to a small sample using a collimated beam.

Upon completion of the design test, the UV AOP supplier can reliably predict scale up of the system and would report and confirm the following:

- An assessment of treatment alternatives evaluated and selection of key design parameters of UV power radiated per volume of water treated and H_2O_2 concentration
- A fixed price quotation for the proposed system
- A statement of performance guarantee and warranty for the system
- An estimate of operating costs
- A schematic flow diagram of the proposed system

Suitability for Reuse and Remediation

For indirect and potable reuse applications, UV AOP is an essential part of the treatment process.. It can be used to treat some contaminants found in wastewater which are recalcitrant to other treatment processes. It can be used against trace organic compounds, including endocrine disrupting compounds (EDC) and pharmaceutical and personal care products (PPCP), which together are classified as contaminants of emerging concern (CEC). This UV process can also destroy volatile and semi-volatile organic compounds (VOCs, SVOCs) – some of which are not effectively removed by granular activated carbon (GAC).

For over 20 years, UV AOP has been successfully used in groundwater remediation. Common pollutants found in groundwater include:

- BTEX – Aromatic compounds, which include benzene, toluene, ethylbenzene and xylene, are found primarily in gasoline and are common contaminants found leaking from underground storage tanks. Concentrations are found in the range from low ppb levels to 100 ppm.
- DCE, TCE, PCE, VC – These compounds (dichloroethylene, trichloroethylenc, perchloroethylene and vinyl chloride) are found in most contaminated groundwaters in the ppb and low ppm levels with TCE identified as the most common pollutant in groundwater. These compounds have seen extensive use as cleaning solvents.
- NDMA – Nitrosodimethylamine is found in some groundwaters and wastewaters, usually in ppb levels, and in water being treated for potable reuse. The most efficient method of treating this compound is UV photolysis.

A UV reactor treating NDMA for potable reuse water via direct photolysis is shown in ***Figure 2*** below.

UV AOP: A Powerful Alternative

A powerful oxidation method, UV AOP is considered for destruction of traditional and emerging contaminants in water reuse and groundwater remediation. The design for a specific application has some complexity because of the chemistry of advanced oxidation. However, there is now a wealth of experience in UV AOP treatment over many applications and the knowledge base on capabilities continues to expand. A design test on a representative sample of the target water is often recommended to size the system. Results of the design test are used for accurate scale up to full-scale design and cost.

As with all treatment technologies, it is important to fully characterize the process and compare the capital and operating costs of UV AOP compared with other alternatives.

Steven Day is Marketing Director for Calgon Carbon's UV Technologies Division and Hyde Marine. He oversees the marketing and product line management functions for UV, advanced oxidation and filtration-based solutions directed at ballast water treatment, drinking water, and wastewater markets. Day has a BS degree in Operations Research/Information Engineering from Cornell University and an MBA from Duquesne University. Calgon is represented by Siewert Equipment in Upstate New York.

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Courtesy of Calgon Carbon Corp.

Figure 2. UV AOP system used to treat pollutant NDMA for potable reuse

UV's Role in the Advanced Oxidation Process – Challenging the Norm

by Jon C. McClean

Modern drinking water facilities face an array of complex and sometimes contradictory problems. On one hand, there is the need to treat micro-organisms that are becoming increasingly chlorine tolerant, while also mitigating the disinfection byproducts caused by high doses of chlorine. At the same time the new emerging contaminants are treated, such as pesticides caused by more intensive land use, pharmaceutical products are consumed in ever increasing quantities by an expanding, aging population. These emerging contaminants are collectively called compounds of emerging concern (CEC).

Water scarcity will inevitably lead to more reuse of water, which will highlight the need to develop and add process barriers to remove these contaminants from the water supply. Few conventional drinking water processes can address this issue, and almost no conventional municipal wastewater process is capable of targeting these problem compounds.

Metabolized and un-metabolized pharmaceutical and personal care products (PPCP's) are not new, however, their potential to cause effect on living tissue is now subject to much scrutiny. A study[1] by the US Geological Survey published in 2002 brought attention to PPCPs in water. Following sampling of 139 susceptible streams in 30 states, detectable quantities of PPCPs were found in 80 percent of the streams.

PPCPs include:

- Sun-screen products
- Prescription and over-the-counter therapeutic drugs
- Diagnostic agents
- Veterinary drugs
- Fragrances
- Cosmetics
- Nutraceuticals (e.g., vitamins)

Sources of PPCPs:

- Agribusiness
- Residues from hospitals
- Human activity
- Residues from pharmaceutical manufacturing (well defined and controlled)
- Illicit drugs
- Veterinary drug use, especially antibiotics and steroids

The US Environmental Protection Agency (USEPA) maintains an active program called the Contaminant Candidate List (CCL) to identify contaminants in public drinking water that warrant detailed study, and may require regulation under the Safe Drinking Water Act (SDWA). The most recent Contaminant Candidate List, CCL3, was finalized on September 22, 2009, and contained 104 chemicals or chemical groups, 12 microbiological contaminants, and for the first time includes 10 pharmaceutical compounds.

The list includes antibiotic pharmaceuticals such as erythromycin, and nine hormones: 17 alpha-estradiol, 17 beta-estradiol, equilenin, equilin, estriol, estrone, ethinyl estradiol, mestranol, and norethindrone.

Ultraviolet alone, or in combination with selected chemical oxidants, has the ability to produce large amounts of the hydroxyl radical (OH^-) and ClO^-. These species aggressively attack organic compounds, either by the abstraction of hydrogen atoms from water (alkanes and alcohols) or by its addition to the compound (olefins and aromatic compounds).

Table 1. Relative Oxidation Power of Main Oxidizing Species

Species	*Relative Oxidation Power*
Chlorine	1.0
Hypochlorous Acid	1.10
Permanganate	1.24
Hydrogen Peroxide	1.31
Ozone	1.52
Atomic oxygen	1.78
Hydroxyl Radical	2.05
Positively charged hole on Titanium Dioxide, TiO_2^+	2.35

Table 1 illustrates how powerful the hydroxyl radical is. It is nonselective and initiates a complex cascade of oxidation reactions leading to mineralization of the organic compound.

AOP History

Advanced oxidation processes (AOP) can be usefully defined as "near ambient temperature and pressure water treatment processes which involve the generation of hydroxyl radicals in sufficient quantities to effect water purification." [2]

The earliest evidence of this phenomenon was recorded by Downes and Blunt,[3] who observed the decomposition of H_2O_2 by sunlight in 1879; and the decomposition of H_2O_2 by UV was later observed by Thiele[4] in 1907. By 1922, Kornfeld[5] had developed reaction products from the photolysis of H_2O_2, so the basic concepts of the modern AOP technologies are over 100 years old.

Today, these processes are an essential tool in the removal of a number of microconstituent compounds such as N-nitrosodimethylamine (NDMA). NDMA is a known carcinogen and is effectively removed using UV light. In the USA, California has recently established a public health goal for NDMA, which will likely serve as an eventual regulation in the state. Ultraviolet light at or close to 228 nm (wavelength in nanometers) is used to photolyze this compound, effectively breaking the bonds within the molecule.

In the north of Holland, the PWN Water Supply Company successfully replaced breakpoint chlorination at their Andijk drinking water treatment plant by using UV/H_2O_2. The plant wanted to provide control against emerging organisms that are chlorine tolerant, while reducing by-product formation and controlling organic contaminants. The effect of UV and H_2O_2 on 12 pesticides was studied. For an electric energy of 1 kWh/m^3 conversion varied from 18 percent for trichloroacetic acid to 70 percent for atrazine. For a combination of ≤1 kWh/m^3 and ≤15 g/m^3 H_2O_2, all pesticides could be degraded by more than 80 percent.[6]

In the United Kingdom, operators at the Mid Southern Water

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ETS-UV by Neptune Benson

ETS-UV by Neptune Benson UV systems shown here used as part of AOP pilot study

plant at Boxall's Lane used UV light to effectively remove a wide variety of pesticide species from well water being abstracted from chalk aquifers. Atrazine, simazine and diuron in concentrations 0.1µg/L to 0.5µg/L were successfully removed using UV light alone, and a higher removal rate was achieved when UV was combined with H_2O_2.

A 12-month study recently undertaken at Greater Cincinnati Water using validated ETS (engineered treatment systems) UV systems equipment examined the ability of a low pressure and medium pressure UV system to reduce seven contaminants of interest. The study included atrazine, metolachlor, MTBE (methyl-tert-butylether), MIB (2-methylisoborneol), ibuprofen, gemfibrozil and 17–∂–ethynylestradiol; some of these contaminants have been found in the Ohio River. The study examined the addition of up to 10 mg/L of H_2O_2 in conjunction with the UV systems, and recorded encouraging degradations under different process conditions.[7] This facility also compared UV-mediated AOP using Cl_2 rather than the conventional H_2O_2, and the improvements in performance measured (and likely cost savings) were striking.

All Is Not Well with H_2O_2 Based AOP Systems

There is a problem using H_2O_2 for the AOP chemical input alone, and the high cost of both the peroxide and the necessary quenching chemicals has led to research to understand the powerful role that chlorine plays in AOP processes.

The H_2O_2 has a low UV absorbance above 220 nm, which means that a very large amount of energy is required to produce an effective AOP reaction. Secondly, the reaction rate between the H_2O_2 and the OH^- radicals is very high. This phenomenon is called scavenging, and results in the majority of the active OH^- species not actually reacting with the target (nuisance) compounds.

This explains why in most AOP scenarios, less than 10 percent of the H_2O_2 is actually consumed during the AOP, and additional chemicals – a stoichiometric excess of chlorine, granular activated carbon, or bisulfite – are required after the AOP to quench the residual H_2O_2.

The use of chlorine in UV-mediated AOP offers a number of advantages both in terms of performance and operating cost:

The UV absorbance of HOCl is higher than that of H_2O_2, and the scavenging rate is significantly lower.

Recent studies carried out by Watts et al. *(2007, 2012)* have shown that UV/Cl_2 AOP is significantly more cost effective than UV/H_2O_2 as an AOP.[8]

Work undertaken by Rosenfeldt et al.[9] at Greater Cincinnati Water Works using ETS UV systems by Neptune Benson showed that UV/Cl_2 AOP is capable of reducing MIB by up to 90 percent, and that this combination out performs UV/H_2O_2 at low oxidant concentrations, with significantly less cost by avoiding the need for quenching agents. Interestingly, the work showed that no disinfection by-products were formed, probably due to the highly reactive nature of the oxidizing species within the AOP environment.

Science of Photolysis

Conventional ozonation or hydrogen peroxide oxidation of organic compounds does not completely oxidize many species to CO_2 and H_2O. In a number of reactions, the intermediate oxidation products can be more toxic than the initial compound. Completion of the oxidation reactions is often achieved using UV light.

Ozone readily absorbs UV light to form OH^- from a H_2O_2 intermediate, as shown here:

ETS-UV by Neptune Benson

The ETS AOP pilot system uses an advanced electrode to generate trace amounts of OH^- and ClO^-/HOCl *in situ* from typical levels of total dissolved solids in the raw water. The active species are formed immediately upstream of the UV lamps, and are effectively consumed during the AOP process.

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$$O_3 + h\nu \longrightarrow O_2 + O(^1D)$$

$$O(^1D) + H_2O \longrightarrow H_2O_2 \longrightarrow 2OH^-$$

The absorptivity of H_2O_2 for UV light at 254 nm (the wavelength produced by low pressure, or monochromatic lamps) is very low. It is increased when polychromatic lamps (medium pressure lamps with broader spectral output) are used, and further increased when high quality synthetic quartz is selected with enhanced UV transmittance below 240 nm. The process is, however, still inefficient due to its low absorbance of UV above 220 nm.

The direct photolysis of hydrogen peroxide leads to the formation of hydroxyl radicals.

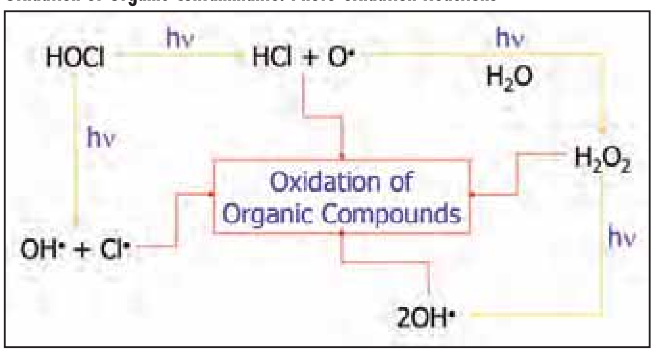
$$H_2O_2 \longrightarrow HO_2^- + H^+ \longrightarrow H_2O_2$$

$$HO_2^- + h\nu \longrightarrow OH^- + O^-$$

The OH^- are scavenged or effectively wasted by reacting with the H_2O_2.

These reaction mechanisms are complex, and varied. The illustration next highlights some of the potential breakdown pathways.

Oxidation of Organic Contaminants. Photo-oxidation Reactions



The active chlorine species are increasingly seen as a critical component of the AOP process. Looking forward, the conventional practice of adding a lot of H_2O_2, to then needing to quench it with expensive chemicals, would seem obsolete.

A Better Way

The ETS approach to UV-mediated AOP is to combine an advanced electrode arrangement upstream of the UV lamps into the AOP system. The electrode consists of an anode and a cathode and is a highly efficient method of converting TDS (total dissolved solids) and other mineral salts found in most ground or surface waters into the active chlorine species and trace amounts of hydroxyl radicals.

The anode and cathode work together to produce trace amounts of OH^- and ClO^-/HOCl, which are formed *in situ* immediately upstream of the UV lamps. The electrodes use a switching power supply to remove any hard water deposits off them. This has the obvious benefit of not requiring the bulk storage of H_2O_2 on site, nor does it require the addition of quenching agents due to the inherent inefficiency of the conventional H_2O_2 AOP.

Ultraviolet-mediated AOP: Logical Next Step

Ultraviolet will continue to play an active role as a disinfection barrier against the chlorine tolerant organisms. As the available water supply dwindles, and we are forced to use and eventually reuse water, so the removal of micro-contaminants, CEC's and PPCPs will become more pressing. Conventional wastewater plants were not built as a barrier to these nuisance compounds so they cannot be expected to effectively remove them. Oxidation using UV light and a number of oxidants would seem to be a logical next step.

Hydrogen peroxide alone probably is not the answer to AOP. Ultraviolet mediated AOP, using chlorine and the active chlorine species, offers significant operational and safety benefits.[9]

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ETS-UV by Neptune Benson

An electrode assembly is being inserted into an ETS AOP system, directly upstream of the UV lamps.

Potential Role of Constructed Wetlands for Treatment of Pharmaceuticals and Personal Care Products in Wastewater

by Douglas J. Daley and Lacey N. Kucerak

The purpose of this article is to introduce opportunities to treat contaminants of emerging concern (CECs) in wastewater effluent using constructed wetlands. CECs are a broad category of synthetic compounds that are increasingly prevalent in wastewater, such as pharmaceuticals and personal care products (PPCPs) or endocrine disrupting compounds (EDCs) *(USEPA 2010)*. Concern regarding CECs has been driving an increasing amount of research over the past decade about the effect of these contaminants on the aquatic environment *(Jones et al. 2005; Kolpin et al. 2002)* and alternative treatments. Potential adverse impacts of CECs in aquatic systems include feminizing aquatic animals (endocrine disruptors), developing resistance among human pathogens (antibiotics) or inducing toxic responses in aquatic organisms *(Huber et al 2005)*. Due to their widespread use, CECs enter the water environment in developed countries largely through wastewater treatment plant (WWTP) effluent. While conventional activated sludge facilities were designed to treat moderate levels of readily biodegradable carbon compounds, removal effectiveness of PPCPs in WWTPs varies greatly because of the wide range of chemical, biological and physical properties *(Verlicchi 2012)* as well as the wide range of influent concentrations that range across six orders of magnitude from 0.1 to 10^5 ng L^{-1} *(Oulton et al. 2010)*.

Highlighted here is recent research being conducted to take advantage of the sorption and oxidation potential of constructed treatment wetlands. Wetland treatment provides opportunities for both small and large WWTPs, either as a stand-alone process or as a polishing step following both conventional and advanced treatment technologies. Research paper citations are provided for those readers interested in gathering specific details or further investigating the feasibility of wetland treatment of CECs.

Research in Review

Analysis of opportunities to control or remove CECs from the water environment tends to focus on end-of-pipe treatment systems. Scientific investigations that have focused on the efficacy

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Photo courtesy of Wendong Tao – SUNY ESF

A constructed treatment wetland, such as this one, may use any combination of free water surface and submerged flow conditions to provide extended biological and physical treatment of contaminants of emerging concern. Vegetation provides treatment benefits, with secondary ecological benefits of habitat and aesthetic enhancement.

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of conventional activated sludge wastewater treatment processes have generally determined that CEC treatment is highly variable – ranging from no effect to completely effective – and depends on the physical and chemical properties of individual contaminants of concern. For example, primary treatment processes have little effect on hydrophilic compounds such as ibuprofen *(Zhu 2014).* Secondary treatment processes may remove ibuprofen to concentrations that present low risk, yet there is still variability in performance, with detectable concentrations ranging across three orders of magnitude (0.001 µg/L to 4.2 µg/L) *(Jones et al. 2003; Zhu 2014).* In contrast, treatment of pharmaceuticals such as carbamazepine, an anticonvulsant, in a biological WWTP is largely ineffective, with 38 studies reporting removal rates of less than 30 percent *(Gagnon and Lajeunesse 2012; Oulton et al. 2010).*

Investigations into treatment or destruction of CECs in conventional treatment systems tend to focus on which operating conditions could be modified to improve removal effectiveness (e.g., sludge retention time, or SRT). Greater SRTs have been attributed with promoting the development and adaptation of microorganisms to remove xenobiotics, as well as improving treatment effectiveness of sorbed PPCPs through improved solids separation. There appears to be little benefit of increasing SRT beyond 30 days *(Verlicchi 2012)* and removal of highly soluble compounds is minimal. Rather than focusing solely on removal efficiency, however, one must consider the potential ecological risk associated with PPCPs in both the treated effluent and the excess sludge. Zhu et al. *(2014)* reports that the predicted no effect concentration (PNEC) of compounds such as sulfamethoxazole is less than 0.5 µg/L in water, and less than 50 µg/kg in sludge. Evaluation of sludge from two WWTPs indicated that sulfamethoxazole presented a "high" risk to the ecological environment, whereas ibuprofen in sludge presented no risk *(Zhu et al. 2014).*

Other studies focus on the use of advanced treatment technologies (e.g., ozonation, chlorine dioxide) as polishing processes. Chlorine dioxide doses ranging from 8 to 20 mg/L following secondary treatment resulted in effective oxidative degradation of 39 active pharmaceutical ingredients in 18-hour bench-scale experiments. However, removal effectiveness was adversely affected by COD (chemical oxygen demand), as treatment effectiveness was insignificant at chlorine dioxide doses less than 8 mg/L. Chlorine dioxide dose less than 20 mg/L was ineffective for 16 of the 39 pharmaceutical ingredients *(Hey et al. 2012).* Overcoming the adverse effects of elevated COD or suspended solids in the effluent will obviously increase capital and operating expenses of oxidation with chlorine dioxide.

Ozonation, an advanced oxidation process (AOP), was used in a pilot-scale reactor to assess removal effectiveness of PPCPs from wastewater effluent following conventional activated sludge treatment. Oxidation rates of PCPPs, such as macrolide and sulfanomide antibiotics, estrogens, diclofenac, naproxen and indomethacin, exceeded 90 percent with ozone doses greater than 2 mg/L *(Huber et al. 2005).* Unlike chlorine dioxide, ozone treatment did not appear to be adversely affected by suspended solids. Sorbed pharmaceuticals were removed equally well in both low and elevated TSS (total suspended solids) effluent streams.

Potential in Constructed Wetland Treatment

As even advanced technologies are highly dependent upon the physical and chemical characteristics of the CECs, it is likely that treatment of CECs will need a suite of complementary technologies, including constructed wetlands, to address the broad spectrum of CECs, PPCPs and their metabolites. As noted, removal of CECs from wastewater effluent may be accomplished by taking advantage of a combination of sorption processes and biological decomposition (a.k.a. oxidation). Given the potential to remove CECs, and the comparatively low construction and operation costs, constructed wetlands continue to get attention as a potential polishing step for wastewater treatment plant effluent.

Constructed treatment wetlands use multiple processes, such as biogeochemical reactions, photolysis and sorption, to remove contaminants through both destructive and nondestructive pathways *(Hijosa-Valsero et al. 2011; Kadlec and Wallace 2009; Matamoros et al. 2009).* In some cases, constructed wetlands are better at removing PPCPs from wastewater than conventional activated sludge processes, possibly due to the combination of sorption potential, plant uptake and longer retention times in wetlands *(Hijosa-Valsero et al. 2011; Matamoros et al. 2009).*

The treatment of pharmaceuticals in constructed wetlands depends on numerous factors, including the wetland flow regime, oxygen availability, vegetation and soil dynamics, and chemical structure of the contaminant *(Verlicchi and Zambello 2014).* Hydraulic retention time (HRT) and hydraulic loading rate (HLR) are commonly cited as design variables that are strongly and positively correlated with treatment of certain CECs *(Dordio et al. 2010; Verlicchi et al. 2012; Zhang 2012).*

The tendency of CECs to sorb preferentially to soil or in the plant substrate in wetlands is indicated by the value of distribution coefficients, such as the octanol-water partition coefficient (K_{ow}) and the solute distribution coefficient (K_d). Greater values of the K_{ow} are associated with hydrophobic compounds, those compounds that preferentially partition into the octanol rather than into the water in a two-phase system; thus, one would expect to find CECs with low Kow in solution. Contaminant sorption in soil is largely driven by the presence and amount of soil organic matter (SOM). Therefore, wetlands provide substantial opportunity using soil, plant roots and plant detritus to treat CECs with elevated K_d.

The review by Li et al. *(2014)* reports that pharmaceuticals with a Log K_{ow} between 0.5 and 3.5 are sufficiently lipophilic to move through plant cell membranes and also sufficiently water soluble to be transported into the plant cell fluids. Carbamazepine (Log K_{ow} = 2.45) is apparently readily absorbed by *Typha* spp. plant roots and transported through the plant to accumulate in the leaves. Antibiotics such as ciproflaxin with Log K_{ow} <0.5, are highly water soluble, so uptake by plants is driven by the transpiration process. Besides absorption and translocation within the plant body, plants in constructed wetlands promote the development and maintenance of microbial populations that can degrade CECs. Plant roots release oxygen into the soil, thereby driving chemical oxidation of CECs.

The Sharif *(2014)* study examined the effect of hydraulic loading rate (HLR) and carbon loading rate (CLR) in experimental microcosms of four CECs (two steroid hormones, atrazine and carbamazepine) where the Log K_{ow} of the compounds ranged from 2.45 to 4.02. Increasing the HLR from 3.4 to 5.6 cm/d decreased the mass removal of each of the four compounds. Atrazine and carbamazepine removal was less than 20 percent under both HLR scenarios, while testosterone and 17□-estradiol (E2) ranged from approximately 50 to 70 percent. Sorption was the primary removal mechanism for carbamazepine, whereas photolysis was responsible for removing approximately 82 percent of the atrazine.

Biodegradation of E2 and testosterone removed approximately half of the mass, while sorption and photolysis removed the remainder.

In Li et al. *(2014)*, prior research for removal efficiency of 36 pharmaceuticals in different types of constructed wetlands was summarized. Constructed wetland types included surface free water (SFW), horizontal subsurface flow (HSSF), vertical subsurface flow (VSSF) and hybrid constructed wetlands. It reported that 13 pharmaceuticals were removed in constructed wetland treatment at better than 70 percent efficiency, including acetaminophen, salicylic acid, sulfadiazine, sulfadimethoxine, sulfamethazine, sulfamethoxazole, sulfapyridine, trimethoprim, atenolol, metoprolol, furosemide, caffeine and tetracycline. In contrast, wetland treatment of ampicillin, erythromycin and lincomycin was efficient by less than 20 percent. There is limited data available regarding what type of wetland provides better performance compared to the others.

Ibuprofen, a.k.a. iso-butyl-propanoic-phenolic acid ($C_{13}H_{18}O_2$), is a nonsteroidal anti-inflammatory drug (NSAID) with analgesic properties. While over 90 percent of ingested ibuprofen is excreted in the urine as metabolites, its widespread and frequent use results in measurable concentrations of ibuprofen in wastewater effluent, streams and rivers. Naproxen ($C_{14}H_{14}O_3$) is the active ingredient in drugs such as Aleve®. Naproxen is also a widely used non-prescription NSAID with analgesic properties and characteristics similar to ibuprofen. Approximately 30 percent of the pharmaceutical is excreted in the urine as metabolites, whereas the majority is excreted unchanged *(Deer and Leog 2013)*. The Log K_{ow} (3.97 and 3.18 for ibuprofen and naproxen, respectively) indicates that both compounds have a medium sorption potential and would be good candidates for wetland treatment.

In the paper by Dordio et al. *(2010)*, it was determined that the primary removal mechanisms of ibuprofen was adsorption to light expanded clay aggregate (LECA) and biodegradation in wetland microcosms planted with *Typha* spp. Removal effectiveness ranged from 82 to 96 percent under summer temperature conditions with hydraulic retention time of seven days. Removal effectiveness was significantly affected by water temperature, indicating that microbial degradation is an important process in removing ibuprofen. Over 50 percent of the influent ibuprofen was removed within the first six hours of treatment in the wetland, largely through sorption.

It is evident from the ongoing research that the presence of CECs in wastewater will continue to present challenges to the wastewater industry. Highly reactive or readily sorbed compounds appear to be the most readily treatable, yet small concentrations of higher toxicity compounds may present the greatest environmental or chronic health risk. While wetland treatment offers some opportunity as a low-cost polishing process, the effect of PPCP accumulation on the wetland biota and the risks associated with PPCP metabolites that result from biological activity have not been fully explored.

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Demonstrating Advanced Oxidation/Biofiltration for Pharmaceutical Removal in Wastewater

Water Environment Research Foundation Project U2R11

EXECUTIVE SUMMARY

Over the last two decades (trace) organic compounds (TOrC) have been repeatedly detected in wastewater and in the environment. Primary sources for these contaminants are wastewater treatment plants, which are not typically designed to remove TOrC. The use of UV-based advanced oxidation to remove emerging contaminants has been well demonstrated in various water matrices including natural waters, drinking water and reuse waters. One of the outcomes of AOP transformation of TOrC is the generation of more biodegradable oxidation products, which may or may not retain the biological activity of the parent compound. For this reason, biological filtration using a biological aerated filter (BAF) was examined as a complementary treatment, to remove biodegradable AOP transformation products. Although the researchers did not conduct experiments to confirm mineralization at the pilot plant scale, earlier bench-scale experiments indicated that it was possible to mineralize TOrC that are transformed by UV-AOP using a downstream biotransformation technology such as BAF.

The general goal of the project was to evaluate the efficacy of UV-based advanced oxidation processes (UV/AOPs) and UV/AOPs followed by bio-filtration, as an integrated treatment solution to remove trace organic compounds from wastewater. The specific objectives were to: 1) determine the rate and extent of iopromide (IOP) transformation by UV-based advanced oxidation and, identify the extent to which IOP byproducts further biodegrade, 2) evaluate the extent to which TOrC are removed in full-scale UV disinfection systems, by photolysis and nitrate-driven AOP and, 3) examine the applicability of UV-AOP followed by biological treatment at the pilot-scale to remove TOrC and oxidation products from wastewater effluent.

The project's goals were achieved over three separate tasks. The results and conclusions from each task are summarized below:

Task 1: Bench-Scale UV/H_2O_2 + Biodegradation Experiments

The first task of the study was to examine the potential of the combined UV/AOP biodegradation treatment to remove TOrC and oxidation products from wastewater, on a bench-scale system. Ultraviolet oxidation was carried out in a UV collimated beam apparatus, and biodegradability was tested in a bench-scale activated sludge system, using 14C-labeled IOP (to monitor the compound's mineralization). An earlier study demonstrated this approach with carbamazepine (CBZ). In this task, IOP (a hydrophilic iodinated contrast media) was tested as probe, to examine the applicability of the combined treatment on different TOrC.

The UV/H_2O_2 oxidation of IOP was highly efficient, occurring through both direct photolysis and HO• reactions, and generating transformation products. While IOP resisted biological degradation, its UV/H_2O_2 transformation products were more biodegradable (with up to 20% mineralization in 42 days of bio-treatment), demonstrating the potential of the proposed UV/AOP + biodegradation treatment train.

Task 2: Transforming TOrC During Full-Scale UV Disinfection Treatments

In the second task the research team evaluated the transformation of TOrC during UV disinfection of wastewater at eight full-scale treatment facilities. Two plants were operated with low pressure (LP) UV lamps, and six with medium pressure (MP) UV lamps. LP UV lamps emit light predominantly at 253.7 nm; while MP lamps emit polychromatic light in the range of 200–400 nm. Irradiation of nitrate with UV light < 240 nm is known to generate HO• radical. LP lamps lack the wavelengths in their spectrum that can photolyze nitrate to produce HO•. Therefore, the degradation processes of TOrC were expected to be: (i) direct photolysis for plants operating LP lamps and, (ii) photolysis combined with HO•, generated through indigenous nitrate photolysis with UV light, for plants operating MP lamps.

Most of the TOrC that were examined did not transform to a significant degree during either LP or MP UV disinfection treatments. These results suggest that, in general, even though some TOrC decay may occur, loss of TOrC is negligible under typical wastewater disinfection conditions (UV fluence < 200 mJ/cm^2; [NO_3] < 30 mg-N/L). The main reason for this result is the relatively low UV fluence applied during disinfection, and suggests that an increased UV fluence would be needed (> 750 mJ/cm^2) to achieve significant TOrC removal.

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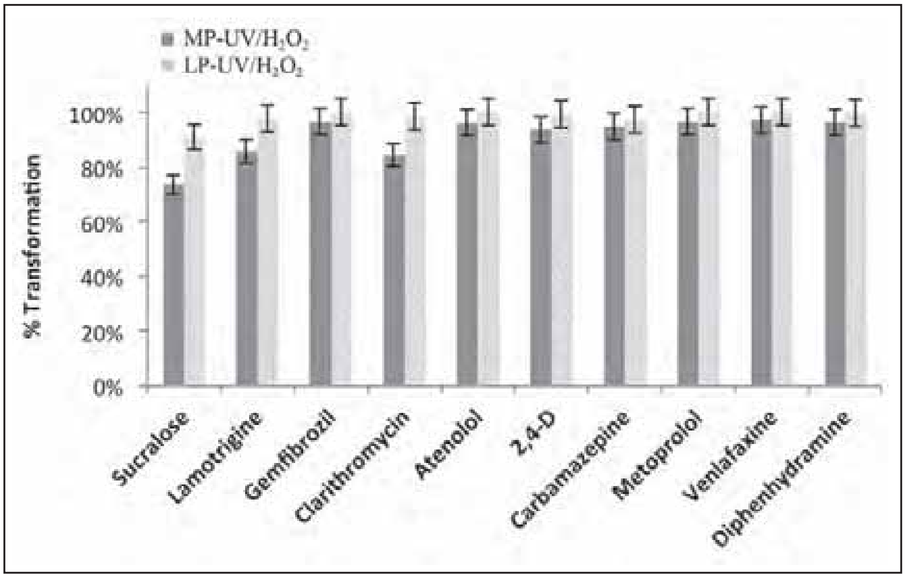
Figure ES-1. Transformation of Targeted TOrC in Pilot Plant Study During AOP

With MP or LP UV and H_2O_2 at Fluence of 1500 mJ/cm^2 and H_2O_2 Concentration of 10 mg/L.



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Task 3: Pilot-Scale AOP/Biofiltration

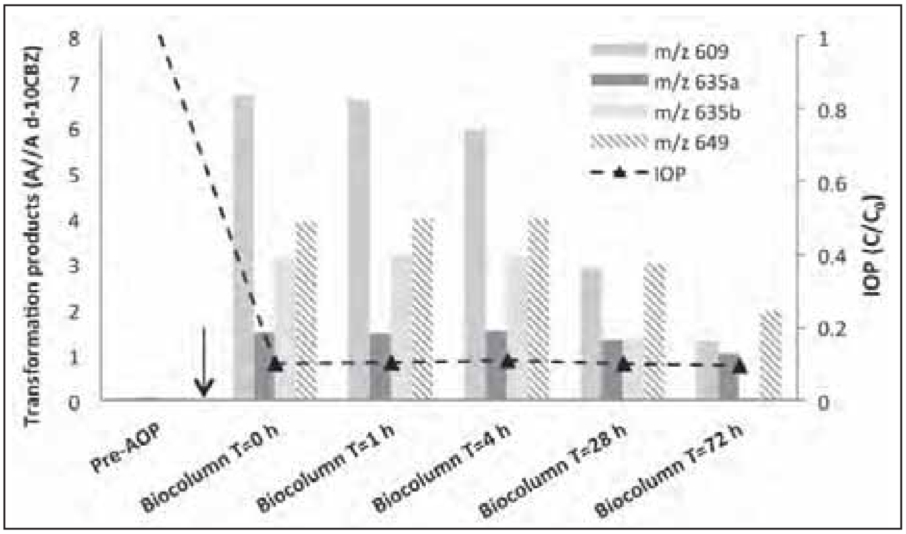
In the final task the research team extended the bench-scale study (Task 1) to a pilot plant that was installed at the City of Boulder (CO) 75th Street Wastewater Treatment Facility. The pilot system included a UV/AOP process followed by a BAF, and examined the combined AOP+BAF treatment train for the removal of TOrC and oxidized transformation products.

The results from the pilot showed that both LP/MP UV/H_2O_2 and MP UV/NO_3 efficiently transformed a large variety of TOrC in the effluent from the full-scale treatment facility, especially at high UV fluence (≥ 750 mJ/cm^2). For example, at a UV fluence of 1500 mJ/cm^2 and H_2O_2 concentration of 10 mg/L, most contaminants ***(listed in Figure ES-1)*** were more than 90 percent transformed by LP UV/H_2O_2 and more than 80 percent transformed by MP UV/H_2O_2.

For the MP UV/NO_3 process (without H2O2), UV fluence of 1500 mJ/cm^2 typically degraded the TOrC by more than 40 percent; while at 2000 mJ/cm^2 the degradation was improved to > 60 percent. In addition, sucralose (a widely consumed artificial sweetener found in high concentration in wastewater effluent) was demonstrated as an efficient conservative probe for the UV/AOP process. Sucralose transformation under all AOP conditions examined was slower than the other tested TOrC due to its resistance to direct UV photolysis and its relatively slow reaction with the HO• radical.

The post-AOP BAF system could not remove the residual parent TOrC (that were not transformed during AOP); however, many of the dominant transformation products (formed during the preliminary UV/AOP process) were biodegraded. ***Figure ES-2*** shows an example of this behavior for IOP, in spiked effluent ($[IOP]_0$ = 10 mg/L). Four important transformation products were detected in the effluent after the AOP treatment, with m/z 609, 635a, 635b and 649. The formation of these products occurs simultaneously with the loss of the parent compound. While the residual concentration of IOP in the subsequent BAF columns remained unchanged (up to 72 h residence time), concentration of most transformation products decreased substantially (by up to 80 percent for m/z 609). These results demonstrate the potential of this treatment approach to effectively remove TOrC and oxidized AOP products from wastewater.

Figure ES-2. Fate of IOP and Transformation Products in the Pilot System



In conclusion, UV-based AOP that uses H_2O_2 and/or NO_3 as HO• sensitizers showed efficient degradation of TOrC in wastewater effluent, by applying a reasonable UV fluence albeit at a level that is higher than that needed to achieve disinfection. The process's efficacy can be monitored using sucralose as a conservative probe, and many of the oxidation products can be further removed by subsequent biological treatment.

For the entire study report, find WERF Project U2R11 at www.werf.org. The Water Environment Research Foundation has granted reprint permission of this Executive Summary.

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Wastewater Treatment by Combination of Advanced Oxidation Processes and Conventional Biological Systems*

by Alessandra Cesaro, Vincenzo Naddeo and Vincenzo Belgiorno

Introduction

In the last years [sic], one of the major concerns to water quality is related to the detection of chemical pollutants in both industrial and municipal wastewater. Most of these contaminants, both synthetic organic chemicals and naturally occurring substances, enter the aquatic medium in several different ways and, according to their water- solubility, can be transported and distributed in the water cycle [1].

The risk associated to these contaminants, such as pharmaceuticals, endocrine disruptor, personal care products, pesticides, is related to their ubiquity and persistence into the environment as well as to their biological activity that may affect the development of aquatic organisms and wildlife [2].

The effluents of urban wastewater treatment plants are among the major responsible [sic] for the release of this kind of contaminants [sic] into the environment [2,3]. Although conventional biological processes are usually efficient for the degradation of pollutants occurring in wastewater, refractory compounds are not effectively removed [4].

In such cases the use of Advanced Oxidation Processes (AOPs) may improve the overall removal efficiency of such compounds.

AOPs are based on the chemistry of hydroxyl radicals (•OH), which are non-selective reactive species, able to oxidize pollutants into mineral end-products, yielding CO_2 and inorganic ions [5].

However, the use of AOPs is not cost-effective if intended to mineralize toxic and recalcitrant compounds in wastewater [1]. Therefore, suitable application of AOPs should not consider, whenever possible, the replacement of the more economic biological processes [6], but the proper combination of both systems.

AOPs can be used as pre- and/or post-treatment of biological systems ***(Figure 1)***. In the former case, AOPs aim to improve biological treatability of wastewaters, thus favouring their processing by means of common microorganisms [7-9]. In the latter, the oxidation step is directed towards the removal of those contaminants not completely degraded during the biological treatment [10].

In order to ensure the economic optimization of the combined process, it is necessary to limit the intensity and/or duration of the advanced treatment. As a result, special attention must be paid to the procedures useful to evaluate the efficiency of the process. When AOPs are used as pretreatment of wastewater for their biological processing, their performances have to be adequately assessed through biodegradability tests [11].

This work discusses the most studied AOPs used as pretreatment of wastewaters for biological processing, in order to highlight the enhancement of wastewater biological treatability supplied by different advanced processes. To this end, wastewater biodegradability assessment is pointed out, with reference to the most spread standard tests and parameters, thus providing an overview of the most reliable ones.

Degradation Mechanisms by Advanced Oxidation Processes

The efficacy of AOPs in improving biological degradability of recalcitrant compounds in wastewater depends on both chemical and physical properties of contaminants as well as on the generation of reactive free radicals, in most cases hydroxyl radicals [12]. The oxidation reaction between these radicals and the contaminants is the mechanism behind the degradation of the contaminant itself.

The generation of these reactive agents can be achieved by means of several processes, including sonolysis [13], ozone-based processes [14], Fenton-based reactions [15], heterogeneous photocatalysis [16] and various combinations of these technologies [17-19]. Each one can be characterized according to the specific method for the production of free radicals.

Sonochemical processes imply the application of ultrasound (US), which refers to sound waves with a frequency ranging between 20 kHz and 500 MHz. When ultrasound propagates in a liquid, it promotes the formation of cavitational bubbles, whose collapse is associated to both physical and chemical effects [13]. In particular, at high frequencies, chemical ultrasonic effects are predominant due to the larger formation of free radicals [20].

These radicals move to the liquid-gas interface to react with the organic substrate [21] or, in the case of high concentration, they recombine with each other to form H_2O_2 [22], which is an oxidative agent as well, thus providing the degradation of contaminants.

Sonolysis is a versatile process, which has been widely studied

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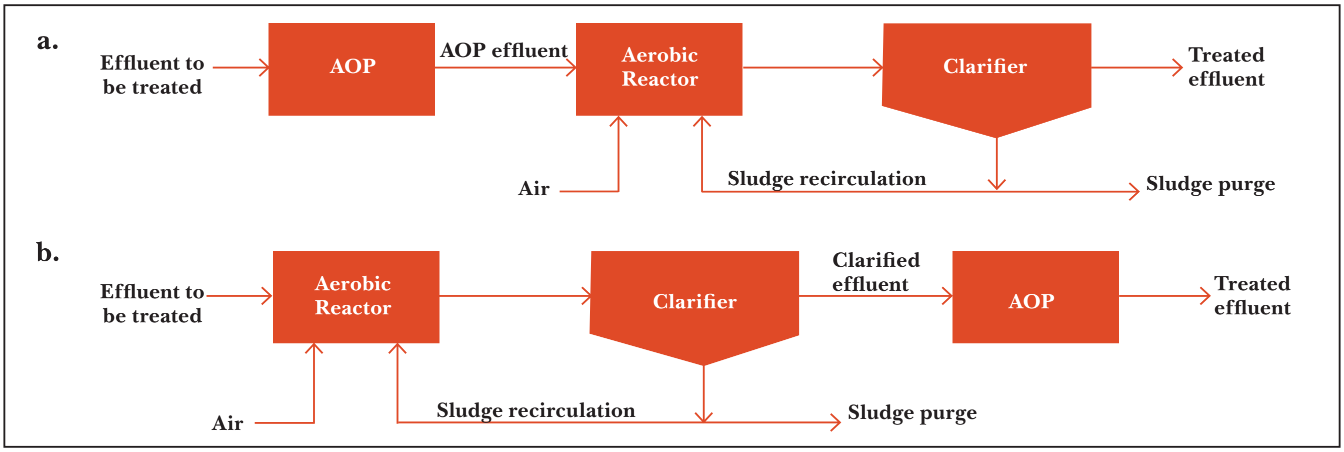

Figure 1: AOP as pretreatment (a) and post-treatment (b) of biological system

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for the degradation of several compounds [23-25] even in combination with other AOPs [26]. Its main disadvantage is related to energy consumption. This item often limits the applicability of the ultrasonic technology to small volumes. Differently, ozonation has shown a very strong oxidizing power with short reaction times, thus allowing the treatment of great amount of wastewaters.

The process relies on ozone, which is unstable in an aqueous medium. It decomposes spontaneously by a complex mechanism that involves the generation of hydroxyl free radicals. Therefore, the degradation of pollutants occurs by both ozone itself and radicals [27], although the latter is more powerful than the former, as highlighted in ***Table 1***, reporting the reaction rate constants for both oxidants with reference to several compounds.

As ozone is an unstable molecule, it should be generated at the point of application. To this end, several methods can be used, but the most common within ozone generation industry is the corona discharge one, which requires a considerable energy input.

Ozone technology has also been studied in combination with ultraviolet (UV) radiation, since UV photons are able to activate ozone molecules. In this way, the formation of hydroxyl radicals is promoted [28,29], but any relevant energy saving can be pursued.

UV radiation, in the wavelength range between 200 and 280 nm, can also be applied in combination with hydrogen peroxide (H_2O_2). The major drawback of this process is related to the small molar extinction coefficient of H_2O_2. Therefore, only a relative small fraction of incident light is exploited, especially when organic substrates will act as inner filters. Moreover, the rate of photolysis of aqueous H_2O_2 is pH dependent: it was found to increase when more alkaline conditions are used [6].

H_2O_2 occurs also in Fenton based processes: its reaction with iron in water, under acidic conditions, determines the formation of radicals. The rate constant for the reaction of ferrous ion with hydrogen peroxide is high and Fe(II) oxidizes to Fe(III) in a few seconds to minutes in the presence of excess amounts of hydrogen peroxide, which decomposes by Fe(III) and generates again hydroxyl radicals. The major parameter affecting Fenton processes are: the pH of the solution, the amount of ferrous ions, the concentration of H_2O_2, the initial concentration of contaminants and the presence of other ions [30]. Moreover, Fenton reagent action can be significantly improved when exposed to UV radiation [31].

Enhancement of reagent yields after light irradiation is the concept on which also photocatalytic processes have been developed.

Heterogeneous photocatalysis is a photochemical reaction, accelerated by the action of a catalyst: one of the most widely used and highly effective is TiO_2 [32]. The mechanism action is based on the transition of electrons from the valence to the conduction band, which is caused by the light irradiation of the catalyst. In particular, both migrating electrons and the holes created in the valence band can participate in redox reactions with compounds absorbed on the photocatalyst [33]. The presence of molecules which compete with the contaminants for reactive sites should be, therefore, avoided.

Compound	O^3	OH•
Chlorinated alkenes	$10^{-3} \div 10^{-4}$	$10^{9} \div 10^{11}$
Phenols	10^{3}	$10^{9} \div 10^{10}$
N-containig organics	$10 \div 10^{2}$	$10^{8} \div 10^{10}$
Aromatics	$1 \div 10^{2}$	$10^{8} \div 10^{10}$
Ketones	1	$10^{9} \div 10^{10}$
Alcohols	$10^{-2} \div 1$	$10^{8} \div 10^{9}$

Table 1: Ozone and hydroxyl radical rate constants, as L/mols [28]

Notwithstanding the possibility of mineralization of several compounds, photocatalysis full-scale application is still not spread due to both technical and economic reasons, mainly related to the proper handling of the catalyst.

Table 2 summarizes main advantages and drawbacks for the discussed AOPs.

The design of AOPs depends on several parameters, including: reagent dosage and ratios with other substances, contact time and reactor configuration. The optimal conditions have to be determined with reference to the treatment scenario of interest [34]. Reasonably, longer contact time as well as higher reagent dosage result in more effective treatment but also in operating costs which can not be sustainable.

Differently, when AOPs are used in combination with conventional biological treatment of wastewaters, their application is not intended to remove refractory compounds and can be cost competitive. In this contest, the feasibility of AOPs is highly dependent on the enhancement of wastewater biological treatability and, consequently, the assessment of biodegradability plays a fundamental role.

Wastewater Biodegradability Assessment

In scientific literature, biodegradability concept has been used to refer to different characteristics of a substrate, such as persistence [35] or bioavailability [36]. In the field of water and wastewater treatment, biodegradability often implies the biological treatability of the investigated substrates [37].

Due to these differences, several tests have been developed in time to assess biodegradability.

OECD (Organization for Economic Cooperation and Development) guidelines distinguish three main groups within the biodegradability test system [38]:

- Ready Biodegradability Tests (RBTs), which are useful for quick screening. They all rely on the principle that biodegradation is monitored as the degree of mineralization, by means of aggregated parameters such as oxygen uptake, carbon dioxide production or reduction of dissolved organic carbon (DOC);
- Inherent Biodegradability Tests (IBTs), to demonstrate the potential degradability of a compound. Differently from RBTs, biodegradation conditions are optimized, thus making them really reliable;
- Simulation Tests (STs), designed to measure the rate of biodegradation in a specified environmental compartment. Test substance concentration varies according to the test aim: it is lower, if intended to provide biodegradation rates; higher to quantify main degradation products. The measurement of degradation rates, moreover, requires specific analysis.

According to this classification, a fundamental step for the evaluation of wastewater biodegradability is the performance of RBTs. A compound can be considered readily biodegradable, if the results of RBTs fit the following criteria [39]:

- O_2 uptake or CO_2 evolution achieves at least 60 percent of the theoretical one or DOC removal reaches 70 percent;
- time elapsed from the start of the mineralization process, defined as 10 percent of the theoretical one until the required plateau is reached, should be no longer than 10 days.

According to OECD guidelines, if these conditions are not fulfilled, the test substance cannot be considered "not biodegradable", but should undergo additional trials, even within the class of the RBTs. Although some of these tests based on respirometry for the determination of O_2 uptake are more versatile than others, their

AOP	Advantages	Disadvantages
US	• Versatile technology • Suitable for small volumes • Interesting upgrade applications	• Energy consuming technology • Sonotrode erosion issues
O_3	• Strong oxidative power • Effective for a wide spectrum of pollutants • Existing full-scale applications	• Energy consuming • High operating costs • Risks associated to ozone generation
O_3/UV	• More effective than O_3 or UV alone	• More energy intensive than single processes
H_2O_2/UV	• UV promote •OH formation • High efficiency	• Turbidity can interfere with UV radiation
Fenton-based reactions	• Not as energy intensive as other AOPs	• Developing technology • Need for acidic conditions
UV/TiO_2	• Can be performed at higher wavelengths than other UV-based processes	• Developing technology • Need for pretreatment

Table 2: Advantages and drawbacks of discussed AOPs

Test	Measured Parameter	Maximum microbial concentration [CFU/mL]	Suitability for compounds Poorly soluble	Volatile	Adsorbing
DOC Die-Away (301 A)	DOC	$(2 \div 10) \bullet 10^5$	–	–	+/–
CO_2 evolution (301 B)	CO_2 evolution (respirometry)	$(2 \div 10) \bullet 10^5$	+	–	+
MITI (I) (301 C)	O_2 (respirometry)	$(2 \div 10) \bullet 10^5$	+	+/–	+
Closed bottle (301 D)	O_2 (respirometry)	$(0,5 \div 2.5) \bullet 10^3$	–	–	+/–
Modified OECD Screening (301 E)	DOC	$(0,5 \div 2.5) \bullet 10^2$	+/–	+	+
Manometric respirometry (301 F)	O_2 (respirometry)	$(2 \div 10) \bullet 10^5$	+	+/–	+

+ suitable; – not suitable; +/– suitable under specific conditions

Table 3: Applicability of OECD (301 series) test methods (adapted from Pedrazzani [40])

applicability depends also on the kind of substances which are being investigated, as shown in ***Table 3*** [40].

Table 4 lists the most performed IBTs, highlighting that the population density is higher than the one of RBTs. This item makes the conditions for the biodegradation optimal. Therefore, a negative result would indicate a high persistence of the test substance, suggesting that no further research on biodegradation should be performed [38].

An important aspect to be taken into account is reproducibility of test results.

One of the most recent studies on the topic [11] was carried out comparing different tests to determine the biodegradability enhancement during the advanced treatment of wastewater samples containing 200 mg DOC/L of a pesticide mixture. Authors found that the results of Zahn-Wellens test were consistent with the ones achieved through the Pseudomonas putida bioassay. The use of this bacteria is standardized within the procedures provided by DIN 38 412 Part 8 (1991) and DIN 38 412 Part 27 (1993) to assess water and wastewater toxicity, by evaluating the growth inhibition in 30 minutes. In the study of Ballesteros Martín et al. [11], the same bacteria species was used as culture mean for a bioassay, incubated for 120 h. As for the Zahn-Wellens tests, biodegradability efficiency of the investigated AOP was assessed in terms of DOC removal.

Results showed that both Zahn-Wellens test and Pseudomonas putida bioassay proved to be the most suitable judging by repeatability and precision. The main advantage of the Pseudomonas putida test is the shorter time required to obtain reliable results, in comparison to the Zahn-Wellens test, lasting 28 days.

The duration of biodegradability tests can be a discriminating factor in the choice of the test itself as well as the operating simplicity, especially in research screening steps. This item has promoted the use of BOD_5/COD ratio, which is quite spread in literature [41] as biodegradability indicator: when the ratio is higher than 0.4, the test substance is considered biodegradable [42].

Although biodegradability tests provide useful information concerning the effect of chemical pre-treatment on subsequent biological degradation of wastewater, experiments integrating chemical and biological degradation are necessary for a more realistic viewpoint of the combined process [1].

Test	Measured parameter	Maximum microbial concentration [CFU/mL]
Zahn-Wellens Test (302 B)	DOC	$(0.7 \div 3) \bullet 10^7$
SCAS (302 A)	DOC	$(2 \div 10) \bullet 10^7$
MITI (II) (302 C)	O_2	$(0.7 \div 3) \bullet 10^6$

Table 4: IBTs (adapted by Struijs et al. [38])

Combined AOPs and Biological Processes for Wastewater Treatment

Most studies dealing with AOPs as pretreatment of wastewater for their biological processing refer to laboratory and pilot scale tests.

One of the main obstacles to the scale up of AOPs for the treatment of wastewater prior to biological processes is related to the oxidant dose. High reagent concentrations determine significant increases in operating costs as well as serious damages to microorganisms [43,44]. On the other hand, low reagent doses could result in inadequate pretreatment of wastewaters.

The effectiveness of AOPs has been extensively proved for the pretreatment of several kinds of wastewaters, including industrial ones [45], as they can be conveniently reused within the productive process.

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According to Scottis and Ollis [46], the kinds of wastewater that can be successfully treated by means of combined AOPs/biological processes are the ones containing bio-resistant or recalcitrant compounds, which are often of industrial origin, as well as the wastewaters containing pollutants resulting in toxicity for microorganisms.

Among bio-resistant compounds, pesticides arise great concern, since their high solubility makes their propagation in the environment extremely easy. Although several processes have been studied for the pretreatment of wastewater polluted by pesticides, the most recent trend is directed toward the combination of Fenton and photo-Fenton processes with aerobic biological treatment [47,48].

Zapata et al. [49] found that the photo-Fenton treatment at pilot plant scale was able to increase the biodegradability of a wastewater polluted with commercial pesticides from 50 percent to 95 percent as well as to reduce its toxicity (from 96 percent to 50 percent of inhibition). Authors also observed that the most suitable point for combining the photo-Fenton process with the biological treatment was after the total elimination of the active ingredients. The efficiency of the combined photo-Fenton/ biological system in terms of mineralization was 94 percent, while the combination bio/photo-Fenton was not successful, thus pointing out the importance of the proper identification of the sequence within treatment units.

Fenton based processes have been also applied to several industrial wastewaters, such as tannery effluents, which are usually characterized by low pH, relatively high temperature and high presence of aromatic compounds.

In the study of Mandal et al. [50], the application of Fenton process as pretreatment for a biological system allowed the reduction of pollutant content, in terms of both COD and BOD_5, thus improving the biodegradability and reducing the duration of biological treatment. The main drawback of the combined Fenton/biological process was the high production of sludge (about 3 kg dry sludge/ m^3), which greatly affect the economic balance, as observed also in the study of Di Iaconi et al. [51].

Fenton reaction was also studied by Feng et al. [52] in combination with a membrane bioreactor (MBR) for the advanced processing of the effluent from an integrated dyeing wastewater treatment plant. In this study, Zahn-Wallens Test was used to assess the wastewater biodegradability enhancement after Fenton process. However, the same effect was also evaluated in terms of TOC, after the Fenton treatment as well as after the combined Fenton/MBR system. Although an IBTs was performed, the estimation of TOC allowed a prompt comparative assessment between the single AOP and its combination with a biological system by means of a parameter that is common and easy to determine.

Similar consideration arises for the study of Oller et al. [53], reporting the combination, at pilot scale, of Fenton process with an attached biomass biological reactor, for the treatment of 4 m^3/d of pharmaceutical wastewater, with a concentration of 600 mg/L of ∂÷-methylphenylglycine and a DOC value in the range 400–600 mg/L. In this case, the removal reached through the combined process was evaluated in terms of DOC and was found to reach values up to 95 percent.

Pharmaceuticals represent only one of the widest categories of concern among emerging contaminants because of their endocrine-disrupting properties. Personal-care products, steroid sex hormones, illicit drugs, flame retardants and perfluorinated compounds are other particularly relevant examples of such emerging compounds, whose high transformation/removal rates are compensated by their continuous introduction into the environment. In order to increase biodegradability and detoxify effluent streams containing such compounds, alternative treatments with AOPs have been studied [54- 56].

Naddeo et al. [24] investigated the application of sonolysis on the degradation of three kinds of pharmaceuticals, both in single solutions and as mixtures spiked in urban wastewater effluent. Several operating conditions were studied and the aerobic biodegradability variation assessed by BOD_5/COD ratio. It was found that the pharmaceuticals conversion enhanced for increasing ultrasonic power densities. Reaction by-products proved to be more stable than the original compounds as well as more readily biodegradable, thus suggesting the effectiveness of sonolysis as pretreatment rather than post-treatment. In the former case, lower energy input can be provided in order to achieve an adequate increase in biodegradability and promote the consequent processing of wastewater by conventional biological systems.

The great potential of ultrasonic irradiation for the degradation of toxic organic compounds in wastewater was also highlighted in the study of De Bel et al. [57]. Authors found that, although there was only a minor decrease in COD after treatment, the BOD/COD ratio of the antibiotic solution increased from 0.06 to a maximum of 0.60.

Sonolysis has been widely investigated as wastewater treatment prior to biological processes [58,59] for the increase of different organic substrates biodegradability [60-62], also in combination with other AOPs [63]. Most studies, however, are focused on the effects of AOPs on organic substance removal rather than the improvement in biodegradability. Sangave et al. [64] evaluated the effectiveness of a combined US/ozone process in improving the aerobic degradation of distillery wastewater and observed a COD reduction up to 45 percent.

A more recent work was carried out with reference to ozonation, applied in the treatment line for remediation of different kinds of wastewater. Integrated schemes considering ozonation alone as both pre- and post-treatment for the biological processing of distillery wastewater allowed around 79 percent reduction of pollutants, expressed as COD, compared to 35 percent COD reduction with a not ozonated sample [65].

Similarly, Di Iaconi et al. [66] operated at demonstrative scale an aerobic granular biomass system (SBBGR – Sequencing Batch Biofilter Granular Reactor) integrated with ozonation for the treatment of tannery wastewater. Results showed the removal efficiencies of the combined process for several parameters, including COD, TSS, TKN, as well as the estimation of sludge production for the assessment of the process economic feasibility. The same process scheme was used in the study of Lotito et al. [67] for the treatment of textile wastewater.

In all cases, any test to assess changes in biodegradability after ozone application was performed, whereas several studies dealing with the assessment of biodegradability enhancement after the application of ozonation to specific kinds of wastewaters are reported in literature ***(Table 5)***.

As shown in ***Table 5***, BOD_5/COD ratio was found to be the most common parameter used to assess the biodegradability of a test substance after ozonation, even in combination with other AOPs [68-75].

The recurring use of this parameter is related to the operational simplicity, although several tests have been standardized to assess biodegradability and to provide specific information about this property.

Wastewater Characteristics	Biodegradability Parameter	Work Highlights	Reference
Municipal WWTP effluent	BOD_5	Biodegradability increase due to the change in molecular structure of refractory compounds decreased inhibitory effects	[68]
Textile dye	BOD_5 increase, BOD/COD, OD/TOC	Under optimal conditions, the BOD/TOC and BOD/COD ratios increased up to 0.58 and 0.27, respectively.	[69]
Phenolic solution	BOD_5/COD	The BOD_5/COD ratio increased to 0.18, 0.26 for the test solutions, under the best treatment time.	[70]
Pulp mill alkaline bleach plant effluent	BOD_5 increase/ COD reduction	Ozone treatment enhanced the biodegradability of the effluent, monitored as 21% COD reduction and 13% BOD_5 enhancement	[71]
Procaine penicillin G formulation effluent	BOD_5	No significant correlation existed between the BOD_5 and the toxicity test results	[72]
Diclofenac in aqueous solution	BOD_5/COD Zahn-Wellens test	Ozonation promotes a more biocompatible effluent of waters containing diclofenac	[73]
Textile wastewater	BOD_5/COD	Biodegradability enhancement by a factor up to 6,8-fold	[74]

Table 5: Evaluation of ozone effect on wastewater biodegradability

Conclusion

Advanced Oxidation Processes represent one of the most promising options for the removal of persistent compounds in wastewater treatment effluents.

The action mechanism of AOPs relies on the formation of high reactive oxidant species, mainly hydroxyl radicals, which can react with recalcitrant compounds until their mineralization occurs. However, when AOPs are intended to remove all these pollutants from wastewaters, their application can be not sustainable. Conversely, their combination with conventional biological processes can be considered a valid option. It has been extensively proved that AOPs can improve the biological treatability of wastewaters, thus enhancing the removal of both organic matter and recalcitrant compounds.

In this contest, the assessment of biodegradability variation after the application of AOPs plays a fundamental role, so that specific procedures have been standardized in time. However, even though they are now well developed, results of the biodegradability variation after AOPs are usually expressed in terms of BOD_5, COD, BOD_5/COD ratio, DOC. Differently from biodegradability assays, these parameters are easy and quick to determine. Moreover, their recurring occurrence in scientific literature allows the immediate comparison of results obtained from different studies dealing with the use of AOPs as wastewater pretreatment for its biological processing.

This aspect is particularly important when considering that the investigation of advanced treatment effects generally follows two different approaches.

In the first one, research is focused on the effectiveness of AOPs in improving wastewater biodegradability. This approach is developed to deepen the study of the viability of the investigated AOPs as biological system pretreatment and/or to assess the qualitative characterization of its intermediates.

In the second one, aim of the experimental study is the integrated AOPs/biological process feasibility. This second kind of approach is pursuable when the enhancement of biodegradability after the application of the studied AOPs is already clear and the feasibility of the combined process has to be assessed.

Therefore, the comprehension of the action mechanisms of investigated AOPs has been extensively studied and the potential of several processes has been recognized.

The gap that scientific research should cover is the assessment of the technical and economic feasibility of AOPs as treatment of wastewater before its conventional biological processing. To this end, further research should be mainly addressed towards:

- the definition of removal kinetics of pollutants after combined AOPs/biological processes, in order to optimize the operating conditions as well as to identify modeling tools to generalize experimental data;
- The assessment of the combined AOPs/biological process efficiency in larger scale continuously operated systems, in order to promote its scale up.

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Still Waters Run Deep on Staten Island

by JoAnne Castagna

Residents of Grimsby Street in Midland Beach, Staten Island, New York noticed a large puddle of water in their neighborhood. Days went by, there stood the puddle; a few months go by, and the puddle still remained. The body of water was there so long that residents began counting the days – 280! A resident said that it got to the point that the neighborhood named it Grimsby Lake.

How that puddle appeared on Grimsby Street really wasn't a mystery to the residents, who for decades have been frustrated by chronic flooding problems. This flooding comes from the fact that the island, which is a borough of New York City, is low lying and has no conventional underground storm sewer system.

To help with this problem, the New York City Department of Environmental Protection (NYCDEP) created the successful stormwater management system – the Staten Island Bluebelt Program. So far, many residents have benefited from it and the agency wants to expand the program to more communities, such as flood prone Midland Beach.

The U.S. Army Corps of Engineers – New York District (Army Corps/District) is helping the city in this effort. The District developed an innovative permitting mechanism that is helping to move the Bluebelt Program along faster and, as a result, it will help reduce flooding, save taxpayer money and improve the environment and wildlife habitats.

Bluebelt Benefits and BMPs

The Staten Island Bluebelt Program is preserving and restoring streams, ponds and other wetland areas – called Bluebelts – in 16 of the island's natural watershed systems. These watershed systems are being used to collect stormwater runoff during rainstorms, hold it, filter it and gradually release it into the Raritan Bay and Arthur Kill.

During a rainstorm, water on the streets needs to be able to drain off into a storm sewer system so that roads, homes and businesses do not flood. In many parts of Staten Island, there is no such system and the rainwater has no place to go.

In the areas served by a Bluebelt Program, conventional storm sewers are built in the beds of city streets, but instead of draining into a large trunk storm sewer, the water is channeled into the Bluebelt wetland systems.

At every point where the storm sewer pipe ends and the Bluebelt begins, NYCDEP builds special drainage facilities called Best Management Practices (BMPs) that minimize the impacts of urban stormwater discharges into wetlands.

Many of these BMPs are manmade wetlands that include weirs that help to reduce the water speed, so the water is much less destructive. Wetland native plants are planted in these wetland areas to help clean and purify the water of sediment and pollutants. These contaminants eventually settle to the bottom of the water in specially designed sumps and are regularly removed by NYCDEP.

The stormwater is detained in some of these wetland areas during the peak of a storm and then slowly released downstream into the ocean after the storm has passed. The amount of water released downstream is carefully controlled in order to prevent flood surges to communities living downstream.

The program is not only successfully controlling flooding, but is also beneficial to the environment and cost effective when compared to conventional storm sewer systems.

Constructing conventional storm sewer systems can have an adverse impact on the environment. The Bluebelt Program is less intrusive and actually improves the environment, allowing for wild-

Courtesy of NYCDEP

After a storm in 2013, large puddles formed at the corner of Grimsby and Bedford Streets in the Midland Beach neighborhood.

Courtesy of NYCDEP

Streets in the Midland Beach neighborhood failed to drain even days after a storm in 2013.

Courtesy of NYCDEP

Water flows over a weir in Arbutus Creek, where NYCDEP maintains a system of best management practices for stormwater control and conveyance.

life habitats and community open space.

Not only is the environment preserved, but also considerable tax payer money is saved. According to NYCDEP, the Bluebelt Program has already saved the city more than $80 million dollars in sewer construction costs.

Regional General Permits Created

Presently, two-thirds of the island drains into the Bluebelt system. For NYCDEP to build out the system it has to design and construct additional BMPs. To do this, NYCDEP must submit permits for review and approval to the Army Corps' New York District. The Army Corps' New York District is responsible for reviewing permit applications for work that is going to be performed in any of the waterways, including wetlands that are within the District's boundaries. These permit applications need to be reviewed to make sure that there will be no adverse environmental impact to the aquatic environment and the work proposed is not contrary to the public interest.

For the Bluebelt Program, NYCDEP has been sending the Army Corps a large number of permit applications every year to perform work.

"Reviewing these applications and having them done within the NYCDEP's timeframe can get very time consuming and resource intensive to the Army Corps and also the NYCDEP," said Jodi McDonald, chief of the District's Regulatory Branch. She added, "These permit applications include a variety of activities such as replacing outfalls, doing minor dredging and creating micro pools."

Many of these permit applications can also be repetitive because they are to perform similar work.

"Most of these tasks have minimal environmental impact. So we decided to create a Regional General Permit that allows the NYCDEP to move forward and perform these minimally environmentally invasive projects without having to submit dozens of individual permit applications to the Army Corps," said McDonald. "After years of working with the NYCDEP and other federal and state agencies, we now have a Regional General Permit that allows the NYCDEP to immediately move forward on a whole suite of activities for the Staten Island Bluebelt Program."

"They can just go and build them," she added, "without having to stop and wait for a permit application to be reviewed and authorization granted. This saves the District and the NYCDEP time and resources and leaves the District time to scrutinize those permit applications that will have more of an environmental impact."

Dana Gumb, chief of the NYCDEP Staten Island Bluebelt Program, said: "This permit really gives us tremendous momentum and this is very significant and important to us. We will be able to construct and get things done much more quickly than if we had had to go the individual permit route."

Progress Being Made

The new permit is already starting to move the Bluebelt Program ahead – specifically in Midland Beach – the location of "Grimsby Lake." Midland Beach is located within the New Creek Watershed. The NYCDEP is restoring the West Branch of New Creek so that it can be used as a channel to move stormwater away from streets. This includes removing large amounts of silt that have accumulated in the channel and moving the channel away from homes.

Next, they will restore an approximately five-acre wetland complex. This will include removing approximately five acres of an invasive plant species called *Phragmites australis* and replacing it with a diverse array of native wetland plants. In addition, there will be construction of culverts under streets, control structures and sediment clean-out locations called forebays and micropools.

"This construction work wouldn't have started for years if it wasn't for the Regional General Permit," Gumb said. "We are easily saving years. When you are building a drainage system for thousands of acres in an urban setting, it's a real big ticket item. It's something that costs lots of money and takes a lot of time to do. Whatever savings in time we can have is very significant. If you're saving time, you are saving money."

Moving the program faster along means quicker results for Staten Island communities. "The Regional General Permit streamlines the permit process so that the remaining Bluebelt BMPs can be constructed faster and the public can realize benefits sooner," said McDonald. "This includes reduced flooding of homes, roads and neighborhoods as well as improved water, fish and wildlife habitat quality."

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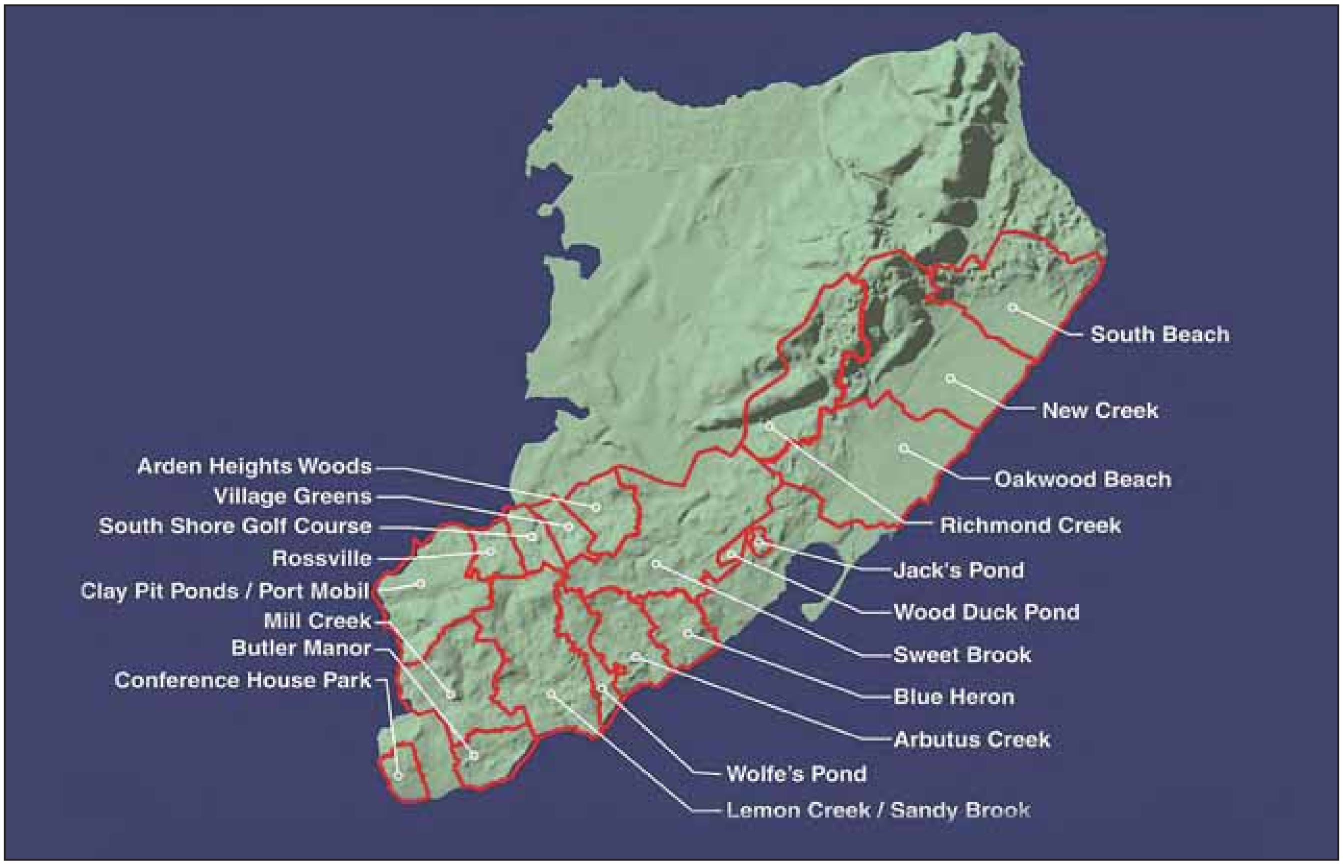
Courtesy of NYCDEP

Aerial of New Creek Bluebelt. New Creek meanders through the Midland Beach neighborhood on Staten Island.

Courtesy of NYCDEP

The Verrazano-Narrows Bridge can be seen from the wetlands in the South Beach watershed.



Courtesy of NYCDEP

Staten Island Bluebelt Watersheds

Gumb noted that: "The permit is a win-win-win situation for everyone. It's a win for the NYCDEP because it can advance our construction program much faster. It's a win for the Army Corps because they are saving staff time and they don't have to review the same kind of applications over and over again. And it is a win for the public because it gets these things built more quickly and can have the benefits in a faster time frame."

Post Superstorm Sandy Connection

Supporting the Bluebelt Program is also helping the Army Corps' post Superstorm Sandy efforts. The District is working in collaboration with the Staten Island Bluebelt Program to construct seawalls along the Staten Island coast to help protect communities from storm surges from the sea. These walls are being constructed in a way that will not only block the sea from reaching communities, but will also allow the stormwater runoff from the Bluebelts to run off into the ocean.

Former Staten Island Borough President, James P. Molinaro, once said at a press conference that he has visited Staten Island communities after rainstorms and to his amazement actually saw ducks swimming by in the street.

The hope is that with the expansion of the Staten Island Bluebelt Program and the help of the Army Corps' Regional General Permit, such large bodies of water will no longer appear and the ducks will find refuge at one on the preserved wetland habitats.

JoAnne Castagna, EdD, is a Public Affairs Specialist and Writer for the U.S. Army Corps of Engineers – New York District. She can be reached at joanne.castagna@usace.army.mil; and followed on Twitter at: http://twitter.com/writer4usacenyc.

How to Develop a Successful Energy Audit: DC Water Case Study

by Ernest Jolly and Rich Atoulikian

Utilities face operating pressures that require an increased focus on fiscal responsibility and cost reductions combined with ever-increasing levels of environmental quality standards. This creates an ideal climate for improving operational efficiencies and optimizing performance. Conducting an energy audit is a good way to evaluate a system for such efficiencies and opportunities.

This overview is excerpted from a paper presented by the authors at the 2010 World Energy Engineering Conference in Washington DC about the energy audit and savings plan being conducted for DC Water based in the nation's capital.

DC Water distributes drinking water and collects and treats wastewater for more than half a million residential, commercial and governmental customers in the District of Columbia and neighboring communities. It operates more than 1,300 miles of pipes, five pumping stations, five reservoirs and four elevated water storage tanks.

DC Water also provides wholesale wastewater treatment services for 1.6 million people in Maryland and Virginia. The utility operates 1,800 miles of sanitary and combined sewers, 22 flow-metering stations and nine offsite wastewater pumping stations. Wastewater is treated at the Blue Plains Wastewater Advanced Treatment Plant, with an average 370 mgd flow. This is considered the largest advanced wastewater treatment plant in the world.

Determining Energy Baseline

The first step in conducting an energy audit is to develop an energy baseline. Before a utility can reduce its energy consumption, it's important to understand where and how it is using energy now. The baseline results provide a framework to identify areas of greatest energy use and potential savings.

For DC Water, the water and wastewater related service areas are generally located in three departments: Water Pumping, Sewer Pumping and Blue Plains (wastewater treatment). Data collected from each department was used to perform comparative determinations among various facilities to identify higher priority opportunities.

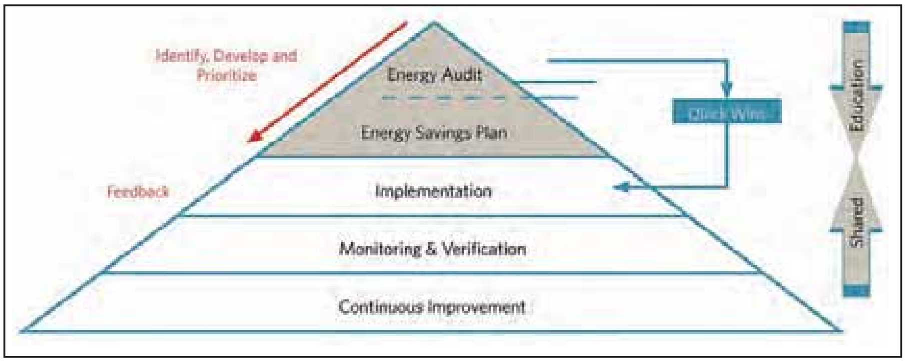
Components of the water and wastewater pumping, distribution and collection systems that were investigated include pump stations, electrical power, HVAC, lighting, building systems, mechanical systems, water systems, and water use. In DC Water's case, the majority of its energy is consumed using electricity, delineated by service area as follows:

- Wastewater Treatment: 258,600 MWh (87 percent)
- Water Pumping: 19,300 MWh (6 percent)
- Sewer and Stormwater Pumping: 20,848 MWh (7 percent)

In addition to extensive data collection and facility site visits, an important part of the energy audit process is conducting staff interviews, both to understand opportunities and challenges, but also to begin the process of organizational cultural change. More than 35 DC Water staff members were interviewed, some more than once, across the various departments, including department heads and other key department staff, the facilities group, the chief financial officer, information technology staff, and others. To supplement the one-on-one and small group interactions, workshops were held with key staff, with an in-depth analysis conducted of the data and resulting recommendations of energy savings measures.

A process model was utilized to evaluate different options for optimizing performance. As noted above, Blue Plains consumes about 87 percent of DC Water's electricity. A more detailed energy baseline was developed for Blue Plains, down to the process level. This baseline provided guidance as to where the greatest energy savings opportunities could lie. As is typical, the greatest energy consumption occurs in the two-stage biological activated sludge processes – solids handling and pumping; so these are the areas the team focused on improving. This energy baseline was set up so it could be readily modified to incorporate ongoing and contemplated improvements as DC Water considers upcoming projects.

An Energy Program's Success Requires Each of These Steps



Courtesy of HDR

Formulating Opportunities

The next step in an energy audit is formulating opportunities. This step consists of taking the data obtained from the field visits, interviews and other sources and using it as the basis for developing specific recommendations. Using standard processes for gathering data and organizing it in databases makes it much more efficient to analyze the data and prioritize results.

A key aspect of this work was to identify and bring forward "quick wins" with respect to energy savings. Quick wins are those items that can be readily implemented at little or no cost. Bringing these forward in a timely fashion provides the opportunity for utilities to start saving money sooner rather than later, which further fuels the organizational cultural change process. A Quick Wins Workshop was held about two and a half months after initiating the energy savings study to present the findings to department leaders.

More than 250 quick win projects were identified that could implemented immediately. The list included upgrading to more efficient lighting, HVAC improvements, building envelope improvements, and resetting set points or installing automated controls. The resulting total savings is estimated to reach over $500,000 per year with very short payback periods, generally ranging from a couple of weeks up to 12 to 18 months.

In addition, many electrical utility rebate programs exist that can offset capital costs associated with implementing energy efficiency projects. This is identified early in the audit process, to enable utilities to optimize their use of such programs.

A prime example of a quick win relates to lighting. DC Water uses more than one megawatt of power to light facilities, which is extremely high compared to the 1 to 1.5 kilowatts used in our homes. By converting to more efficient lighting and ballasts, and installing motion sensors that turn the lights on and off based on when the facilities are occupied, energy consumption could be significantly decreased, resulting in several hundred thousand dollars in energy savings.

Data and Project Analysis

Once the quick wins are identified, the remaining opportunities go through an initial screening by looking at financial metrics, such as initial capital cost, payback period or return on investment. Ease of implementation and alignment with organizational strategies are also important considerations. Project opportunities that pass this test are then developed further, to better quantify these metrics before they are presented in a Project Prioritization Workshop.

As part of DC Water's efforts, renewable energy, such as wind turbines, solar power or small hydro, was explored in more depth. Large wind turbines did not appear practical at Blue Plains, since it is in the flight path for Reagan National Airport. While these devices could be used at some other facilities, the amount of wind energy generation potential was not sufficient to provide a reasonable payback period. Solar energy is a viable alternative, and installing solar panels at one DC Water facility as a pilot project became one recommendation. Rebates and financial incentives make that alternative financially attractive, and favorable public perception associated with DC Water's use of renewable energy further strengthens the case for solar. Micro turbines in the flow stream at Blue Plains are another possibility, and could be placed just downstream of the effluent filters where the water quality is expected to be good. However, one challenge is how to best combine more than 80 individual effluent pipes into a smaller number that would make this option more attractive.

Project Prioritization Workshop

In this workshop, project opportunities that meet financial and feasibility criteria are presented to the group. Many times, the prioritization process entails rating the projects based on different criteria and seeing how their rankings change, i.e., ease of implementation to determine what can most readily demonstrate success; low capital cost if funds are limited; or payback period/return on investment if that metric is most important to the organization. An interactive prioritization tool can be used to manage and prioritize the various projects.

As part of this process, more than 40 potential project opportunities totaling over $3 million in annual savings were identified at DC Water. The top projects identified offer the potential to save an annual $2 million with paybacks of 12 to 18 months. These projects generally fell into the following categories:

- Capital projects, which require detailed design and construction contract development;
- Procedural/programmatic activities, such as development of standard operating procedures for use of high efficiency or premium motors, or modifying building thermostat set points;
- Maintenance related activities, such as installing power monitoring to enable equipment operating in parallel to be compared, to see if any individual device may be operating out of standard performance and consuming extra power (e.g., on a pump, due to a clogged line or broken impeller).

To further effect organizational change, it was also recommended that the regular reviews of ongoing projects be held from an energy perspective; this would be most appropriate for projects in the planning and design phases. Capital cost, operational flexibility, reliability or redundancy tend to be the drivers for a project's progression from the study phase through design and construction. However, in the new world of energy management, a look at the impacts of energy on cost, operations, etc., is just as important. As is commonly known, the greatest ability to impact a project is in the early phases, and this is where the value associated with reviews from an energy perspective can be most impactful.

Conceptual Design of Long-Term Potential Project Opportunities

Projects selected to move from the Project Prioritization workshop to conceptual design generally fall into one of the three categories noted above. These consist of the following measures:

- Motor replacement: standard motors can be up to 10 percent less efficient than premium efficiency types. Typically, the delta in motor efficiency is the highest for motors with a relatively low

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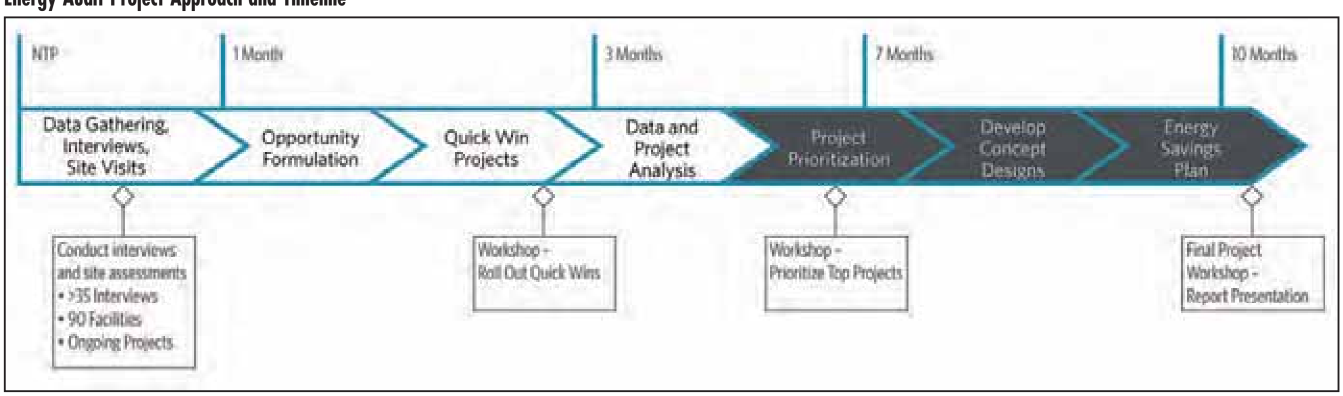
Energy Audit Project Approach and Timeline



Courtesy of HDR

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capacity and vice versa. In addition, premium type motors can have a significantly higher power factor. The combination of both can result in efficiency gains of up to 30 percent, particularly if the existing motor has been rewound.

- Replacing the air cooled chiller condenser with a water cooled type. The more stable condenser temperature will result in a chiller efficiency gain. The preferred water source is the process water (final effluent) system, treated appropriately.
- Solar photovoltaic arrays: with potential roof and land availability for just under 500 kW, DC Water has the potential to reduce long-term energy bills and utilize a zero-carbon energy source.
- Raising the water levels on the suction side of certain pumps was also identified as a potential opportunity. Since horsepower consumption is proportional to pumping head, raising the suction level reduces horsepower. When implementing, certain operational strategies must be modified to mitigate potential adverse impacts.
- Incorporating an energy dashboard into DC Water's overall control system. This would reinforce cultural change and raise awareness of the importance of energy management in DC Water's day-to-day activities, and show the respective organizational goals and real-time progress toward those goals.

Delineation of annual identified cost savings by category is as follows:

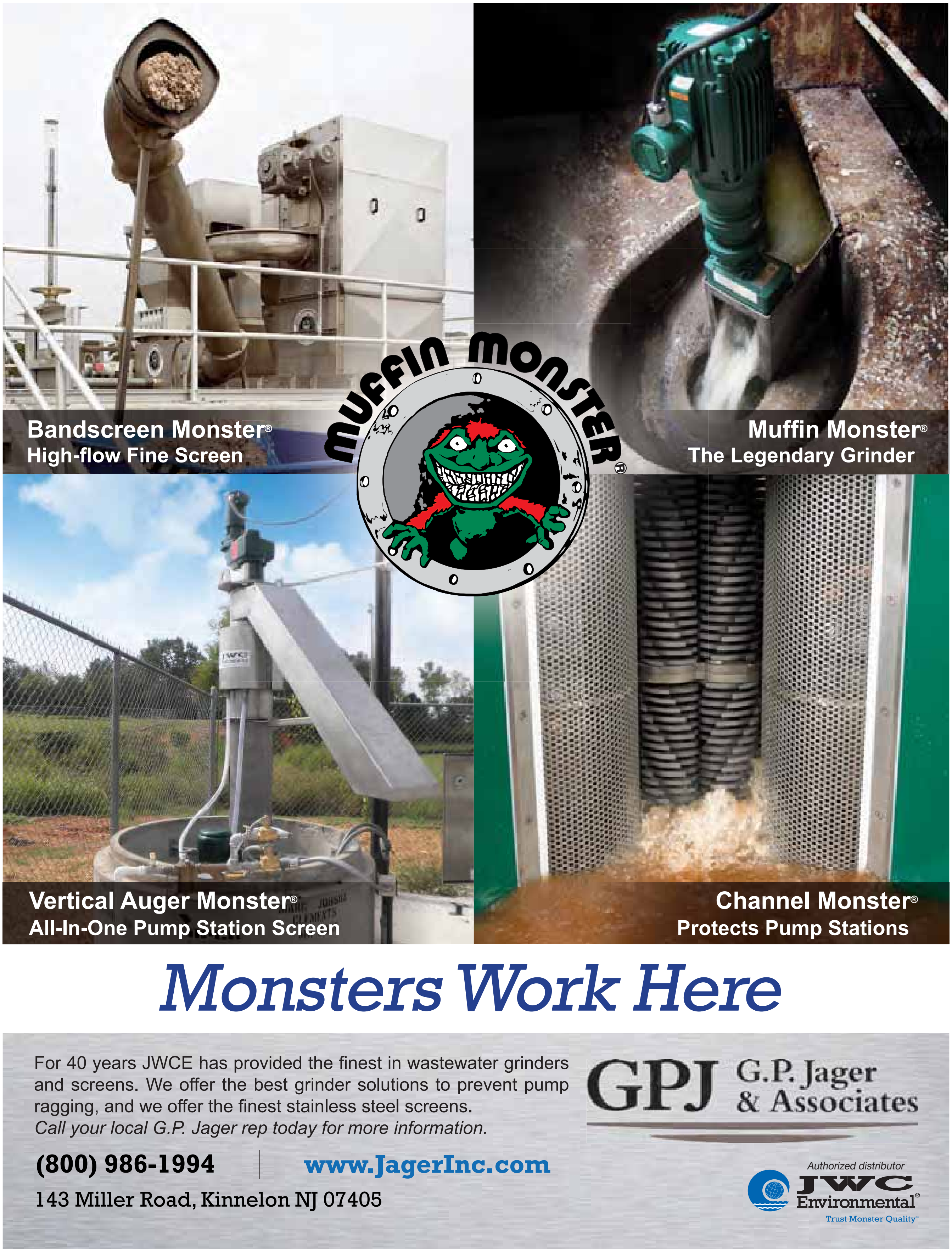
- Lighting: 32 percent
- Equipment Optimization: 30 percent
- Renewable Energy: 25 percent
- Process Modifications and Equipment Substitution: 13 percent

Energy Savings Plan

Developing an energy savings plan is the final step in the energy audit. DC Water is evaluating the changes it will ultimately make, and the findings from its Energy Savings Plan will be an important consideration as the water authority develops its ultimate path forward. But through consistent process improvements, employee engagement and training and equipment adjustments, DC Water will have significant opportunities to positively impact energy usage and thus decrease energy costs. In addition, the projects identified would reduce DC Water's carbon footprint by nearly 10 percent, a significant reduction for a leading utility in our nation's capital.

***Ernest Jolly** is the Strategic Planning Chief with DC Water and can be reached at ernest.jolly@dcwater.com. **Rich Atoulikian**, PMP, BCEE, PE, is a Vice President with HDR and can be reached at rich.atoulikian@hdrinc.com. The authors conducted the energy audit and savings plan for DC Water described in this article.*

***Acknowledgments:** Bert Wellens, Robyn McGucken, Ken Brischke and George Simon.*



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Hornell Takes Guarantee to Realize Energy Savings in Wastewater Treatment Operations

by Jon Sorensen

It will snow this winter in Upstate New York, the geese will have flown south, and the City of Hornell will soon be saving at least $40,000 a year thanks to energy efficiency improvements at its Water Pollution Control Plant (WPCP).

Who says there are no guarantees in life?

In the case of Hornell, the city has signed a $2 million energy performance contract with its general contractor Johnson Controls that includes an "Assured Performance Guarantee" for cost cutting improvements to the city's aging wastewater plant. Under this guarantee, Johnson Controls has agreed to deliver energy savings of between $43,728 and $76,678 a year for a total of $1.174 million in cost reductions over the next 20 years.

While performance guarantees have been around for decades, energy performance contracts in New York have largely been confined to school districts. Now Hornell and a growing number of local governments in New York are seeing the benefits – and the dollars – from these energy saving guarantees.

Photo courtesy of Johnson Controls – ©Gary Hodges Photography

Hornell's Water Pollution Control Plant

Photo courtesy of Johnson Controls – ©Gary Hodges Photography

NYS Environmental Facilities Corporation President/CEO Matthew Driscoll and Hornell Mayor Shawn Hogan, center, lead a groundbreaking ceremony on September 4, 2014 launching energy saving improvements at the Hornell Water Pollution Control Plant on Park Drive.

Updates for Hornell Plant

The Hornell plant treats an average of 2.7 million gallons of polluted water a day and discharges cleaned, recycled wastewater into the Canisteo River. The city last updated the facility in 1985. Construction is now underway and work should be completed by the end of March 2015.

"It's important that we provide our residents with quality services while staying within our budgets. With this project we have found a way to get the repairs we need done while saving our resources," said Hornell Mayor Shawn Hogan. In addition to the guaranteed savings from improvements at the plant, Hogan has also reduced costs thanks to a $630,000 Community Development Block grant, a $30,000 Engineering Planning Grant from New York State and $2.8 million in low cost financing from the New York State Environmental Facilities Corporation (NYSEFC or EFC).

"The Environmental Facilities Corporation provides local governments with an affordable way to finance vital infrastructure projects in their communities," said NYSEFC President and CEO Matthew Driscoll. The NYSEFC provides low cost financing for local governments to improve their wastewater and drinking water infrastructure. In the previous federal fiscal year, New York State led the nation in loaning more than $2 billion to local governments through

Workers remove part of the structure of the Hornell Water Pollution Control Plant to make room for a new blower building to be constructed.

the NYSEFC and the state's revolving funds program. The guaranteed energy savings will help Hornell pay the repayment costs for a 30-year loan which is expected to be approved by NYSEFC next year.

An energy study at the Hornell WPCP determined that a total reduction on electrical energy use of 454,573 kWh per year – or a 39 percent approximate reduction in overall electrical use - was achievable. The study identified two principal improvements that would result in significant cost avoidance: replacement of the interior and exterior lighting and controls; and replacement of the existing aeration system with a fine bubble system, new turbo blowers and automatic dissolved oxygen set point control. The new aeration system will save up to $40,232 a year, improving the treatment process while also saving on operation and maintenance costs. The present system is 25 years and beyond its useful life.

The project is designed to make the facility easier and more efficient to operate and will also help the plant meet state and federal discharge permit requirements. At the same time, the city will save energy, reduce its carbon pollution and help the environment.

The plant's Chief Operator Rich Dunning is thrilled to replace the plant's 30-year-old surface mounted agitators with ultrafine bubble diffusers at this time. "We recently received a new SPDES (state pollutant discharge elimination system) permit with new requirements for nutrient removal. This brand new technology will not only save operation and maintenance costs but the level of treatment will be improved. The Canisteo River and the Chesapeake Bay will continue to get cleaner through projects like this one. We greatly appreciate the EFC's assistance in making this project more affordable to the taxpayers of Hornell."

If the guaranteed cost savings target is not met in a particular year, the contract provides for adjustments in future years or a direct payment to Hornell. The contract also allows the contractors to make adjustments at the plant to achieve the intended energy savings.

"Last fall we had a major sewer collapse and failure on our main trunk line, which necessitated a declaration of emergency by my office," said Mayor Hogan. "We were able to get construction financing (from EFC) at about .23 percent. That's almost like free money."

Hornell was also among the 196 cities, towns and other local governments that have saved money since 2011 after the NYSEFC refinanced more than $3.1 billion in previous loans for water quality infrastructure. Hornell saved more than $33,000 this year, while municipalities statewide have saved more than $448 million (in current dollars) with NYSEFC's comprehensive refinancing initiative.

NYSEFC Expanding its Efforts

"As we mark the 25th anniversary of New York's Clean Water State Revolving Fund," said NYSEFC President Driscoll, "the EFC is expanding its efforts to help local governments create reliable infrastructure for the collection and treatment of wastewater and stormwater."

"The New York Conference of Mayors applauds the successful efforts of EFC to reduce the infrastructure-related interest costs incurred by local governments and their taxpayers," said Peter A. Baynes, executive director of the New York State Conference of Mayors. "At a time when cities and villages are struggling to fund the water and sewer system improvements necessary to enhance the quality of life and economic development capacity of their communities, EFC's lowered interest rates will be of tremendous assistance." The bond-rating service, Fitch Ratings, affirmed in October the Triple-A credit rating on NYSEFC bonds originally issued in 1991. Many of those 1991 loans were among the sewer and water loans refinanced by the NYSEFC this year. The Chicago-based rating agency cited NYSEFC's strong financial structure as well as the high quality of its outstanding debt.

Jon Sorensen (jon.sorensen@efc.ny.gov) is the Director of Public Information for the New York State Environmental Facilities Corporation in Albany.

Photo courtesy of Johnson Controls – ©Gary Hodges Photography

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The existing surface aerators will be replaced with a more efficient aeration system.

Operator Quiz Test No. 106 – Pumps, Equipment and Safety

The following questions are designed for trainees as they prepare to take the ABC wastewater operator test. It is also designed for existing operators to test their knowledge. Each issue of *Clear Waters* will have more questions from a different section of wastewater treatment. Good Luck!

1. A pump with a mechanical seal has developed a leak at the gland. What could be causing this?:
   a. The pump packing has failed allowing water to slowly drip out.
   b. The pump ran dry ruining the seal faces.
   c. This is normal operation for mechanical seals.
   d. When the seal spring was installed, it allowed pressure between the two seal parts allowing water to leak out.

2. How does maintaining a standard three-phase, single speed, synchronous AC motor compare to maintaining a standard three-phase, variable-speed AC motor?
   a. The single speed motor does not need cleaning and lubrication included in its preventative maintenance program.
   b. The single speed motor does not need testing of electrical circuits included in its preventative maintenance program.
   c. The single speed motor does not need attention to slip rings and carbon brushes included in its preventative maintenance program.
   d. The variable-speed motor does not need lubrication or slip ring and carbon brush attention included in its preventative maintenance program.

3. When inspecting an electrical motor it is noticed that a film has developed on the slip rings. What should be the next course of action?
   a. What is seen is oxidation of the slip rings and it should be completely removed for proper operation of the motor.
   b. What is seen is oxidation of the slip rings and it should remain on the slip rings for proper electrical flow.
   c. What is seen is oxidation of the brushes and the brushes should be replaced immediately.
   d. What is seen is mechanical wear of brushes due to light pressure between the slip ring and brushes. The brushes need to be properly adjusted on the slip rings.

4. When inspecting a failed pump, it is found that the main cause of failure was damage of the bearings due to brinelling. This can best be described as:
   a. Misalignment of the bearing during installation
   b. Over lubrication of the bearing with incorrect lubrication
   c. Under lubrication of the bearing resulting in contamination
   d. Dents formed in the bearing race or bearing

5. An automatic controller excessively starts and stops an induction motor. The resulting short cycling causes the motor to fail. This failure is most commonly due to:
   a. An automatically controlled induction motor only has a limited amount of start sequences.
   b. Increased frequency of increased amps at startup overheated the internal winding.
   c. Decreased frequency of planned shutdowns for maintenance
   d. Internal contaminants due to insulation failure

6. The packing gland is pulled from the stuffing box of a locked out and tagged out centrifugal pump and excessive leakage occurs. What should be the next course of action?
   a. After removing the packing and determining it was not the cause, examine the shaft sleeve and replace if scored or grooved.
   b. Remove the packing, examine the alignment of shaft, realign if necessary
   c. Check bearings for wear and rough spots
   d. Check operating temperature of bearings before startup

7. How do Material Safety Data Sheets (MSDS) differ from Safety Data Sheets (SDS)?
   a. SDSs are not concerned with the composition and handling of liquid chemicals.
   b. MSDSs do not outline the dangers of specific chemicals and substances.
   c. SDSs will be obsolete in 2015.
   d. SDSs serve the same purpose of MSDSs, however, they are formatted to a standardized 16 section Global Harmonized System.

8. Which of the following is not required when entering a permit required confined space?
   a. Wearing appropriate Personal Protective Equipment (PPE)
   b. Testing for atmospheric hazards to determine acceptable conditions are maintained
   c. An attendant to monitor personnel and air quality in the confined space
   d. MSDSs for chemicals in the plant

9. A wall mounted gas meter display is reading high levels of H_2S and dangerous LEL and the alarm is not going off. After further inspection it was found that the alarm wire was disconnected. The most appropriate immediate action would be:
   a. Ignore the gas readings – the alarm was disabled most likely due to false readings.
   b. Obtain all necessary tools to re-attach the wires and recalibrate the meter.
   c. Leave the area immediately and contact the proper personnel.
   d. Obtain a portable gas meter to compare to wall mounted display.

10. Liquid Sodium Hypochlorite, NaOCl, is commonly used for disinfection of final effluent waters. Which of the following statements about this material is INCORRECT?
    a. If mixed with acids, chlorine gas may be released from the solution.
    b. If mixed with organic compounds, explosive and volatile organic compounds could form.
    c. If mixed with wastewater, fecal counts may increase.
    d. NaOCl exists as sodium and hypochlorite ions in water.

11. An inline grinder is found to be tripped and needs to be addressed. The most proper first step is to:
    a. Electrically reverse the rotation to clear obstruction.
    b. Remove the inspection plate and inspect with a flashlight and prodding rod.
    c. Properly shut down the piece of equipment and lock and tag out.
    d. Isolate the grinder by closing the suction and discharge valves.

12. The common practice of tailgate safety is most commonly described as:
    a. Short reminders and continued conversation with employees on the importance of safety, safe conditions and procedures, and reviews of potential hazards
    b. Making sure nobody trips over the cooler
    c. Assuring the bungee cords are properly attached to the truck bed supports
    d. Structured hour-long classes discussing a multitude of safety issues

Answers on page 62.

For those who have questions concerning operator certification requirements and scheduling, please contact Tanya May Jennings at 315-422-7811 ext. 4, tmj@nywea.org, or visit www.nywea.org/OpCert.

continued from page 7

Highlights of Energy Specialty Conference, continued

Alex Wright of ClearCove Systems speaks on reaching net zero energy.

Vince Apa from CDM Smith talks about Rahway Valley's progress to becoming a resource recovery facility and net neutrality.

Right: Peter Radosta and Gregg Palmer of Koester Associates

Left: WEF President Ed McCormick gives the keynote address during the luncheon.

Below: Ely Greenberg from ERG Process Energy helps moderate Session I.

Michael Whelan represented the Hydra-Neumatic Sales Company.

Rob DeGiorgio conducts business during the break.

Carter Strickland of HDR talks about private financing and design of biogas projects.

Bucky Brennan stands next to the Milton CAT exhibit. Milton CAT was a co-sponsor of the conference.

Heather Higgins and Brent Solina from MicrOrganic Technologies

Richard Lyons of Albany County and NYWEA President Steven Fangmann

Resources

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Clear Waters: Statement of Ownership, Management, and Circulation

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(15) Extent and Nature of Circulation	Average No. Copies Each Issue Preceding Twelve Months	No. Copies of Single Issue Published Nearest to Filing Date
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b. Paid Circulation (by mail and outside the mail)		
1. Mailed outside-county paid subscribers	2290	2280
2. Mailed in-county Paid Subscribers	139	142
3. Paid Distribution Outside the Mail	–	–
4. Paid Distribution by Other Classes of Mail through the USPS	82	72
c. Total Paid Distribution (sum of 15b (1), (2), (3), (4))	2511	2494
d. Free or Nominal Rate Distribution (by mail and outside the mail)		
1. Free or Nominal Rate outside-county copies	293	291
2. Free or Nominal Rate in-county copies	13	13
3. Free or Nominal Rate Copies Mail at other Classes through USPS	18	11
4. Free or Nominal Rate Distribution	13	11
e. Total Free or Nominal Rate Distribution (sum of 15d (1), (2), (3), (4))	337	326
f. Total Distribution (sum of 15c and 15e)	2848	2820
g. Copies Not Distributed	52	80
h. Total (sum of 15f and 15g)	2900	2900
i. Percent Paid (15c divided by 15f times 100)	88%	88%

(16) The Publication Statement of Ownership will be printed in the Winter 2014 issue of this publication. (17) Signature and Title of Editor, Publisher, Business Manager, or Owner. I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties). Date: 9/24/14

Winter 2014, Vol. 44, No. 4

Clear Waters

New York Water Environment Association, Inc.

Answers from page 59: 1 B, 2 C, 3 B, 4 D, 5 B, 6 A, 7 D, 8 D, 9 C, 10 C, 11 C, 12 A

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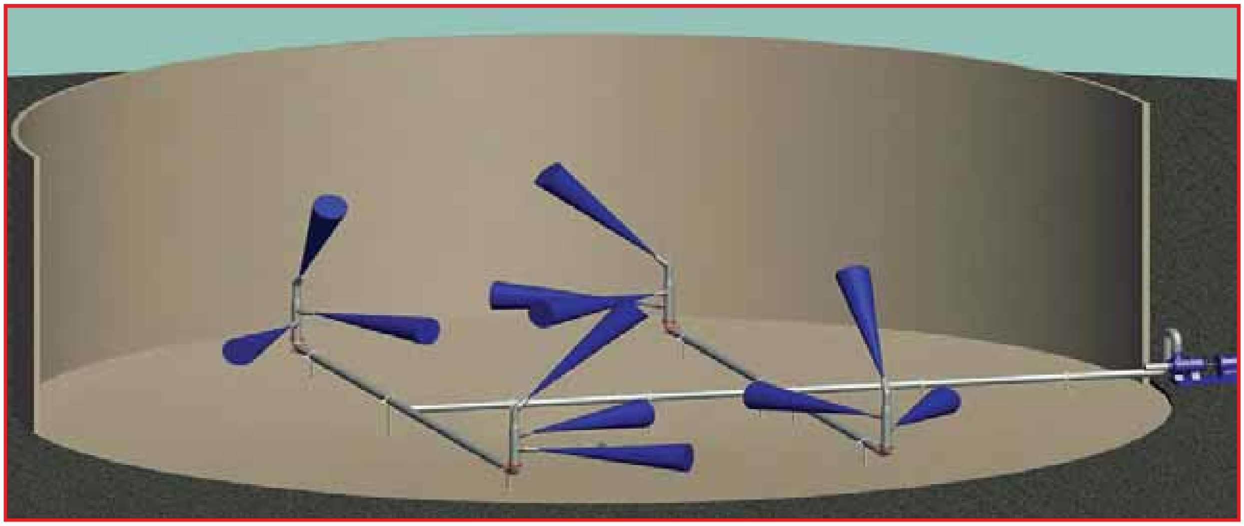

MULTIPLE ZONE SLUDGE MIXING

JET MIXING IN EQUALIZATION TANKS

MIXING AND AERATION IN pH CONTROL TANK

HYDRAULIC SLUDGE MIXING APPLICATIONS

- Digester mixing
- Mixing anaerobic digesters
- Sludge holding tanks
- Equalization tanks
- Variable liquid level tanks
- Single, double and triple zone mixing
- No rotating equipment in digesters

HYDRAULIC SLUDGE MIXING BENEFITS

- Energy efficient
- Stainless steel nozzles
- Nozzles hardened to a Brinell hardness of 450+
- Chopper pumps
- CFD mixing analysis

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