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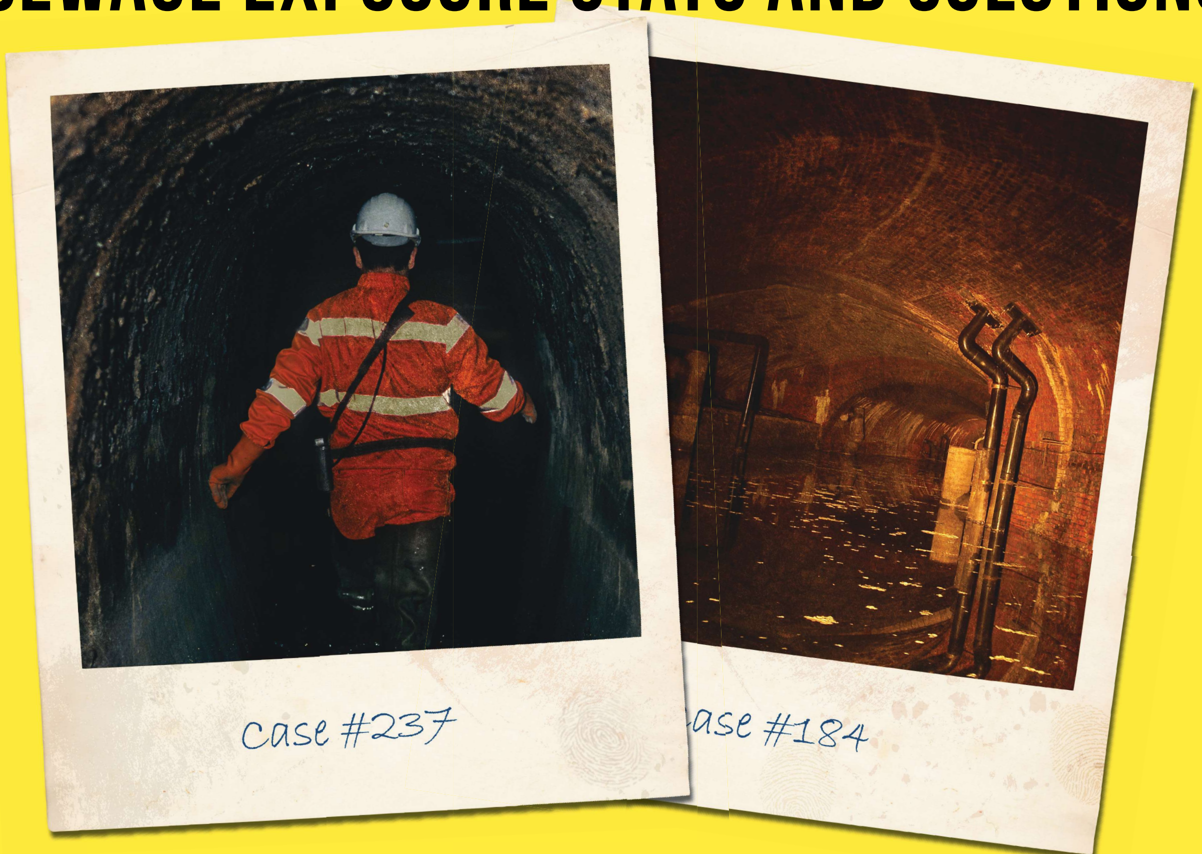

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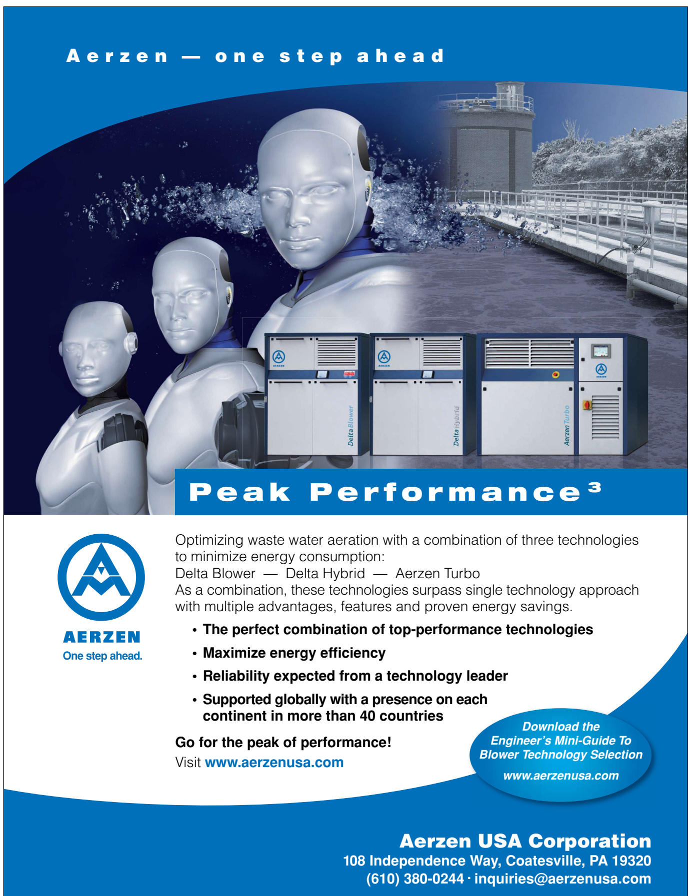

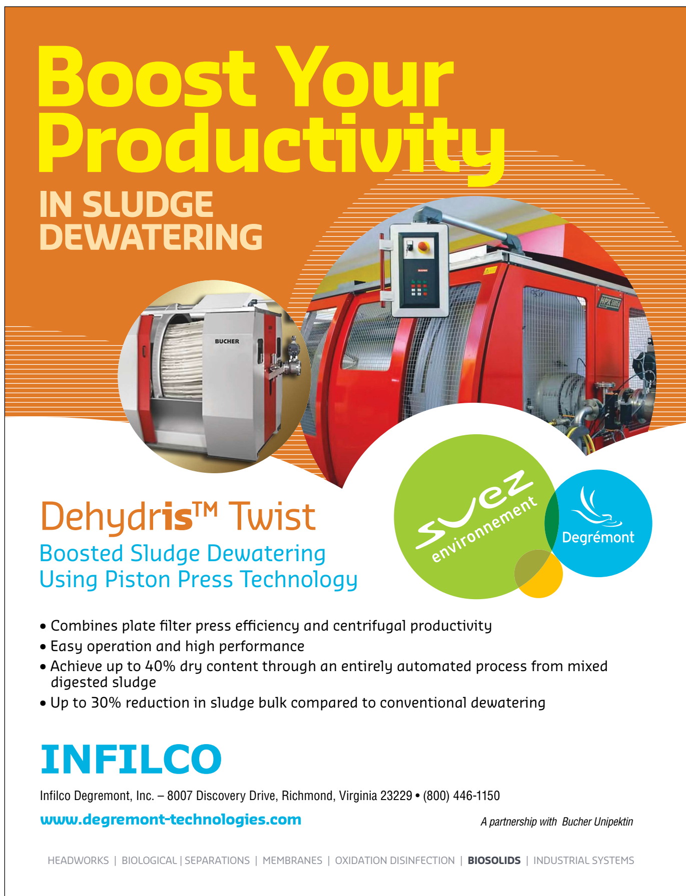

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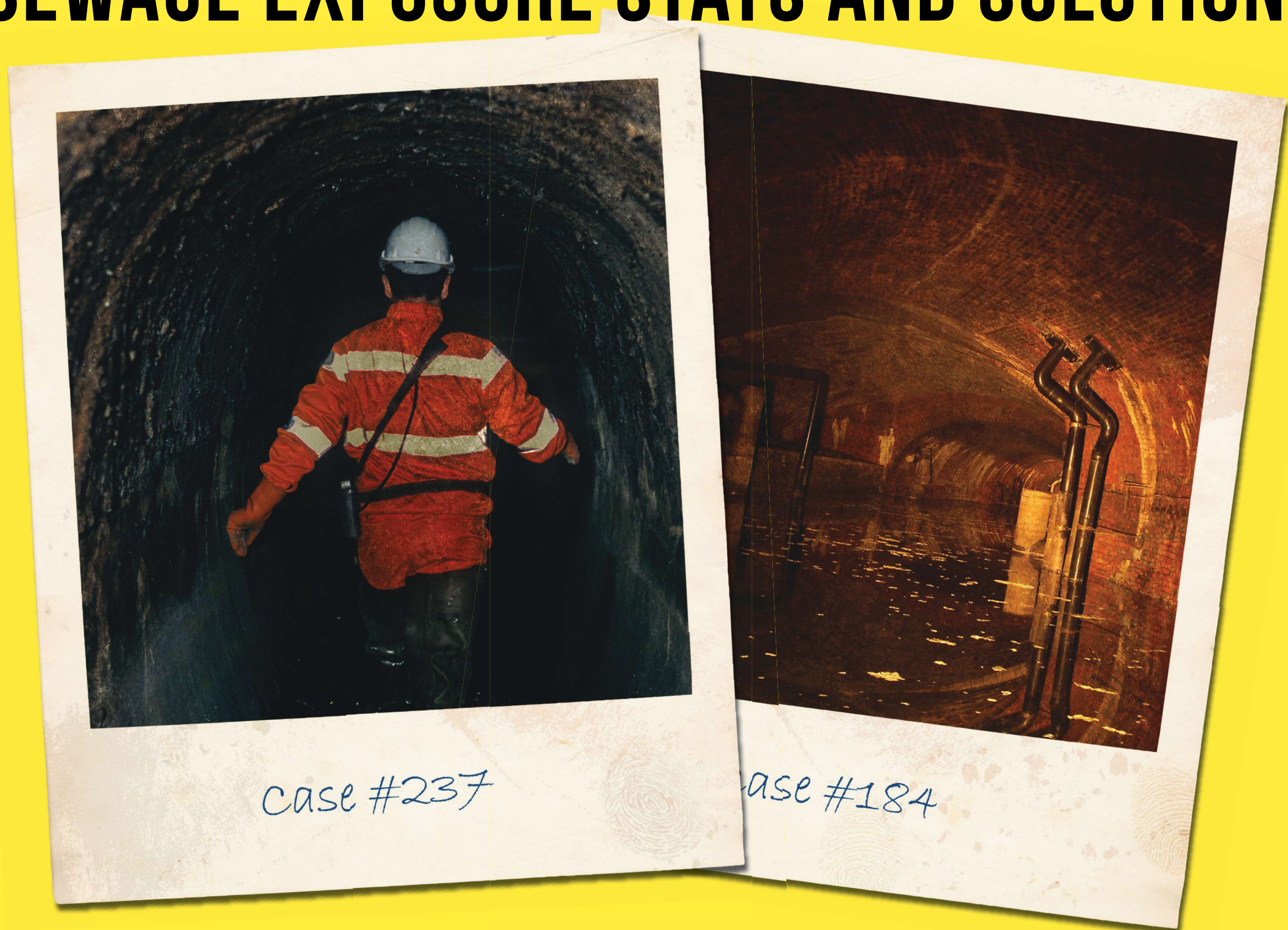

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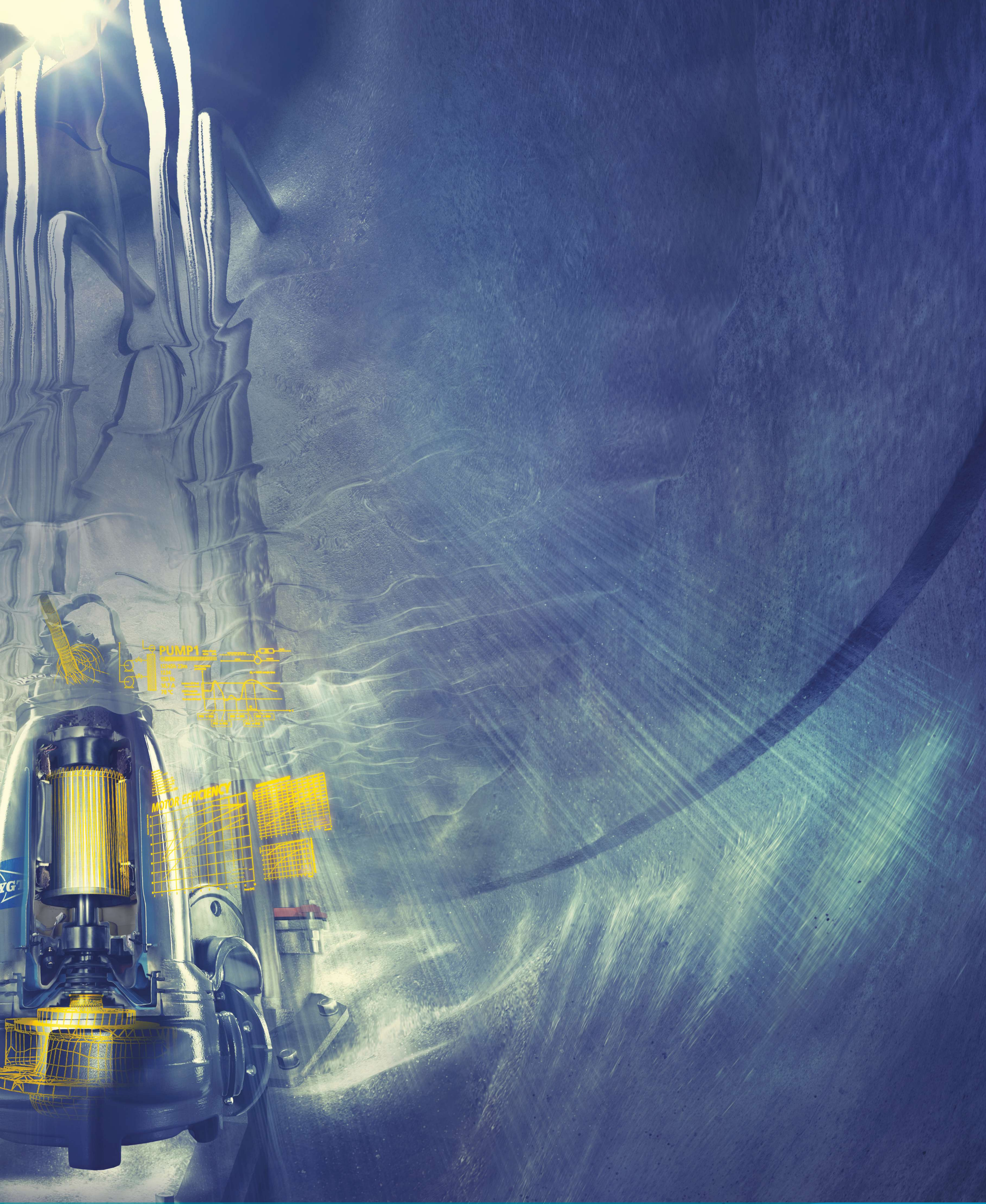
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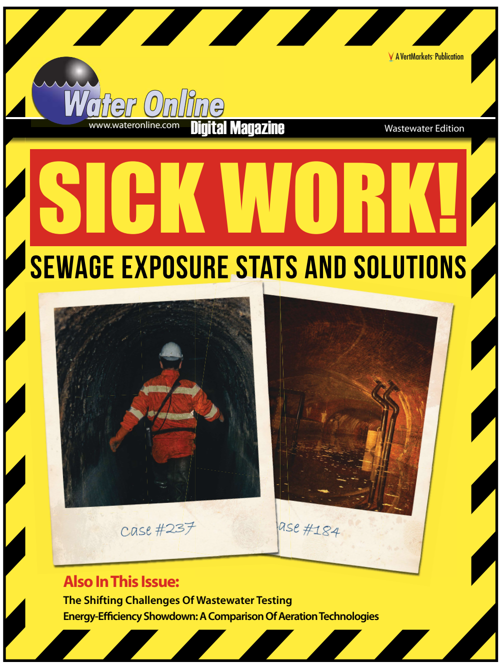

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Rinse, Repeat: The Rise Of Water Reuse

I may not be "old school" in the water/wastewater industry, but I have been around long enough to see a number of ideas graduate from sideshow to center stage. In wastewater, the topic in the spotlight at the moment is water reuse — and its role won't soon diminish. Depending on your part of the world, it will sooner or later be the norm — but the smart ones are planning ahead.

Some of the brightest minds in our field were on the panel at WEFTEC 2013's Water Leaders session where water reuse dominated the discussion. Three of the four panelists, in fact, had significant stakes in water reuse for their cities and businesses.

Heiner Markhoff, president and CEO of GE Power & Water, shared results from a recent international survey conducted on attitudes toward water reuse. The findings showed not only firm support for the idea but found that 54 percent of respondents were willing to pay more for reused water. Furthermore, 90 percent agreed that water reuse should be a national priority for their respective countries.

GE conducted a similar survey in 2012, focused on the U.S., revealing that 80 percent or more of Americans support reuse for non-drinking water applications such as water-intensive industrial practices, as well as landscaping, toilet flushing, and car washing. The real seismic shift in the industry, however, is the rise of reuse for drinking-water applications.

Water Leaders panelist Sue Murphy, CEO of the Water Corporation in Perth, Australia, presides over what she called a "lost" water supply. Murphy said that in the last 30 years, the climate has changed dramatically, rainfall has fallen off 20 percent, and the runoff into dams is just one-sixth of what it was. Because of the scarcity situation, more than half of Perth's water supply comes from desalination, but Western Australia Water Minister Terry Redman announced in August 2013 his plan to tap a new source. Within the next decade, another 20 percent of Australia's water is predicted to come from indirect potable reuse (IPR).

Meanwhile, the Australian Academy of Technological Sciences and Engineering (ATSE) recommends the country go a step further, releasing a report in October 2013 on the benefits of (and inevitable need for) direct potable reuse (DPR). Those benefits, compared to IPR, include reduced energy use and greenhouse gas emissions, as well as lower capital and operational costs. The main impediment, of course, is public perception.

Chew Men Leong, chief executive of Singapore's national water agency, the Public Utilities Board (PUB), has faced down this challenge and scored a rousing victory — so decidedly that the PUB's NEWater program is a point of national pride and considered a model for the world. Leong, who was also part of the WEFTEC Water Leaders panel, recalled how PUB first sought understanding and acceptance from the media, which in turn helped promote buy-in from the general public. The Singapore NEWater Visitor Centre is another exemplary outreach effort. Opened in 2003, it features interactive models, games, videos, and a viewing area to showcase and explain the recycling process.

Contributing to its vanguard status, PUB hosted its first Water Utilities Leaders Forum just prior to WEFTEC, attracting more than 180 top water professionals from more than 45 countries. Among them was George Hawkins, general manager of the District of Columbia Water and Sewer Authority, who reported upon his return, "I wanted to see firsthand what they are doing … we need to learn from the world's best."

Hawkins, who is a leading voice in U.S. water treatment, noted that Singapore, as a small island with limited resources, was perhaps guided by necessity. However, Singapore and PUB only achieved their current lofty status by continuing to innovate, further adopting green infrastructure and desalination as they learned the virtue of forward-looking water policy. "The rest of us," Hawkins concluded, "need programs of similar strategic breadth."

Leong himself summed up the proper vision and approach for the future best at the Water Leaders session, stating, "We need to take the risk of adaptive technologies." He then added — striking at the heart of the water reuse movement — "not being prepared for the future is a much bigger risk."

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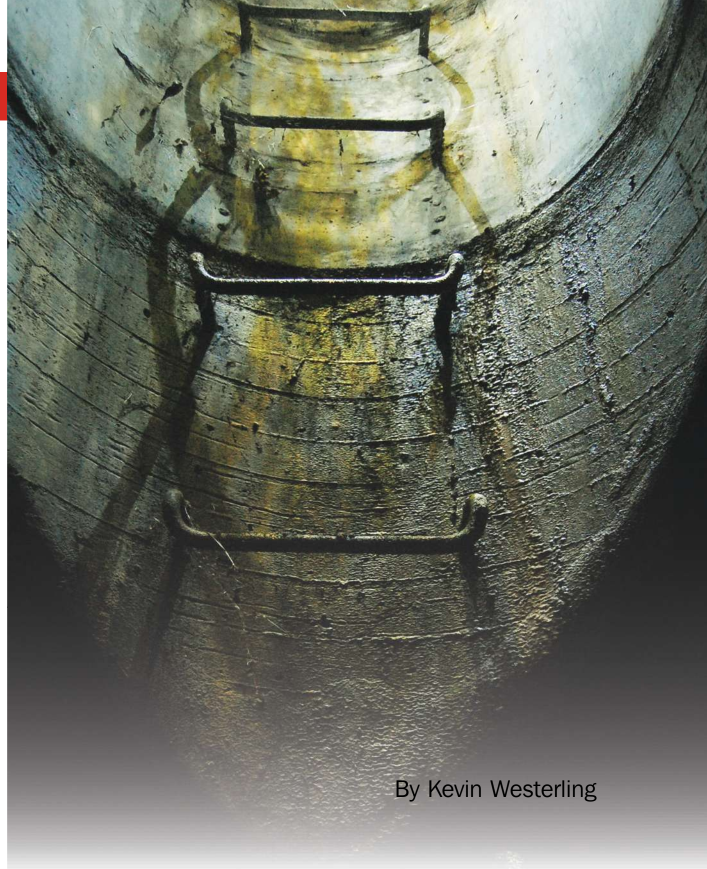


Sick Work! Sewage Exposure Stats And Solutions

Everyone knows that sewer work is a "dirty job," but there are factors – and real-life stories – that suggest the incidence and risk of sickness are rising.

By Kevin Westerling

Bedpan contents from quarantined hospital patients, radioactive chemicals, industrial chemicals, human blood from morgues, animal blood from labs — it all ends up in the sewer. Then, of course, there's the usual: anything and everything that goes down the toilet or drainpipe. Sewer workers are a hardy breed, and they know full well that they're dealing with some pretty gross … um, stuff. It may be an unwelcome surprise, however, to learn that the "stuff" they encounter is becoming increasingly pathogenic, and that the job is getting ever more dangerous.

Viruses Trending Up

There are approximately 3,000 viruses recognized in nature, but that merely scratches the surface of what exists. As scientists continually seek to identify more, they often visit the sewers, which are both a destination and a breeding ground for viruses. Many viruses are brought in by human and animal feces and urine, plant material, and the insects and rodents that make the sewers their home, but then they proliferate. The viral count expands when the host viruses infect the bacteria, rotifers, amoeba, and fungi that readily (and rapidly) grow in raw sewage. The longer sewage sits, the more viruses are created. Consider that a single bacterium will split, under proper conditions, every 20 minutes; the exponential growth rate amounts to 69 billion in a matter of 12 hours. With today's water conservation efforts creating less flow and longer retention times — think low-flow toilets and urban sprawl — sewers are virtual petri dishes for new bacteria and viruses.

In 2011, scientists from the American Society for Microbiology (ASM) were among those who took to the sewers searching for viruses. Most of what they found was brand new — at least to the science and medical community. "The ratio (43,381/3,027) of novel to known viral sequence reads is approximately 10:1," the ASM study concluded. "Our data demonstrate that known viruses represent a small fraction of the viral universe."[1]

Unknown viruses have equally unknown effects — and some viruses can lay dormant in humans for months or years before surfacing — so there is plenty of potential for unpleasant consequences in the future. But there are also consequences being realized here and now.

The Devil We Know

The ASM study identified 234 viruses of the known variety in its sewer search, 17 of which are communicable to humans. Such viruses included human adenovirus, human papillomavirus (HPV), cholera, typhoid, HIV, and H1N1. Other scary findings from researchers conducting sewer dives include methicillin-resistant *Staphylococcus aureus* (MRSA) bacteria, poxviruses, herpesviruses, and hepatitis A virus (HAV). The journal *Occupational and Environmental Medicine* released a study specific to HAV stating that "frequent occupational exposure to raw sewage was a significant risk factor for HAV infection." The study noted that, "of 50 employees who reported occupational exposure to raw sewage most of the time, 30 (60 percent) had had HAV infection."[2]

MRSA has even made its way to the treatment plant. From 2009 to 2010, University of Maryland (UMD) researchers tested four water reclamation facilities, taking numerous samples from each throughout the treatment processes. While half of all the extracted samples contained MRSA, only one of the four facilities tested positive for MRSA at the end of treatment.[3] Though that is certainly one too many, it is noteworthy that the plant did not employ tertiary treatment by chlorinating its water regularly. With the rise of water reuse and the potential for direct public exposure to the product, this is a sound lesson for reclamation facilities.

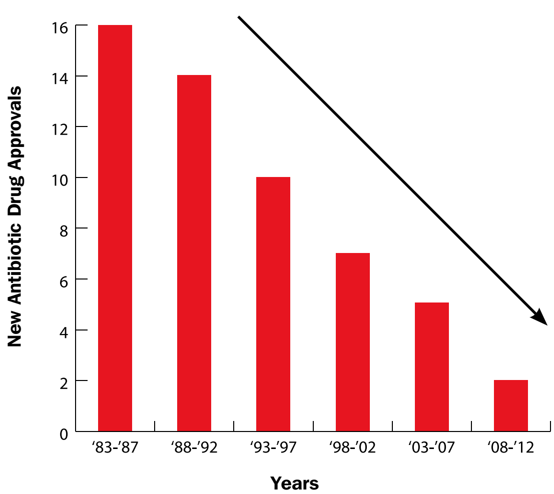
Meanwhile, the same UMD study revealed that 83 percent of the raw sewage samples coming into the plant contained MRSA, giving indication of its prevalence in sewers. What distinguishes MRSA from most other infections is its antibiotic resistance. Unfortunately, that may not be an exceptional trait for long.

Stronger Viruses, Weaker Medicine

As previously mentioned, bacteria split, grow, and form new bacteria. The characteristics of each are continually swapped around, and one such characteristic is antibiotic resistance. In what amounts to survival-of-the-fittest evolution, “superbugs” are created, and antibiotics render diminishing returns. A worst-case scenario paints a grim picture for public health in general — and it has not gone unnoticed by the World Health Organization or the Centers for Disease Control and Prevention (CDC) — but it is especially significant for sewer workers who are at much higher exposure levels and greater risk to bacterial infections and illnesses.

TJ Suiter, a former wastewater worker who now designs safety equipment for the profession, shared with me some stories he gathered during a 10-city tour doing field research for his safety systems. True to what the studies suggest, he encountered two cases of hepatitis and a case of MRSA among the workers he met. Suiter also described two separate incidents where workers suffered cuts — one while working on a lift station, the other in a manhole — and contracted meningitis and

Figure 1. Dramatic Decrease In Antibiotic Drug Approvals



Antibiotic development is dwindling.[4]

cellulitis, respectively. The former is out on lifetime disability, while the latter “was one day away from an amputation.” Both were saved by antibiotics. Current trends dictate, however, that these same antibiotics will soon be obsolete. Not only are antibiotics on the whole becoming decreasingly effective, but they are also being approved at a decreasing rate (see Figure 1). Even vancomycin, which is considered an antibiotic of last resort for the treatment of numerous bacterial infections, has lost much of its efficacy — a problem the CDC labels as a serious threat to public health.[5]

How Employees Can Protect Themselves

The perfect storm of factors conspiring against the health of sewer workers is no doubt distressing, especially since there is little to nothing individual workers can do to reverse the course of the negative trends themselves. The daunting task of keeping medicine a step ahead of evolving strains of bacteria will be one for the science and medical communities to share. In the meantime, there are immediate actions workers can take to better protect themselves.

The number-one defense is still simple hygiene. But simple doesn’t necessarily mean typical. While rubber gloves, boots, and protective clothing are thankfully commonplace, safety glasses apparently are not. “It’s very rare, frankly, to see workers wearing glasses,” says Suiter, who has been watching workers in the field for more than 25 years. This particular oversight — or style choice, if that’s the case — is a risky proposition. Suiter explains why: “Your eyeball is a perfect environment for viruses and bacteria to enter your body, simply because it’s a moist, wet, and warm environment where liquid can be readily taken in. It's the same with your nasal membranes and your mouth; bacteria quickly multiply when they're in a warm, wet environment."

Take the note: *Add facemask to go with specs.*

The National Institute for Occupational Safety and Health (NIOSH) has weighed in with its own sanitary guidelines, which include frequent hand-washing with anti-bacterial soap (be sure to scrub under your nails with a brush, they say) and a particular advisement to wash up before eating, smoking, or drinking.

A novel way to clean a dirty hose

So simple, it almost sounds childlike (cue flashbacks of mom telling you to wash up for dinner). And yet …

"You go out on any sewer crew and you're going to find guys who are working in the hot sun, wiping the sweat off their face, and taking drinks of their water with contaminated gloves on," describes Suiter. "You'll see them finish up the job, take off their gloves, pick up that very same water bottle — contaminated with feces and every other thing that's in the sanitary sewer — and carry it into the truck with them. Then they'll immediately eat a snack, or put some chew in their mouth."

Contaminated clothing and boots may expose family members to pathogens.

Sound familiar? If so, it's more risky business — even for the grizzled veterans of the sewer, many of whom are under the impression that they've developed immunity from the dangerous bacteria. While that may be true to a point, it doesn't pertain to the new strains of bacteria that are continuously developing. *All* workers need to maintain hygiene awareness throughout their shift in order to stay healthy.

And just so the good health extends to the home, NIOSH adds another warning: Wash your clothing on-site, not at home. Contaminated clothing and boots may expose family members to pathogens, and conventional washing machines don't reach the extreme heat required to destroy them.

How Municipalities Can Protect Employees

Beyond setting strict protocol and enforcing it (i.e. babysitting), municipalities can make sure that their workers have the appropriate personal protective equipment (PPE) to look after themselves. That includes Tyvek suits, protective glasses, and facemasks, and it could also include specialized equipment.

One of the most commonly used tools of the trade for sewer cleaning and maintenance is the high-pressure jet hose. Because it travels through the sewer and then goes back on the truck, it is also one of the most contaminated tools. For Suiter, this was an opportunity to synch innovation and sanitization. He invented the Vanguard System, whereby the hose is sanitized with antibacterial-infused water as it travels through a pulley on its way out of the manhole and onto the hose reel. It also features a manual component so workers can spray down other equipment, themselves, and each other.

Personally, I have not seen very much else in the way of innovation with regard to decontamination equipment or PPE, and that may be because we already have the essential tools at our disposal. Even the system described above is a very simple (but smart) concept: It cleans equipment and people, but it makes it easier to do so. If workers in the field are a bit dismissive or nonchalant about following through on proper equipment and cleaning, then a little ease-of-use may promote more compliance. Putting systems in place with proven efficacy may also reduce a municipality's insurance costs.

However you get them there — with updated equipment, training programs, site monitoring, etc. — the buy-in and follow-through from the workers will always be the key to maintaining their safety.

If all else fails, you can also resort to scaring the bejesus out them. Just have them read this article. ■

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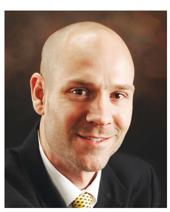
2. R Brugha, J Heptonstall, P Farrington, et al. 1998. Risk of hepatitis A infection in sewage workers. Occup Environ Med doi: 10.1136/oem.55.8.567

3. Bob Roehr. 2012. MRSA in waste treatment water poses potential risk. Environ Health Perspect BMJ 2012;345:e7673

4. B Spellberg, The Epidemic of Antibiotic-Resistant Infection, CID 2008:46

5. U.S. Department of Health and Human Services Centers for Disease Control and Prevention. 2013. Antibiotic Resistance Threats in the United States, 2013



Kevin Westerling has served as the editor of Water Online, the Internet's premier source for water and wastewater solutions, since 2008. Kevin's education includes a bachelor's degree in English literature, a minor in journalism, and certification as a Web content developer. He can be reached at editor@wateronline.com.

High-Speed Turbo Blowers: Need … Or Just Want?

There are important considerations to make before you purchase an aeration blower.

By Juan Loera

High-speed, direct-drive turbo blowers are the latest game-changing technological application in the wastewater industry. But what makes them the must-have tool for today's wastewater treatment plants (WWTPs)? To answer that question, we must look at the daily challenges WWTP operators and managers face. Shrinking budgets, increased service demands, and more stringent regulations require treatment plants to do more with less. In fact, for a typical WWTP, more than half of the plant's total energy demand is related to process air requirements (Figure 1), and energy costs represent roughly 75 percent of the total blower life-cycle cost.

Thus, aeration blowers are an enticing target for energy efficiency improvements and the desire to cut power costs. In particular, high-speed, direct-drive turbo blowers offer potentially significant energy efficiency and power savings when compared to other centrifugal or positive-displacement blowers.

Understanding how the blower will perform with your system and application is crucial to picking the right equipment.

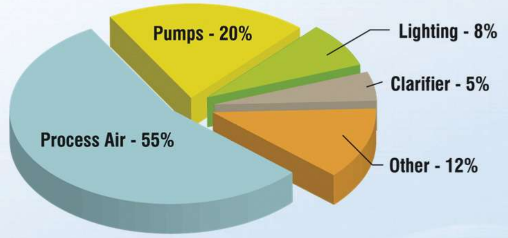
To put it simply, a case of perfect timing and multiple forces pushing in the same direction drove the evolution of high-speed, direct-drive turbo blowers in the wastewater industry. However, they are not necessarily the best solution for every project. There are a variety of factors that influence blower selection, including design flow rates, number and redundancy of blower units, turndown requirements, maintenance experience and preferences, coordination of air demand and control, and site-specific operating conditions. While it may seem that having a high-speed turbo blower is the panacea for all your plant's energy efficiency woes, there is a lot more to think about before you select this technology.

Which Blower Is Right For Your Needs?

You probably wouldn't buy a top-of-the-line smartphone for someone who doesn't text, use email, or surf the Internet. Why pay for features that aren't appropriate for the user? The same is true with blowers. When considering a new blower, turbo or otherwise, the first step for any WWTP manager is to look carefully at the different technologies available and match the right technology with the treatment plant's needs. Over the past few years there have been significant innovations to blower technology, and the entire industry, from engineers, manufacturers, and end users, have helped usher in a new era of blower designs and applications. So, should you get a single-stage blower? Multi-stage centrifugal? High-speed centrifugal? Positive displacement? Or should you really get that fancy, new, high-speed turbo blower? What will be most efficient for your system, and what will give you the best value?

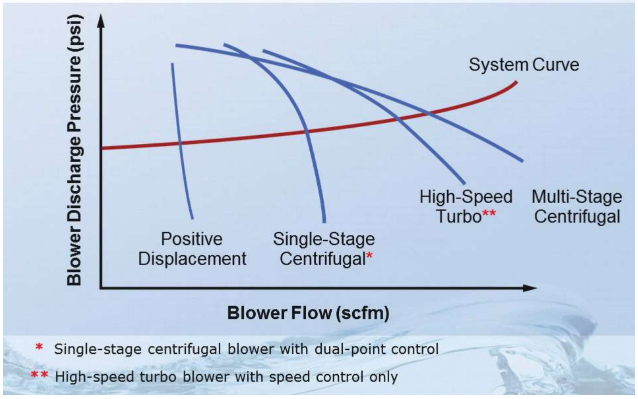
Figure 2 on the next page shows a comparison of blower performance curves for each of the major types of blowers. As you can see, each type of blower has its own characteristic performance curve and, therefore, will operate and respond differently to each WWTP facility, which is why a one-size-fits-all approach hardly ever works. Understanding how the blower will perform with your system and application is crucial to picking the right equipment, and making sure you don't spend a lot of

Figure 1



Energy usage at a typical WWTP

Figure 2



money for something that won't get you the results you need.

But performance isn't the only consideration. Operations and maintenance (O&M) issues must factor into your decision. Will your operators be confident handling the complex instrumentation on a single-stage centrifugal system, or would something simpler be better, even if it's less efficient? How difficult are the blower components to maintain? Will you want to maintain components such as the air bearings yourself, or add a maintenance contract to the blower purchase? What level of noise from the blowers will be acceptable for your facility, and can noise issues be efficiently mitigated by other measures? Answering these questions, and a few others, will help narrow your choice and get you closer to making the right blower choice for your facility.

Four Things You Can Do To Make A Better Blower Decision

1. **Correctly determine the process air requirements for your system and desired blower efficiency and capacity turndown.** The table below lists the blower types already discussed and their nominal blower efficiency and turndown rates. While higher efficiencies always look more attractive, remember that this is just one consideration. A lower efficiency blower might have O&M offsets that still save you money and effort in the long run, making it a better value.
2. **Clearly define and specify a pressure rise to the surge point across the entire blower operating range, from the design point to the minimum airflow capacity.** Blower surge, a form of unstable operation that involves reversal of flow, is a condition that occurs frequently with blowers in WWTP facilities, and can result in blower shutdowns or damage. Centrifugal blowers are more efficient when they operate close to the surge point, which is why there is a tendency to design blowers to operate at that range. Yet every blower manufacturer has its own criteria on how close it designs to the surge point. Therefore, by specifying a pressure rise to the surge point that you are comfortable with, all manufacturers can design their blowers for you using the same criteria.
3. **Indicate your site-specific operating conditions.** We are frequently presented with blower performance numbers that are not based on the project location conditions or actual system operations. This is kind of like buying customized snow skis in Hawaii. Sure, you can get them, but will they do what you need them to do? Blower performance numbers need to be calculated using the project location temperature and atmospheric pressure, and the specified guaranteed performance points should be based on your treatment plant's actual operating conditions. Otherwise, you'll receive performance numbers based on conditions that are more favorable for that particular blower, which may not be accurate for your purposes.
4. **Do your research.** In Carollo Engineers' experience, we have found that testing methods are not consistent among manufacturers. When talking to blower representatives, it's important to qualify their performance and O&M claims. Ask specific questions about the equipment, its intended operation, its optimal operation, what kind of standard maintenance is involved, and so on. Don't just accept their numbers at face value.

Blower Type	Nominal Blower Efficiency (percent)	Nominal Turndown (percent of rated flow)
Positive Displacement	45-65	50
Multi-Stage Centrifugal (inlet throttled)	50-70	60
Multi-Stage Centrifugal (variable speed)	60-70	50
Single-Stage Centrifugal, Integrally Geared (with inlet guide vanes and variable diffuser vanes)	70-80	45
Single-Stage High-Speed Turbo	70-82	50

Increasing blower efficiencies while reducing power costs is important for every wastewater treatment plant, but understanding how a specific blower will perform for your plant is even more important. Matching your needs with the right technology might not get you the newest, shiniest product in the marketplace, but it will help you achieve the ultimate goal of improved plant reliability, efficiency, and peace of mind. ■

Juan Loera *is a company-wide expert with Carollo Engineers on blower designs. He has worked on a number of wastewater projects in various aspects of analysis, design, and construction of aeration blowers and aeration air system projects, with installations in facilities ranging in capacity from 2,000 to 29,000 standard cubic feet per minute (scfm) per blower.*

The Shifting Challenges Of Wastewater Testing

Wastewater constituents are getting more plentiful and complex, requiring more advanced tools to maintain regulatory compliance.

By Jeanne A. Mensingh and Colin Thurston

Wastewater treatment, like other industries that rely heavily on dynamic sampling programs, has had to implement far more rigorous testing in recent years. But, unlike food safety, oil and gas, or even drinking-water monitoring, the biggest challenge hasn't come from stricter regulations or standards. The most significant hurdle has been a fundamental change in the wastewater stream itself.

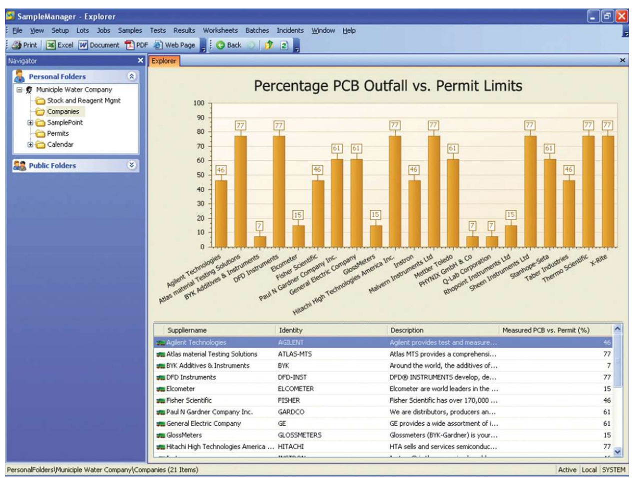
The wastewater stream is more contaminated than ever, with more diverse and exotic compounds — overprescribed pharmaceuticals, for example — and this places a heavier burden on treatment facilities to ensure their output is safe. Providers must dramatically increase their sample load, and the overall number and complexity of tests, simply to remain in compliance with pre-existing regulations.

How can these already overtaxed sampling programs increase throughput without financially straining the communities or organizations they serve? How can they maintain public health in the face of unprecedented wastewater contamination? One answer is data management: using a laboratory information management system (LIMS) to do more with less. Automating tests and eliminating manual procedures through a LIMS allow wastewater treatment systems to shoulder increased testing loads while actually improving efficiency and testing efficacy.

The Changing Waste Stream

We know that new contaminants are taxing the wastewater stream, but why are they such a problem? To answer that question, we first need to explore what happens to wastewater. While there are many final destinations for treated wastewater, it has a consistent (and obvious) source, and sampling begins early on. Water treatment providers dispatch technicians to upstream sample wells across their regions to test wastewater before it reaches a treatment facility. In the past, test results were handwritten on paper, and the data slowly made its way into a hard-copy report. With a LIMS, however, technicians use mobile devices to record bar codes, readings, and coordinates, allowing real-time (and more accurate) sample reporting and aggregation. Downstream plants can use this data to prepare for treatment ahead of time, expediting the process.

The wastewater treatment process, from primary and secondary treatment to disinfecting, is complex, and involves multiple steps. Rigorous testing is done throughout to ensure that any water exiting a treatment facility — for any eventual use — is safe. Technicians use spectrometry, chromatography, and wet chemistry to analyze wastewater for harmful contaminants such as heavy metals and antibiotics. Antibiotics — which recent reports from the Centers for Disease Control and Prevention, among others, show are being over-prescribed — enter the wastewater stream through human waste and improper disposal of leftover pharmaceuticals



A LIMS provides easy-to-access and easy-to-read data.

down drains and toilets. Over time, this practice can lead to the emergence of antibiotic-resistant bacteria that could ultimately impact humans as the treated effluent travels beyond the facility.

Testing for and eliminating antibiotics and drug-resistant bacteria are increasingly important functions of water treatment facilities. Knowing the precise levels of bacteria in water undergoing treatment is essential to determining how much chlorine to add. Similarly, wastewater contaminated with heavy metals, such as lead, must undergo special treatment as an extra precaution. The complex process of determining which treatment options to use is greatly simplified using a LIMS. Because the platform integrates with the instruments used to track contaminant levels as wastewater is treated, the LIMS can help technicians identify trends that improve treatment performance and efficiency. This data is also critical for regulatory compliance, auditing, and reporting purposes, and ultimately plays an important role in determining where treated wastewater is put to use.

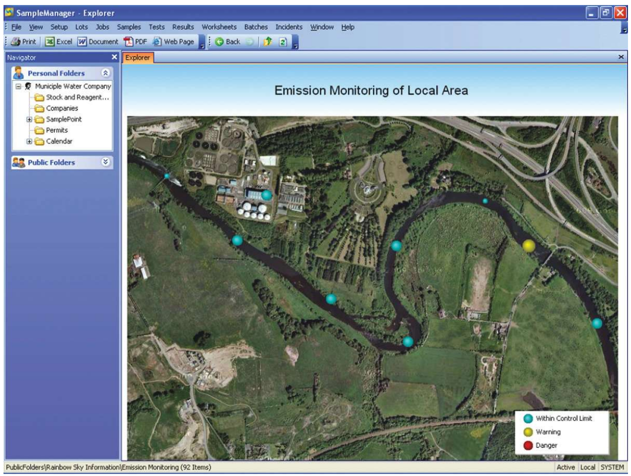
Where Does Wastewater End Up?

Although wastewater is no longer potable (although now it's technically possible, and many international locations are implementing this level of recycling), it has a myriad of productive uses. Some of the water ends up in lakes, rivers, or oceans, where it must be safe enough to avoid posing a public health risk, either through human contact or wildlife contamination. Other destinations for reclaimed water include street cleaning, plumbing (e.g. flush toilets), landscaping irrigation, and even crop watering. This last use alone shows how important proper wastewater treatment is to public health and safety. This is precisely why the broader-reaching capabilities afforded by a LIMS are becoming so important for wastewater treatment providers.

Sadly, analytical instruments alone can't provide the measure of protection consumers have come to expect. This spring, for example, the U.S. Food and Drug Administration identified commercially available rice imported from China and Taiwan containing 120 times the acceptable level of lead. Investigation revealed that producers had watered the rice with improperly treated wastewater that contained raw industrial effluent. Would a better system of data capture and reporting have alerted officials to the problem before the rice was shipped?

In Canada, officials discovered salmon that contained significant traces of ibuprofen in their bloodstreams. It's likely the fish ingested the drug through improperly treated water entering nearby rivers and streams. While ibuprofen is certainly not deadly in these amounts, the incident raises questions about other drugs that could be entering our food supply through improperly treated wastewater.

Although a LIMS doesn't ensure more accurate or frequent testing, it does bring a discipline that enables water treatment systems to be more proactive, responsive, and compliant, all of which are precursors to better public safety. If upstream contamination does occur, for example, a paperless lab enabled by a LIMS is much more likely to detect and help mitigate the issue quickly — before it impacts the treatment system. The LIMS also stores information about the origins of contamination, as well as where wastewater is released, enabling facilities to identify problems in near real time, trace them to the source, and ensure that similar problems don't occur in the future.

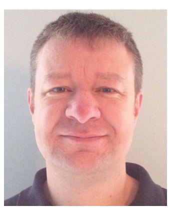


LIMS dashboards provide graphical representations of information to allow lab managers to visualize critical data in various forms.

Data To The Rescue

The changing dynamics of wastewater treatment are taxing many facilities, and more rigorous sampling is seen as the best course of action. As sampling throughput increases, the wastewater treatment industry — like other industries — is looking to better data aggregation and application to lead the way forward. A LIMS can transform data management from a limiting factor to a driving force for business success by improving accuracy, ensuring compliance, and helping managers identify trends. It's unlikely we'll see fewer contaminants like antibiotics enter the wastewater stream, so it's incumbent on the industry to shift priorities and adapt. And a LIMS is certainly an important part of that shift. ■

Jeanne A. Mensingh *is president and founder of Labtopia Solutions, which provides tailored quality system advisory services to help businesses meet regulatory requirements and enhance performance. She is also a National Environmental Laboratory Accreditation Program (NELAP) assessor.*



Colin Thurston *joined Thermo Fisher Scientific Informatics in 1996 and is currently the director of products strategy, process industries, responsible for identifying new market opportunities within the sector. He is a graduate of Salford University (Manchester, UK) with a BSc in chemistry.*

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Low-Cost Computational Fluid Dynamics Modeling For Pump Stations

Avoid pump station failures, protect the environment, and save money through computer simulation.

By Franz Jacobsen

There are freely available open source computational fluid dynamics (CFD) software packages, such as OpenFOAM (OPEN Field Operation And Manipulation), that have been used for many years and produce results that compare favorably with commercial packages. In this article the CFD simulation of a pump station will be compared with a physical prototype model. The comparison of results includes swirl angle and other flow phenomena, with excellent correlation. Some of these techniques used to aid post-processing and engineering analysis will be presented.

Why Use Modeling For New And Existing Pump Stations?

For most pump stations, standard guidelines suffice. For complex applications — new or refits — there are cost-effective CFD modeling tools available that result in:

- minimized maintenance costs
- minimized commissioning time
- minimized pump station failures and possible effluent discharge into the environment.

CFD modeling is especially valuable to operators, as well as designers. Throughout the industry, typically 10 percent of existing pump stations experience substandard performance or regular failures, and many of these pumps operate below design capacity. Pump stoppages, which require emergency bypass measures, can incur costs of tens of thousands of dollars per day or more, and, in the case of wastewater pump stations, may potentially incur EPA fines. These costs can accumulate and eat away at yearly budgets. An initial moderate investment of a CFD model can have a favorable cost/benefit outcome for the operator. CFD modeling results are user-friendly and easy to visualize, with flow paths highlighted by tracers and animations.

Throughout the industry, typically 10 percent of existing pump stations experience substandard performance or regular failures.

The assessment of flow characteristics, such as swirl and uneven inflow velocities, are typically assessed as per the recommendations of the American National Standards Institute Hydraulic Institute (ANSI/HI) 9.8 guidelines. The recommendations of ANSI/HI are: swirl angle not greater than 5 degrees and velocity profile at all points within 10 percent of the cross-sectional area averaged velocity. For pump stations with four or more pumps, the ANSI/HI guidelines recommend model studies. Pump stations with flows greater than 5,000 GPM (315 l/s) per pump also require model testing.

Undesirable flow conditions include submerged and free-surface vortices, preswirl at the pump entrance, non-uniform distribution of velocity, and swirling flow, which can suck entrained air or bubbles. These adverse flow conditions lead to reduced pumping head capacity, detrimental effects on power consumption, and increased noise and vibration, leading to costly breakdowns and repairs.

ANSI/HI pump standards recommend that for physical model studies, a free surface vortex type of 3 is considered the maximum allowable, as prototype strength may be slightly underestimated as a result of possible scale effects. This is not an issue with CFD models, which represent the full scale.

Subsurface vortices should be eliminated from any design because their presence imposes fluctuating loads on the impeller and the resulting low-pressure areas may cause cavitation, which results in damage to the pump.

The configuration of pump stations is an essential aspect of pump station performance. Poor design can lead to failures. The application of a CFD model can determine undesirable flow conditions and recommend remedial action, such as vanes and baffles, to provide a solution to eliminate the

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problem. CFD modeling is effective for both wet well and pipe work applications.

The development of CFD models can be fraught with uncertainties for the inexperienced — and not so inexperienced — modeler. The simulation results can vary radically depending on assumptions made regarding boundary conditions, model domain, turbulence parameters, etc. The acquisition of valuable experience and engineering judgment comes with observation of relevant experimental data. The old adage of garbage in/garbage out is very relevant to CFD modeling. Therefore, comparing CFD and physical modeling results is essential to instill confidence in application of CFD modeling techniques.

About The Open Source CFD Software

The OpenFOAM continuum mechanics toolbox can simulate a wide range of problems, including complex fluid flows with chemical reactions and conjugate heat transfer, solid dynamics, multiphase phenomena, acoustics, and even the pricing of options.

OpenFOAM includes numerous preconfigured solvers, utilities, and libraries that allow it to be used like conventional simulation tools. The code is, however, open source (GNU General Public License [GPL] v2), which means customers and consultants have full and free access to the source code, allowing unlimited customization and development of new functionality. OpenFOAM is currently the most widely used open source CFD code, and its continued adoption in industry and academia has forced major changes in the CFD landscape, with reduced pricing for high-performance computing licenses being the most noticeable.

Straightening Out The Serpentine

The Serpentine Road Pumping Station is located in an existing Brisbane Water pipeline in Queensland, Australia. Flow is delivered into the station from 18" and 12" diameter inlets from three existing pumping stations. The Serpentine Road Pumping Station is equipped with two variable-speed, dry-well mounted pump units. The purpose of the physical model study was to verify the pumping station arrangement. Site restrictions placed limitations on the area that the pump station could occupy, leading to a nonstandard arrangement.

An OpenFOAM-based CFD model was developed to validate numerical simulation against physically measured data. The HELYX-OS graphical user interface (GUI), designed for use with OpenFOAM, was also employed. The numerical model was able to reproduce all the flow characteristics reported by the physical model. These flow characteristics included:

- surface vortices ahead of the pump
- preswirl in pump
- submerged vortices adjacent to pump
- calculated swirl angle.

The results presented in the physical modeling report consisted of flow visualization results and quantitative swirl angle calculations.

A single-phase solver can often be used in pump stations, assuming the water surface is flat. In this case, the lowest operational water level produces a cascading water surface profile; therefore, a turbulent, transient multiphase flow solver was chosen for the analysis. A dynamic large eddy simulation (LES) turbulence model was chosen for the numerical simulation.

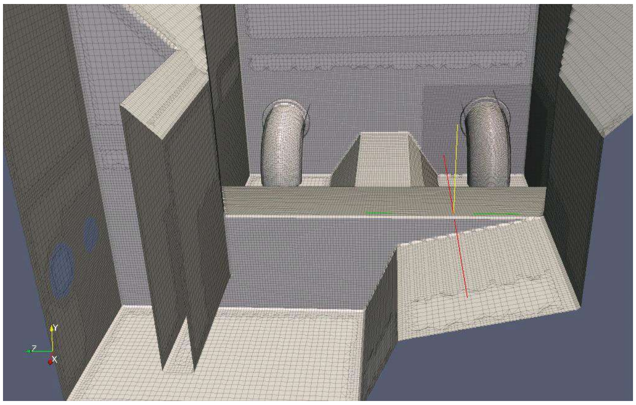

Figure 1: CFD model layout

The meshing model was constructed with the OpenFOAM in-house meshing tool. In this type of model, uniform distribution of cell grading is required with refinement in areas of interest. A general view of the CFD domain is shown in Figure 1. The surface adjacent to the outlet boundary had a higher refinement level than walls and floor surface regions. More complex geometry based on CAD drawings is uncomplicated using open source CFD software.

Wall boundary conditions consist of wall surfaces modeled using turbulent kinematic viscosity, based on turbulent kinetic energy to represent the smooth concrete surface. Inflow and outflow boundary consists of steady mass flow

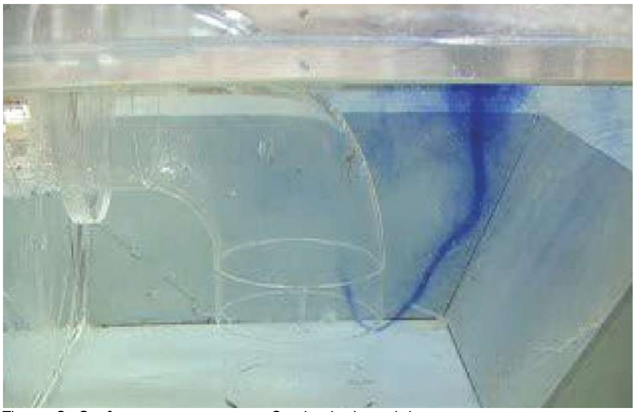

Figure 2: Surface vortex at pump 2, physical model

rate. Prerotation induced by the pump's rotation element does not affect upstream flow patterns when the pump is operated at design flow; therefore, including a rotating element in the numerical model is not required.

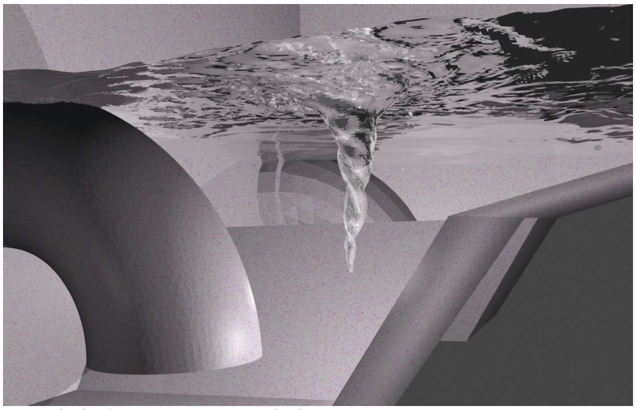

Figure 3: Surface vortex at pump 2, CFD model bottom view

CFD vs. Physical Modeling

Animations of the physical model show that the location of the surface vortex is unstable; it appears submerged and subsurface at various times and tends to periodically disappear. The fully developed form is that of a surface vortex extending to the pump inlet.

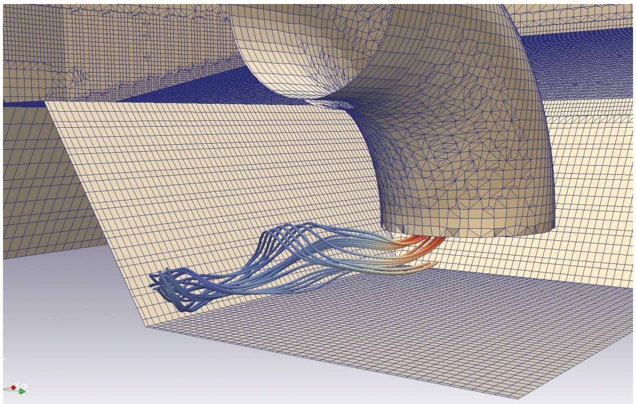

Figure 4: Back wall subsurface vortex at pump 2, numerical model

Figures 2 and 3 show the same vortex forming at pump 2 with a pool surface elevation of -3.4' (-1.05m). Further refinement is required to fully capture the very fine core of the vortex; this is not necessary for the purpose of this assessment.

Submerged vortices adjacent to pump 2 were analyzed during the physical study. The numerical results are shown in Figure 4, which shows agreement with the physical model.

Angling For A Solution

The preswirl at the floor directly under pump 1 was also captured by the numerical model. The angle is calculated based on the ANSI/HI standards. For the physical model, a rotating vane is used to determine the swirl angle.

Intense bidirectional fluttering interspersed by periods of defined rotation was observed, along with a swirl angle of 2 degrees. A plot of the swirl angle from the CFD model is shown in Figure 5. The same bidirectional flow characteristics are observed by the CFD model. The swirl angle is 5 degrees, which is higher than reported for the physical model. This can be attributed to friction loss at the vane, and the prototype flow strength may be slightly underestimated as a result of possible scale effects. It is not uncommon for physical model discharges to be increased by a factor to compensate for these scale effects.

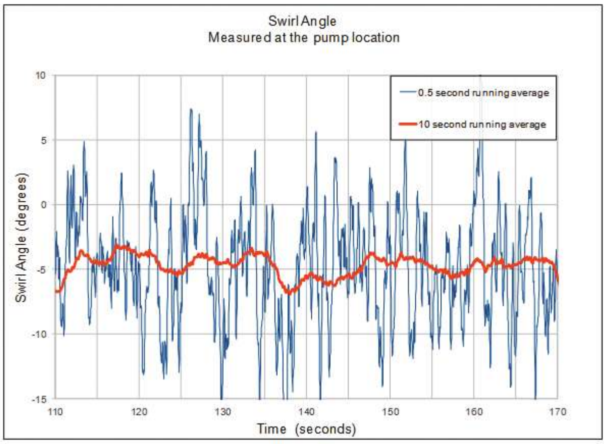

Figure 5: Swirl angle plot

Summary: The Benefits Of CFD Modeling

This article briefly describes the complex analysis of pump stations using open source software. CFD modeling can be undertaken relatively inexpensively due to freely available software.

Advantages of CFD modeling of pump stations include:

- optimization of the design pump stations
- identification of adverse hydraulic conditions
- reducing probability of costly pump station failure
- meeting performance criteria
- easier pump station commissioning. ■

Franz Jacobsen has worked widely within the field of civil engineering, including construction and design. His experience includes dams design and other hydraulic structures, as well as river and floodplain modeling. In recent years he has been specializing in hydraulic engineering utilizing complex CFD flow.

Energy-Efficiency Showdown: A Comparison Of Aeration Technologies

On paper and in practice, aeration options and their corresponding efficiencies are calculated and compared.

By Mark Gehring and John Lindam

Research and experiences within biological treatment have led to greater ability among municipal water resource recovery facilities to review and upgrade equipment and subsystems to reduce energy consumption. In most cases, processes and equipment involving aeration are the major consumers of energy. It has been estimated that up to 60 percent of a plant's power consumption can be attributed to aerobic reactors in the activated sludge process of secondary treatment.

In this article, factors pertaining to power requirement and oxygen transfer of aeration systems in biological treatment are discussed, with emphasis on the difference and effects on energy efficiency between fine-bubble aeration and mechanical surface aerators. In particular, oxidation ditches are discussed; with numerous installations in the U.S. and worldwide, they present a number of engineering challenges with respect to aeration and mixing.

Oxygen Transfer And Efficiency

In order to discuss aeration efficiency, the term "efficiency" must be clearly defined. It is generally acknowledged that oxygen transfer efficiency (OTE) plays an important role.

Equation (EQ) 1: OTE = oxygen transferred/oxygen supplied
Where:
OTE = oxygen transfer efficiency (percent)
Oxygen transferred = oxygen transferred from bubble to mixed liquor, kg (lb)
Oxygen supplied = oxygen supplied aeration equipment, kg (lb)

When OTE is measured under standardized conditions, as described by American Society of Civil Engineers (ASCE, 2007), the term Standard OTE (SOTE) is used. Comparing performance of different equipment for aeration must be done under standardized conditions to validate and normalize performance data.

With regard to energy consumption, the common expression for efficiency is the standard aeration efficiency (SAE), which factors in pressure and efficiency of the mechanical equipment required to achieve a de facto oxygen transfer. The standard aeration efficiency is the amount of oxygen transferred per unit of energy consumed:

EQ 2: SAE = SOTR/P
Where:
SAE = aeration efficiency, lb O2/horsepower-hour (kg O2/kWh)
SOTR = oxygen transfer rate, lb/hr (kg/h)
P = power required to transfer one mass unit of oxygen per unit time, HP (kW)

It should be noted that the definition of power must always be stated clearly; herein, power is defined as the total input energy of any mechanical equipment required to achieve the rate of oxygen transfer for the biological process as stipulated by the European Committee of Standardization (2009) and ASCE (2007).

Available Technologies

There is a wide range of equipment suitable for delivering oxygen to aerobic reactors in biological treatment. Aeration devices, such as mechanical aerators and coarse and fine-bubble diffused aeration systems, cover a large portion of aeration equipment installed at water resource recovery facilities globally. The aeration equipment selection process should consider system capacity, operating range, and equipment reliability. Assessment of the aeration system performance should consider total system efficiency, evaluating individual aeration system component efficiencies along with the aeration control system.

Table 1 shows a brief summary of estimated SAE values for common types of aeration equipment used for biological treatment. Aerator types include high- and low-speed surface aerators, submersed jet aerators, fine-bubble disc diffusers, and high density low flux (HDLF) fine-bubble diffusers.

Table 1. Efficiency ranges for various types of aeration equipment (Tchobanoglous et al, 2003)

Type	SAE, kg O2/kWh	SAE, lb O2/hp. h
Low-speed surface aerators	1.5-2.1	2.5-3.4
High-speed surface aerators	1.1-1.4	1.8-2.3
Submersed jet aerators	0.9-1.4	1.6-2.3
Fine-bubble diffusers, discs	2-7	3-10
HDLF fine-bubble diffusers	3-8	5-13

Note that the SAE values in Table 1 should be used as reference; exact figures are equipment and application specific.


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Fine-bubble diffusers, in particular, present major advantages in both capacity and power consumption. However, in order to achieve maximum ratio of oxygen transfer to energy consumed (SAE), a number of factors relating to the floor density and air flux of the diffusers must be evaluated.

When full floor diffuser coverage systems are considered, diffuser floor density refers to the ratio of area covered by diffuser membranes to the total floor area. Diffuser flux, expressed as flow per membrane area, is directly related to the diffuser density if a fixed oxygen transfer rate requirement is considered. With extensive oxygen transfer test data at hand, oxygen transfer can be accurately predicted by taking into account the variables associated with the configuration of any full floor coverage diffuser installation.

In summary, the driving forces behind oxygen transfer in fine-bubble systems in clean water can be attributed to the following:

- Diffuser flux
- Diffuser density and airflow uniformity
- Depth

Obtaining high transfer efficiency requires optimizing the bubble retention time, thereby increasing the total amount of oxygen transferred, per volume of air supplied to the system. Bubble retention time correlates to spiral flow effects, which are more or less present in any bottom diffuser installation and depend on the density and membrane flux of the installed system. The phenomenon of spiral flows is described in Figure 1 below. A densely installed diffuser system with low membrane flux mitigates secondary flow effects, allowing slower bubble rise within the reactor.

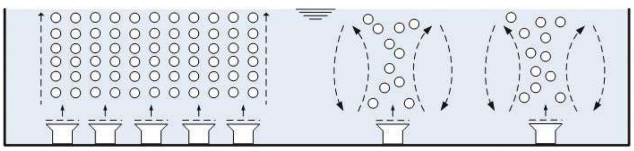

Figure 1. Principle of spiral flows. Left: High membrane density fine-bubble diffuser system. Right: Low density-high flux installation, generating secondary spiral flows causing reduced bubble detention time and oxygen transfer rate.

The system as a whole, including air blowers, responds positively to an increase in diffuser density, leading to lower flux and higher SOTE. In what can be described as a positive feedback response, high SOTE generates lower air flow, pressure, and power requirement. The depth of the aerobic reactor is a vital factor in assessing the oxygen transfer capacity of the aeration system as well as the OTE and the overall SAE. While increasing reactor depth increases the oxygen transfer rate or transfer efficiency SOTE of a bottom diffuser system, its relationship is sub-linear; i.e. SOTE increases slower than linearly versus diffuser submergence. At the same time, system pressure has a nearly linear relationship with diffuser submergence. The dynamics of these major factors in aeration system design should be taken into consideration during the engineering and design phase of an activated sludge facility.

Oxygen Transfer In Oxidation Ditches

The discussions above pertain mainly to conventional activated sludge processes, but the dynamics of air flux, diffuser density, and depth affecting performance are relevant to all variations of the activated sludge process. Oxidation ditches traditionally operate on the basis of supplying oxygen to the biological process in dedicated aeration zones, utilizing simultaneous mechanical generation of horizontal flow to ensure mixing of liquor and transfer of dissolved oxygen to non-aerated zones. Depending on the design of the ditch, non-aerated zones may also provide anoxic conditions for denitrifying bacteria.

Surface Aerators Versus Fine-Bubble Diffused Aeration In Oxidation Ditches

Similar to conventional activated sludge reactors, the oxygenating capabilities of mechanical surface aerators and their SAE should be considered when assessing the power requirements for an oxidation ditch application. In one common design, surface aerators rely on producing plumes of droplets above the liquid surface which create a large water-to-air surface area for oxygen transfer from the air to the liquid droplets.

Oxygen transfer also occurs as air is drawn into the bulk liquid with the mechanical device. The mixing flow pattern in the reactor transfers oxygenated liquid from the surface. Inevitably, a gradient of dissolved oxygen levels forms, where the highest level of dissolved oxygen exists close to the surface and in the proximity of the aerating device. In the first generation oxidation ditches — many of which are still in operation today — the mixing requirements within an oxidation ditch were satisfied by the aeration device, as vertical or horizontal shaft aerators create a horizontal flow pattern. Installation of equipment above the liquid surface was seen as an attractive feature of surface aerators.

There may be a number of limitations in such installations, including limited reach of oxygenated liquid in deep tanks, insufficient mixing of liquor, limited turndown capacity, low SAE, and generation of aerosol in the vicinity of the reactor, as well as frequent maintenance of rotating parts. The mixing capabilities of such equipment may also limit the horizontal transfer of dissolved oxygen along the lanes of the ditch. Table 2 summarizes features and advantages of surface aerators and diffused aeration. See Figure 2 on the next page for the working principles of vertical shaft mechanical aerators and fine bubble diffusers with low-speed horizontal mixers.

Fine-bubble diffused aeration offers many advantages over mechanical surface aeration — as discussed previously — in oxidation ditches in particular. General benefits of diffused aeration in combination with submersible mixers include increased SAE (including mixer power), high oxygen transfer rates, independent mixing and aeration devices, completely submersed systems with low maintenance needs, and elimination of aerosol formation and associated odor reduction from rotating parts at the reactor liquid surface.

With independent aeration and mixing devices, fine bubble

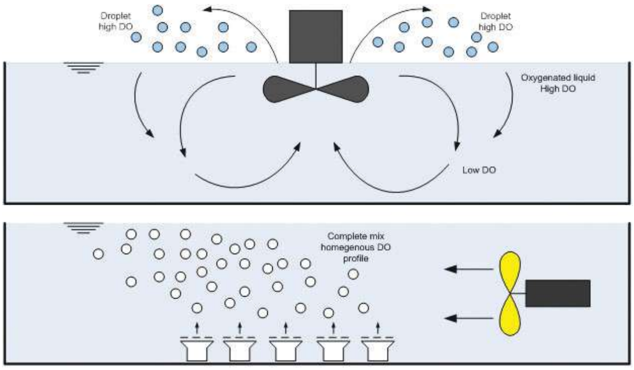

Figure 2. Upper image: Vertical shaft surface aerator which oxygenates liquid by generation of plumes of droplets above the surface. Lower image: Diffused aeration in combination with submersible low-speed mixers, enabling an effective horizontal flow and enhancing the oxygenation of mixed liquor.

diffused aeration systems not only provide the highest level of OTE, but also provide the capacity to efficiently address a wide range of operating conditions. Independent mixing and aeration offers another level of process control to minimize air flow requirement, adapting blower air flow or control valves against required and observed process parameters such as ammonia-nitrogen and dissolved oxygen concentrations. This level of operational control is restricted with a traditional single device serving both aeration and mixing demands.

Table 2. Features of diffused aeration and surface aeration in oxidation ditches

Feature	Diffused aeration	Mechanical surface aerators
SAE	Potentially as high as 7-8 kg O2/kWh	Limited to approximately 2 kg O2/kWh
Installation	Diffuser system with piping and blowers. Submersible mixers to generate horizontal flow.	Single unit installation. May require additional stand-alone mixers and/ or supplemental aeration.
Flexibility in engineering design and capacity	Stand-alone units enable tailor-made solutions which meet oxygen transfer demands.	Limited oxygen transfer variability. Number and size of units are the main flexibility factors.
Installation cost	Depends to a large extent on diffuser density and number of blowers and mixers required. Cost highly related to ef-ficiency.	Relatively low-cost with few additional components. May require additional concrete reinforcements.
Aerosols and icing in cold climates	Very limited to none.	Common issue due to droplet generation required for oxygen transfer.
Process control capacity	Highly flexible with inde-pendent blower air flow and/or valve control.	Very limited.
Maintenance	Few mechanical parts which need maintenance.	Frequent maintenance of rotating aerating parts.

Combining Fine-Bubble Aeration With Horizontal Flow

In order to mix liquor in a biological reactor, sufficient thrust must be generated to keep particles in suspension. The use of thrust as a standardized parameter to measure and compare mixer performance is described by ISO:21630 (2007). Practically, a certain flow velocity should be maintained throughout an oxidation ditch. The relationship between the required thrust and horizontal flow velocity can be described by equation 3 (Uby, 2012):

EQ 3: F~k*u2
Where:
F = thrust, N
k = reactor momentum loss factor,
u = horizontal flow velocity, m/s (ft/s)

For un-aerated ditches, a horizontal flow velocity of 1 ft/s (0.3 m/s) most often satisfies particle suspension and mixing of liquor. The loss factor k is a function of tank geometry and obstacles present in the reactor. For oxidation ditches with dedicated aeration zones, the values of both k and u in equation 3 need to be determined as functions of the aeration/mixing horizontal flow effects expanded on below.

Using fine-bubble diffused aeration and low-speed mixers to generate a horizontal flow around an oxidation ditch presents additional consideration of the momentum losses generated by the vertical rise of bubbles across aerated zones. Proper placement of aeration and mixing equipment is required to ensure optimum performance with respect to mixing and aeration, otherwise spiral flow effects may develop, reducing transfer capacity and efficiency.

Assessment of the ability to produce an even horizontal flow can be done by considering the modified Froude number for such systems. The modified Froude number (Uby, 2012) can be correlated to the total aeration loss factor, where a low loss factor for optimal performance is desired.

EQ 4: $Fr = u^2/gS \cdot u/u_q$
Where:
Fr = Froude number,
u = average cross-section horizontal flow velocity, ft/s (m/s)
g = acceleration by gravity, 32 ft/s2 (9.8 m/s2)
S = submergence of diffuser, ft (m)
uq = air flow per aerated total aerated area, ft3/ft2/s (m3/m2/s)

Figure 3 describes in qualitative terms the correlation between the Froude number and the aeration loss factor.

For oxidation ditches, a Froude number value estimated using equation 3 should exceed 0.3 (an approximate critical Froude number) to eliminate spiral flows and ensure high oxygen transfer rates and efficient mixing of wastewater (Uby, 2012).

Designing a robust oxidation ditch with stable performance requires a critical Froude number that strikes a proper balance between design depth (relating to S), diffuser flux (relating to uq), and mixer thrust (relating to u). The need to establish a critical Froude number relates to the point at which the horizontal thrust produced by submersible mixers breaks through the bubble curtain generated by the diffusers.

While the aeration loss factor can be implicitly quantified in part by calculation of the Froude number, tank geometry, liquid viscosity, aeration grid layout, and mixer positioning also constitute important parameters, as they influence aeration loss.

The need to appreciate an oxidation ditch as a system with dynamic behavior — whose individual components operate in unison — must be emphasized.

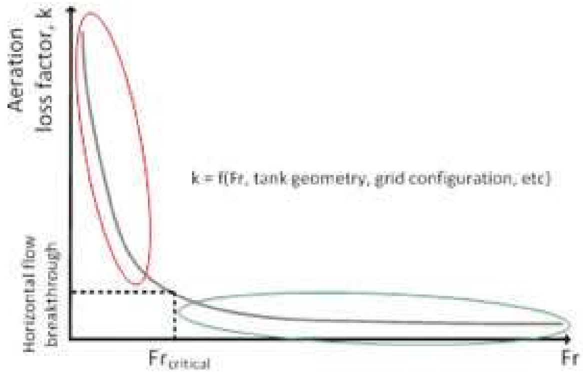

Figure 3. Depiction of the correlation between the Froude number and the aeration loss factor in horizontal flow-aeration dynamics

Lessons Learned

In recent years, significant improvements have been observed at wastewater treatment plants (WWTPs) that have operated oxidation ditch biological reactors with the use of mechanical surface aerators, illustrated at Big Gulch, WA. This plant replaced mechanical aeration with diffused aeration in combination with submersible low-speed mixers, experiencing improved performance and reduced maintenance needs.

At Big Gulch WWTP, until 2009, two oxidation ditches were in operation using mechanical brush aerators. The plant experienced maintenance issues concerning the mechanics of the surface aerators in addition to aerosols around the bioprocess basins. To cope with increased influent total suspended solids (TSS) and biochemical oxygen demand (BOD) loadings, the two ditches were upgraded to operate with a diffused aeration system with automatically dissolved oxygen controlled turbo blowers. Low-speed mixers were installed to generate the required horizontal flow (U.S. Environmental Protection Agency, 2010).

Although the intent with the upgrade was primarily to improve operation and reduce maintenance and noise levels, the plant also enjoyed lower power consumption following the upgrades. The diffused aeration upgrade provided an annual energy savings of $10,000 compared to the four years before the upgrade when mechanical aeration was used.

From a process perspective, the diffused aeration system improved performance by reducing the impact of filamentous organisms on sludge settling. Chlorine usage, previously used to control filamentous outbreaks, has been reduced with the aeration system upgrade. Fine-bubble diffused aeration has provided a much wider control range, enabling the operators to control dissolved oxygen (DO) levels during the aerobic phases of the process, along with oxidation reduction potential (ORP) monitoring during the anoxic phases.

The facility has also benefited from the elimination of aerosol previously produced by the brush aerators, providing a safer area around the basins. Clearly, Big Gulch showcases operational advantages apart from energy savings.

Summary And Conclusions

Two viable alternatives for aerating biological reactors in municipal water resource recovery facilities often stand side by side: mechanical surface aerators and fine-bubble diffused aeration. Mechanical surface aerators are often found in oxidation ditches but lack many of the features required to provide low operating cost with optimized aeration efficiency. Such installations face problems in maximizing oxygen transfer capacity without compromising mixing. Diffused aeration is an engineered solution that requires insight into the factors affecting the degree of oxygen transfer for a given reactor geometry and diffuser configuration. However, with experience, such installations offer tangible advantages to mechanical surface aeration, including high aeration efficiency, independent mixing with increased process control flexibility, low maintenance, and a safer working environment.

Oxidation ditches present additional challenges in achieving an adequate horizontal flow throughout the reactor. Highlighted in this study is just one example of successfully incorporating diffused aeration systems with low-speed horizontal flow mixers to lower operational costs, while at the same time improving treatment performance and reducing equipment maintenance. It has been demonstrated that, with the proper engineering experience, diffused aeration and submersible low-speed mixers can provide increased treatment capacity, improved energy efficiency, and operational flexibility when compared to mechanical surface aerators. ■

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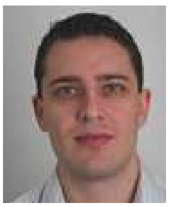

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