Winter 2021, Vol. 51, No. 4

New York Water Environment Association, Inc.

Clear Waters

Odor Control – Striving to Be a "Good Neighbor" and Protecting Infrastructure

Also Inside:

Women of Water Summit

Great Lakes Update

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Cover: There are many complex facets of odor control. Many of the measures for an effective vapor phase odor control system are shown in this image – covers on tanks (capturing and containing the odors), ductwork transporting odors, odor control vessels, and an exhaust stack. Most importantly, the image shows the neighboring community in the background. Our odor control efforts are primarily designed with our neighbors in mind. *Phil Nace, BioAir*

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nywea.org

NYWEA believes in sustainability as a core value. *Clear Waters* magazine is produced using soy-based inks and recycled materials. This is done in an eco-friendly process, that recycles virtually all chemical, paper and metal waste.

President's Message | Winter 2021

Farewell Message: Reflect. Protect. Connect.

It has been a bittersweet year as president of the New York Water Environment Association, filled with glimmers of hope for a life more normal and making critical decisions to protect the health of our members and the organization. As those on the NYWEA board of directors can attest, we are fortunate that the leaders before us were so forward thinking in their organizational planning, we were able to stay in the realm of tough decisions versus impossible ones. We continue to be so grateful for our volunteers, sponsors, advertisers and exhibitors who continue to breathe life into the organization, even if only over Zoom.

We are also grateful for the publication committee and the champion of this edition, Dick Pope, who has been the go-to for odor control on the program committee as long as I can remember. We have a packed edition, highlighting the evolution of odor control over the past 50 years (by Robert Bowker, page 16) as well as designing odor control measures more effectively to save money and become a good neighbor (Phyllis Diosey, page 41). As depicted in the show, *How I Met Your Mother*, not many people want to be in the "Dowisetrepla" neighborhood (Downwind of the sewage treatment plant)! There are so many treatments to help in addressing odor problems.

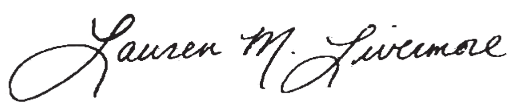
While we all have been missing the in-person aspect of most of our NYWEA events, we have not been sitting idle. In fact, I think our dedicated group of volunteers and staff have worked harder than they ever have before to make sure we continue to carry out the educational mission of NYWEA by providing industry-focused training to our members. These are just the highlights of our key events over the past year:

- Shortly after the 2021 annual meeting, we hosted an Effective Utility Management Workshop with help from U.S. Environmental Protection Agency (USEPA).
- We hosted a Joint Legislative Forum with our colleagues at the New York Section AWWA and the New York Rural Water Association.
- Our spring meeting was held virtually in June with highlights on the transformation of Onondaga Lake.
- The watershed conference ended up going virtual in September, with a packed day on watershed management.
- We held the first-ever NYWEA Women of Water Summit, in person in Albany where we brought water leaders from all stages to grow stronger together.
- Multiple webinars were held on COVID surveillance in wastewater and how it is being used as a tracking tool as the pandemic continues.
- And, of course, we held numerous training sessions through the Thomas J. Lauro Member Education Training Program.

I would be remiss if I did not share some of the other amazing tasks we have completed:

- Our amazing *Clear Waters* magazine had issues focusing on Water Workforce Development and Diversity Equity and Inclusion with articles from our members that were motivating and inspiring.
- Among several meetings with staffers of our state politicians, and letters of support for various initiatives, we have had input on the creation of the Low-Income Household Water Assistance Program (LIHWAP), modeled after the Home Energy Assistance Program (HEAP).
- To make sure we are collaborating with our friends at New York Section AWWA, we created the One Water Committee to keep an open line of communication, identify joint efforts between the organizations, and bring our One Water message to our local officials.
- We created a Future Conferences Task Force to evaluate trends and opportunities as we navigate the dynamic world we are living in today.
- We also created a Civil Service Task Force to help overcome the hurdles of hiring in the public sector.
- A new, nonvoting position on the NYWEA board was created to bring in a representative from the New York State Environmental Facilities Corporation (NYSEFC) to make sure we bring that important funding connection to our board and our membership, just as we have the connection on our board with New York State Department of Environmental Conservation (NYSDEC) and USEPA.
- Thanks to Tim Murphy we provided testimony at State Senator Michelle Hinchey's hearing on water infrastructure funding.

As I close out this year as president, I want to thank everyone for their commitment and dedication to the organization during these trying times. I am sure I said it last year, too, but I can't wait to have a glass of wine with everyone at the president's reception at the spring meeting in Syracuse as we toast to our incoming president, Khris Dodson!



Lauren M. Livermore, P.E., BCEE
NYWEA President

Lauren Livermore welcomes participants to the Women of Water Summit in October, 2021. See more on page 47. *Madison Quinn*

Clean Water Act – New York State Led the Way!

As we celebrate the 50th Anniversary of the Clean Water Act it is important to remember that it was New York state that undertook a major comprehensive water pollution control program in 1965. The federal government and a number of other states followed New York's lead. New York's well-crafted pollution abatement program was strengthened by the support provided in the 1966 Federal Water Pollution Control Act. This was followed by the 1972 Clean Water Act, which included many of the provisions pioneered by the New York State Pure Water's Program. So, it was New York's initial program that sparked the success of the national all-encompassing and comprehensive Clean Water Act as we know it today.

The Clean Water Act was **a response to public concern for the environment and for the condition of the nation's waters** and set out to restore and maintain clean and healthy waters. The Clean Water Act brought in much needed funding to improve the conditions of our nation's waters. Building water utilities across the nation improved dramatically how pollution was handled. It is still a guiding document, but certainly needs continuous work to address the clean water challenges that many water resource recovery utilities face, including aging infrastructure (physical and human), emerging contaminants and climate change to name a few.

New York state funding was and will always be at the forefront of clean water improvements. Our predecessors would be proud of the $5 billion allocated for clean water initiatives and the pending Clean Water Clean Air, Clean Jobs Bond Act worth another $4 billion on the November ballot.

These significant allocations of money are a result of the leadership of our elected officials who understand and appreciate the connection between water and public health.

Our work is never done, and we continue to engage and educate elected officials at all levels about their responsibility to know more about water quality. A great example of engagement with local elected officials took place in the City of Watertown where the city council recognized the Water Bears for their second place win in the national Division 3 Operations Challenge at WEFTEC in 2021. The Water Bears were honored by proclamation; however, the real recognition came when council members were invited and came to the utility to see the work they do and a demonstration of one of the events during the competition.

Watertown Water Bears: (l-r) Seth Foster, Richard Lacey, Angel French, Jay Slate and Mark Crandall. *Donna Grudier*

The brisk winter weather this year makes me think of the operators who work in all weather conditions. I think we need a water resource recovery motto … perhaps "neither snow nor rain, sleet, heat, frigid temperatures, nor gloom of night keeps these essential workers from their tasks to bring us clean water services!"

In 1972, the people of the United States celebrated the creation of the Clean Water Act. For those of you operating and maintaining these utilities, 24/7, we celebrate your essential hard work.

Patricia Cerro-Reehil, pcr@nywea.org

P.S. Many thanks to Dick Pope for his work in the development of this issue!

On Thursday, Feb. 10, 2022, Khristopher Dodson Became NYWEA's 94th President.

Khris is the associate director of the Syracuse University Environmental Finance Center, which serves local government agencies and municipalities in both managerial and financial capacities with assistance related to water, wastewater and stormwater infrastructure.

Khris has always loved the outdoors, even before he bought the book *50 Simple Things Kids Can Do to Save the Earth* in 1990. As an undergraduate environmental science major at Binghamton University, Khris wanted to learn all he could about the environment to better communicate with those whose work impacts nature. Before joining the SU-EFC in 2009 Khris received two master's degrees, one from Syracuse University and another from SUNY-ESF. Khris is skilled at public outreach and effective communication and has served as adjunct professor at SUNY-ESF teaching Public Speaking and other communications courses.

Khris was attracted to NYWEA's incredible mission and the work that is carried out by its members. He has been on the NYWEA board of directors since 2012, serving as the Public Education Committee representative to the board before becoming an officer. He has also served as the Public Engagement Committee Chair and has received a NYWEA Public Education Award and a Select Society of Sanitary Sludge Shovelers (SSSSS) silver shovel.

Khris is a City of Syracuse resident where he lives with his husband Jesse and their two sons, Eli and Justin. He could live happily the rest of his life on a diet of Mexican, Indian and Asian foods.

Khris succeeds Lauren Livermore who stepped down as NYWEA's president Feb. 10, 2022.

Khristopher Dodson with his husband Jesse, and sons Eli and Justin.


Membrane Systems
Biological Processes
Aeration and Mixing
TOTAL WATER MANAGEMENT SOLUTIONS
Aerobic Granular Sludge
Ozone Systems
Cloth Media Filtration

Water Views | Winter 2021

Great Lakes Update

The federal government appears ready to increase baseline funding for the Great Lakes Restoration Initiative (GLRI) to about $340 million, with added increments to this base funding projected over the following four years. In addition, the $1 trillion "hard" infrastructure legislation provides $200 million each year for the next five years. These funds will expedite the restoration of an enormous watershed that contains about 20% of the Earth's available fresh water.

The GLRI focuses on: (i) contaminant remediation in Areas of Concern (AOC); (ii) reducing nutrient pollution from runoff, which triggers algal blooms; (iii) addressing contaminants of emerging concern (e.g., PFASs); (iv) stopping the spread of new aquatic invasive species and mitigating the effects of those already arrived; (v) restoring coastal habitats; and (vi) increasing natural resilience to flooding, especially in the face of worsening climate extremes.

Great Lakes cities and towns have a lot of aged clean water infrastructure to repair. The pending federal budget and the hard infrastructure legislation will more than double the federal funds to New York that support low and interest-free financing via the Clean Water State Revolving Loan Fund. The federal infrastructure legislation funding allows for grants of up to 50%.

Governor Kathy Hochul has allotted $265 million to NYSDEC's Water Quality Improvement Project grant program, with grants awarded in December 2021. Moreover, the governor approved $400 million for the next round of the Environmental Facilities Corporation's Water Infrastructure Improvement Act and Intermunicipal grant programs.

In 1988, a comprehensive *25-Year Strategy for Restoring and Protecting the Great Lakes* was prepared, then updated in 2011 as the *Interim Great Lakes Action Agenda*. To date, almost 85% of the original 124 recommended actions have been completed or are underway. NYSDEC is updating the action agenda for early 2022. The new *Great Lakes Action Agenda (GLAA) 2030* will integrate existing core regulatory programs with watershed-scale management/restoration plans to achieve six key goals.

The Resilience and Economic Development Initiative was deployed in response to Lake Ontario's record high, 500-year water levels in 2017 and 2019. New York committed $235 million for municipal infrastructure resilience, $15 million for navigation channels, $30 million for restitution of business losses, and $20 million for emergency mitigation of damaged shoreline properties. Progress is underway.

NYSDEC completed 12 *Resilient NY* stream studies in the watersheds of lakes Erie and Ontario. These advanced studies identify specific projects to reduce riverine flood and ice jam risks. Of New York's six designated AOC, the Oswego River AOC has been restored and delisted, and Buffalo River, Rochester Embayment and Eighteenmile Creek AOCs have substantially accomplished all restoration actions. Monitoring results will determine if these sites can be formally delisted. See the *Great Lakes 2020 Highlights*: *https://www.dec.ny.gov/docs/water_pdf/greatlakes2020reportfinal.pdf*

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

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Focus on Safety | Winter 2021

Noise: A Sneaky Workplace Hazard

A loud hazard – but sneaky. Why?

First, without pain, we have no warning that damage is happening – unless, of course, you are near a loud explosion or a jet engine taking off. Sound produces vibrations in the air that reach our ears and cause nerve cell hairs in the inner ear to move back-and-forth; the attached nerve cells send signals to the brain. Loudness is how much energy the sound has; frequency is the pitch. Loud noise causes these hairs to whip back-and-forth violently; high pitch makes this movement more rapid. These hairs can become bent or break off (and are not regrown); the attached nerve cells can become inflamed and even slowly die. Noise damage is permanent. No matter what your age, you must preserve your hearing (or whatever hearing you have left).

Second, noise injury may go undiagnosed because of hidden hearing loss. This happens when you pass a hearing test in the doctor's office but cannot hear/understand other people in a noisy environment. In a quiet testing room/booth, only a few nerve synapses are needed to pick up sounds. But in a noisy environment, the ear must activate specific synapses and, if these are not all operational, it is difficult to make sense of words. So, you need to tell this to your doctor (and not just suffer in silence – bad pun).

Third is the combination of noise and long work hours. The Occupational Safety and Health Administration noise regulation of 90 decibels (dB) as a time-weighted-average (TWA) is based upon an eight-hour day. If you work more than eight hours, noise measurement interpretation and hearing protection need to match your work hours. For example, if you work for 16 hours at 90 dB, the 8-hour TWA is 95 dB. So, you should have been wearing hearing protection all day.

Fourth is chemicals can be toxic to ear nerves. And some chemicals can combine with noise exposure and produce even more damage. Lead, carbon monoxide, and several solvents have shown this. Caution suggests that, if a chemical is known to damage the nervous system, a hearing test should be added to your medical exam (regardless of your workplace's noise levels).

Fifth, loud noise has been linked to nonauditory health effects such as sleep disturbance, stress, high cholesterol and high blood pressure. Moreover, workers with a history of loud workplace noise were less likely to have monitored blood pressure or cholesterol – known risk factors for cardiovascular problems.

You could be sneaky, too – by using a NIOSH smartphone app for noise levels that is available for a free download at iTunes. For best results, the app needs a special microphone attachment for your smartphone. While not a substitute for a true sound level meter, you could check a suspect noise problem and then request further evaluation.

– Nellie J. Brown, MS, CIH, ILR School, Cornell University

Odor Control – Clearing the Air … Makes Good Scents!

by Richard J. Pope, PE, BCEE

Just when you thought you had your plant under control, complying with all water effluent and solids/biosolids disposal requirements, you are rudely reminded that there is a "third effluent" from the plant – air/odor emissions – and the rest comes in the form of nuisance odor complaints!

Why is it that odorous emissions from water resource recovery facilities do not get the "respect" that the liquid and solids streams do? Several factors are at play, and they include but are not limited to the fact that:

A. *There are no federal odor regulations.*
   The U.S. Environmental Protection Agency (USEPA) has made it clear that it regulates public health and not public nuisance.

B. *Odors are subjective.*
   Each person's sense of smell is different, and each has their own unique physical and environmental interpretation of what is a nuisance.

C. *Quantifying odors is difficult.*
   We can analyze air samples to determine the individual compounds present but when you combine them, new and unique odors are created! The odor industry has developed a way to evaluate air samples to determine how many times one must dilute the sample before the average person can detect or recognize that an odor is present. This is called dilution to threshold (D/T), but this value has no reference as to whether the odor is annoying (a nuisance) or pleasant.

D. *Most states have air regulations that refer to meeting "quality-of-life" requirements.*
   Interpreting quality of life is left up to the nearby resident who is suffering from the bad odors, trained (hopefully) inspectors, and/or the courts. There are no metrics associated with quality of life, other than perhaps odor complaints. How then does a utility define "nuisance odor," and what degree of control must they apply when trying to be a "good neighbor"?

E. *Some states specify limits for odorous compounds.*
   Some states, like New York, make it more difficult to forget about the third effluent by adding limits for specific odorous compounds such as hydrogen sulfide (H_2S), a typical odor commonly associated with wastewater, in addition to quality-of-life requirements.

F. *Unbalanced consequences/penalties.*
   The consequences/penalties associated with noncompliance for wastewater and solids/biosolids are so much greater than those for air/odor emissions.

But the fact remains: compliance for odors is not as closely monitored by the regulatory agencies, and in many instances is prompted by odor complaints. How odor complaints are received, logged, verified, evaluated, trended, and followed up is a whole other discussion left for another day or magazine special issue!

Odor Control

Odor control means different things to different stakeholders. Therefore, the definition of odor control is in the eyes – or rather the nose – of the beholder. Some would have you believe that odor control means no odors, EVER! This is a favorite position for elected officials and utility board members, despite how impractical this position actually is. It is impractical for three simple and basic reasons:

1. Nature of the wastewater – it is odorous! The public rushes to flush it out of their homes. And all those odors combine and accumulate in the collection system and end up at the plant to be treated and turned into a reusable product.
2. Mechanical systems are used to process/treat the wastewater and control the odors. Even though mechanical systems are maintained and serviced, there are times when they can breakdown despite our best attention and intentions!
3. Humans operate the mechanical systems. Although we would like to believe that an operator will be attentive 100% of the time, we recognize that this may not always be the case.

At any point in time something can and sometimes does go wrong and odors are released to the atmosphere and are detected by the community. Yes, we can work hard on reducing and minimizing mechanical and human error so that any of these odor excursions occur very infrequently and are of short duration, but we cannot control them 100% of the time. It is like driving a car and saying that I am never going to get a flat tire. I try to avoid the glass, nails and potholes in the street, but I cannot see them all especially at night. Accordingly, off-site odors are inevitable and therefore it may be wiser not to promise what we cannot be sure we can deliver.

As the third effluent from the plant, odors always seem to take a back seat to wastewater and solids operations simply because the consequence of noncompliance is so much greater for them over odors. As a result, operations and maintenance (O&M), monitoring, and preventative maintenance do not always seem to receive the same level of attention, especially when no odor complaints are received. These conditions are only exacerbated these days as the plant staff are being asked to do more with less staff, and/or as staff retire and are not replaced. When push comes to shove, the odor control systems are the more expendable pieces of equipment. That is, until odor complaints surface and the pressure to control plant-based odors is high. Welcome to the new reality! These are just the nuisance odor facts!

Some more facts:

❖ *Wastewater odors are more than simply H_2S!*
   There are a number of compounds that are normally associated with municipal wastewater. Many of these other compounds contain sulfur (mercaptans, dimethyl sulfide, dimethyl disulfide, carbonyl sulfide, carbon disulfide) or nitrogen (ammonia, amines, indole, skatole) based compounds. So why are these compounds so important to nuisance odors? The simple answer is they can be detected by the human nose at extremely low concentrations – parts per billion (ppbv) and parts per trillion (pptv) by volume in air!

❖ *In addition, many of these compounds are very persistent in the atmosphere.*
   Persistence means they have "hang time," or their level of odor intensity (i.e., how individuals perceive an odor as mild, moderate or strong) does not vary much as the odor is diluted in the atmosphere. This means that just like that skunk that you continue to smell with the same degree of intensity as you walk away from its spray, these odors can be perceived with a sustained intensity even as you move away from the source.

❖ *H_2S plays a critical role in corrosion.*

Not only is H_2S a nuisance odor compound with an extremely low level of human detection but it also plays a critical role in collection system and treatment plant infrastructure corrosion. H_2S is directly corrosive to metals, particularly ferrous metals, and is converted to sulfuric acid in the headspace of sewers, channels, wet wells, and tanks by microorganisms. Sulfuric acid is corrosive to unprotected concrete and metal surfaces.

❖ *Each individual has a different sense of smell and so odors are subjective.*

❖ *Our past environment influences our judgment/interpretation of odors.*

❖ *Odor concentrations are not additive.*

Combining two odors creates a new scent with different characteristics. Look at coffee as an example. Coffee is comprised of many individual compounds that are unrecognizable on an individual compound basis, but all combine to create that wonderful scent we love to smell in the morning after we wake up.

❖ *The sense of smell is the only one of our five senses that is directly hard-wired to our brain, and that part of the brain that is the center for memory and emotions.*

❖ *The community approaches nuisance odors from their own unique perspective that utility staff are constantly struggling with.*

For example, the community smells with their eyes, believes perception is reality, and "if I can smell it, it must be harming me!"

Whoever said trying to implement an odor control program and coming across as a good neighbor would be easy? As we have been trying to convey, odors are complex.

What Can We Do?

So how do we address odors from the collection system and water resource recovery facilities (WRRFs) to reduce odor complaints and assure compliance with the applicable regulations? After nearly 50 years of active odor control experience, we answer those basic questions raised by utilities across the country: Where are the odors? What are the characteristics of the odors? How strong are they? How do we control them? What is it going to cost? How long is it going to take to implement? All these questions are part of the odor assessment and control process.

For this *Clear Waters* magazine edition, we have compiled articles from several experts with 300 years of combined experience in assessment, control and other odor-related services that represent a full view of odor control for facilities that process wastewater from when it all started to become a concern until today. Each author has taken a piece of the odor market and provided their perspective that helps define it and makes it more practical.

After reading these articles you should walk away with a better understanding of just how complex solving odor and the associated corrosion-related problems are at wastewater facilities. And that by solving one problem – odors – does not make the other problem – corrosion – go away! Be aware that to dig deeper and research the odor and corrosion assessment and control topics, available resources are quite limited and/or dated. Arguably, the best up-to-date resource is the WEF Manual of Practice #25 – *Odor Emissions and Control for Collection Systems and Water Resource Recovery Facilities* – Second Edition (July 2020). Or consider contacting any one of the article authors who are always very willing to share their knowledge on the topic!

Richard J. Pope, PE, BCEE is a vice president and odor services leader with Hazen and Sawyer and may be reached at rpope@hazenandsawyer.com.

See the issue's featured authors, continued on page 13

continued from page 11

The Odor Control Issue's Featured Authors

Richard J. Pope, PE, BCEE – Articles Curator

Mr. Pope has spent 43 years concentrating on odor and air emissions from municipal facilities (his main focus) and industrial operations. Due to the lack of academic courses and literature texts on odor control he gained his experience in the field while working in 23 out of 25 of the largest cities in the United States, in 37 out of 50 states and 10 foreign countries. A recognized odor expert, he is well versed in all aspects of odor assessment and control from facility monitoring, to odor dispersion modeling, to planning and design, to start-up and optimization, to training, to expert testimony, to regulatory coordination and to the all-important community outreach. In addition to being a frequent presenter at state, national and international conferences, Mr. Pope is a contributing author to texts like the Water Environmental Federation's (WEF) Manual of Practice #25 – *Odor Emissions and Control for Collection Systems and Water Resource Recovery Facilities* (July 2020), which is one of the most comprehensive sources of municipal wastewater odor-related information. He is a professional engineer and a Board-Certified Environmental Engineer with the American Academy of Environmental Engineers and Scientists.

Robert P.G. Bowker, PE – Historical Perspective

Mr. Bowker has over 45 years of odor assessment experience starting with the research work he conducted for the USEPA as they were gathering information and data for their initial publications on odor and hydrogen sulfide. Bob provides a unique perspective of the growth of odor control over the past 50 years.

Randy Nixon – Material Corrosion

Mr. Nixon has spent his 45-year career studying the effects of corrosion on materials of construction in the environment with a good portion focused on wastewater, microbially-induced corrosion and hydrogen sulfide. His article focuses on the link between odor and corrosion, and how dealing with one does not always address the other completely.

Gary L. Arthur – Noncorrosive Material

Fiberglass reinforced plastic (FRP) is a popular noncorrosive material of construction commonly used in odor control covers, ductwork, technology vessels, chemical storage tanks and exhaust stacks. Mr. Arthur has been in the FRP industry all his working life from the age of 16 when he started working in his family's FRP fabrication shop. He understands firsthand what it takes to specify and fabricate FRP products and what a good fit FRP products are for the odor control industry. He also recognizes that there are limited standardized controls over the fabrication process. Gary will discuss today's problems with FRP specifications and certifications and offer solutions as a representative of a nonprofit group that is trying to help owners in getting the FRP product they expect.

Ryan McKenna, PE – Field Monitoring/Sampling

Mr. McKenna has spent the last 10 years focusing on odor assessment and control planning and design. At the essential core of that work, he has been involved with collecting wastewater and air samples and analyzing the samples, where applicable, in the field to avoid preservation issues and delays in reviewing the results. This data becomes the driving force behind the odor control decisions that are subsequently made and implemented. Ryan is familiar with all the current, industry-standard, continuous datalogging equipment and outside laboratories that must be used for special testing requiring high-end analytical equipment like gas chromatograph/mass spectrometers (GC/MS) or odor panel work where humans evaluate the samples under strict ISO-backed procedures.

Phyllis G. Diosey, PhD, QEP – Odor Dispersion Modeling

Ms. Diosey has been studying the short- and long-term transport of constituents in air throughout her career beginning with her research in physical wind tunnels during and after her doctorate work. The wind tunnel research gave her a better understanding of near field impacts of meteorological conditions. For the past 45 years she has been studying and executing air models, sponsored by USEPA, that are the gold standard for demonstrating compliance with regulatory limits, be they odors or criteria pollutants. Phyllis continues to remain current with the recent trends in odor modeling and applies commercial graphics software to make the modeling results easier to understand by simple inspection through aerial illustrations rather than tables and charts.

Calvin Horst – Chemical Addition

When you need to know information about chemical addition to the collection system to address odor and corrosion issues, Evoqua is the company and Mr. Horst is one of their lead field planners and implementers. He has spent his nearly 10 years at Evoqua developing, running, monitoring, troubleshooting, and optimizing chemical addition systems in collection systems and treatment facilities in order to address and reduce collection system odors in the community and corrosion to the infrastructure.

Chris West – Vapor-Phase Odor Control (Biological)

Mr. West represents the leading edge of vapor-phase odor control that uses microorganisms to achieve what chemicals – mostly hazardous – and limited-capacity dry medias have been trying to accomplish for decades: reduce odors from wastewater facilities. Active in the odor control field for 25 years, he and his team continue to conduct research on how to improve the removal of H_2S and other reduced sulfur compounds present in wastewater and solids that have been annoying nearby communities for decades. He will present a background on vapor-phase control technologies with a focus and a case history on biotrickling filters that harness the ability of microorganisms to reduce odors without chemicals.

Chester M. Morton, PE – Vapor-Phase Odor Control (Carbon)

Mr. Morton will discuss how activated carbon has been a staple in controlling nuisance odors for the 40 years he has been recommending this technology for the appropriate application. Because of this dry media's simple operation, consisting of a fan and a vessel to hold the media, and its ability to remove most odorous compounds, it has been used as a polishing stage after other technologies remove the bulk of the odor load, as well as a prime odor control device. Chet will also delve into the intricacies of this popular vapor-phase odor control technology.

The Evolution of Odor Control – A Fifty-Year Perspective

by Robert P.G. Bowker

Introduction

Fifty years ago, "odor control" was rarely in the vocabulary of wastewater treatment plant operators or engineers. Operators were often defensive ("It's a sewage treatment plant; we were here first.") and engineers knew nothing about measuring odor or how to control it. Plants were generally sited away from residential areas, and when odors were detected, people were often tolerant of the odors ("Oh yeah, that's the sewer plant. We get the smell once in a while."). Wastewater treatment plants designed with positive odor control technology, such as covers and scrubbers, were rare.

Exacerbating the problem was the trend toward larger, regional facilities in the 1970s. Local plants with small collection systems and low odor emissions were replaced with pump stations that conveyed the sewage to the new regional facility that was miles away. Lo and behold, the sewage was now ripe with hydrogen sulfide after cooking in the force main for hours. Not only did this hydrogen sulfide cause odor complaints, but it also caused corrosion of the sewers and plant components. Operators and engineers realized that odors and corrosion were problems that had to be addressed.

Things began to change, beginning with the realization that treatment plant odors are an "effluent" that often needs to be controlled to ensure that the facility is a good neighbor. The other thing that we learned is to be proactive: once the plant is considered a nuisance by the community, it's an uphill battle to change that perception. The following explores some of the changes that have occurred in a) community values and b) science and technology that have shaped how we perceive and control odors.

Community Values

Community values, and people's tolerance of odors, have changed over the years. Recently in my hometown of Portland, Maine, the community mourned the closing of B&M Baked Beans, the pleasant aroma that could often be detected when passing through the city. Other odor sources were not so pleasant: an uncovered, overloaded sewage treatment plant, and, if the wind was right, the pulp and paper mill in the next town (smells like money?).

In my over 45 years in the wastewater industry, I never met anyone who liked the smell of sewage. Plus, if anyone tells you that a well-operated treatment plant has no odor, well, they are full of it.

People have become less tolerant of objectionable odors and have asserted their right to enjoy their backyard free from such nuisance. One factor is development: the old warehouse district near the sewage treatment plant is being redeveloped with shops and restaurants. (Hey, it's waterfront property!) Encroachment of residential and commercial development has reduced the buffer between the source of odors and those that might complain about it. What was once a relatively remote facility may now need millions of dollars in odor control equipment to make the neighbors happy.

I have always believed that to fully appreciate the severity of odor impacts, one needs to live in the affected area. Community odor surveys are hit or miss ("you should have been here an hour ago") and may lead to erroneous conclusions about the severity of the problem. That is why a relatively new tool called "dispersion modeling" can be very useful, as discussed later.

People learned that community activism can produce change. "I can't even barbecue in my backyard!" became a familiar cry.

Unpleasant odors in the neighborhood? *Bowker & Associates*

Citizens committees were formed, the people spoke and the local politicians listened. People sued their municipalities, with the courts almost always finding in favor of the people. Sometimes the improvements came painfully slow, but the people kept up the pressure. The engineers and scientists had no choice but to respond. What else changed?

Science and Technology

The evolution of the science and technology of odor control may be viewed through the following lenses:

- Measuring odors
- Estimating odor impacts
- Adding chemicals
- Containing odors
- Treating odorous air
- Processing wastewater

Measuring Odors

Fifty years ago, engineers and operators did not know much about measuring or characterizing odors. About the only smelly chemical that was measured in the air was hydrogen sulfide (H_2S) because most people knew it could be deadly and smelled like rotten eggs. It also caused corrosion, but a lot of folks were not aware of how destructive it could be. Publications in the mid to late 1980s clearly established the link between H_2S and corrosion. Instruments to measure H_2S improved, with better sensitivity and data-logging capability. Hydrogen sulfide monitors can now record to the part per billion by volume (ppbv) level.

A major breakthrough was the development of a standardized laboratory procedure for measuring the strength of the odor by how many times it must be diluted with odor-free air to render it undetectable (dilutions to threshold). The adoption of a method to measure the overall levels of odor in actual air samples from sewage treatment plants replaced subjective plant surveys that rarely got it right. The procedure measured odor, independent of the myriad chemicals that might be causing it. The widespread use of this method led to improvements in olfactometry and the development of portable devices to estimate ambient odor levels. Within the past 10 years, there has been considerable research on, and use of, "electronic noses" to monitor odor levels at waste-handling facilities.

Another breakthrough in the characterization of odors was the ability to detect, at very low concentrations, specific chemical compounds contributing to the odor. It was quickly learned that other foul-smelling compounds were in the air, such as methyl mercaptan and dimethyl disulfide. Like H_2S, these compounds could be detected by the human nose at concentrations of less than 1 part per *billion*. So even if one were able to knock out the H_2S with chemicals, it did not always solve the odor problem, as some of these other smelly compounds were harder to remove and their "rotten vegetable" odor remained a problem.

A state-of-the-art odor laboratory. *St. Croix Sensory*

Flux chamber system used for odor sampling.
Webster Environmental Associates

Along with improvements in measuring odors and their constituents, better sampling procedures were developed. The "flux chamber," developed for USEPA to measure emissions from hazardous waste impoundments and contaminated soils, was applied to wastewater treatment plants to capture the emissions from odor-emitting surfaces such as primary clarifiers, aeration basins and sludge drying beds. The flux chamber allowed measurement of the "odor emission rate" from these sources, which is a key parameter used to rank the sources of odor as well as provide input into an odor dispersion model.

Estimating Odor Impacts

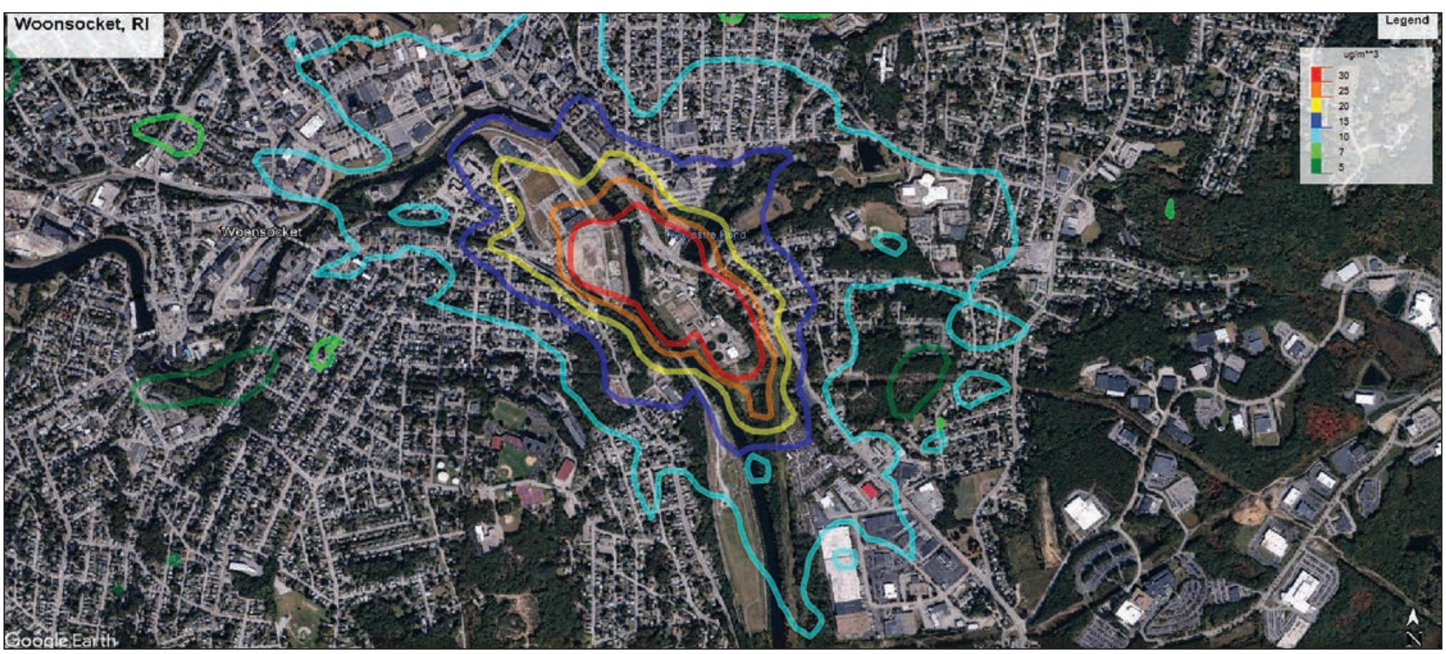
For community odor surveys to be effective, one needs many observations under a variety of environmental conditions. Even so, such surveys are unlikely to capture worst-case odor impacts that might occur, for example, in an infrequent atmospheric temperature inversion.

Here is where air pollutant dispersion models have become very useful tools in estimating the severity of a potential odor impact. The models can be used to predict the strength of the odor (dilutions to threshold) as well as the frequency that it may occur at various points downwind of the odor sources. These sophisticated models, which use actual weather and terrain data as well as physical plant conditions, have become much easier to use. By evaluating the reduction in odor impact of various odor control strategies, the models can help answer a question that has long eluded engineers: "How much odor control do I need?" Before using odor dispersion models, decisions on prioritizing odor sources were subjective, and often did not reduce community complaints.

Adding Chemicals

Fifty years ago, about the only attempt to control odors was to inject chemicals. Some plants could pre-chlorinate, which helped reduce odors, but overdosing was a problem with downstream

continued on page 19



Dispersion model output for estimating odor impacts. *Bowker & Associates*

continued from page 17

biological processes, and there was always a concern with leaks of chlorine gas. Potassium permanganate was another strong oxidant that could also be used to suppress odors from sludge handling processes. It was effective, but expensive and hazardous to handle. Iron salts such as ferrous chloride precipitated most of the sulfide but did not do much for the other odorants.

Several new approaches emerged: the injection of pure oxygen into force mains to prevent the generation of sulfide; the use of magnesium hydroxide to increase pH and prevent release of H_2S; and the injection of nitrate solutions to prevent the formation of H_2S and promote oxidation of existing sulfide. Hydrogen peroxide was also demonstrated to be an effective and economical chemical for sulfide control in gravity sewers.

Oxygen dissolver used to control hydrogen sulfide. *ECO2*

Flat covers over primary clarifier effluent channels. *Bowker & Associates*

Traditional dome and wet scrubber system. *Bowker & Associates*

While chemicals did a pretty good job of controlling H_2S and reducing corrosion, they did not always provide the expected level of odor reduction. The industry needed better ways to capture and treat the odorous air.

Containing Odors

When odor containment was necessary, primary clarifiers, sludge thickeners, and other odorous tanks were often covered using domes. While allowing easy access for maintenance, domes created a confined space. Proper ventilation of the dome required a large air flow rate and a correspondingly large and costly odor control system. Today, most covers are flat and not designed for routine entry, reducing ventilation rates and odor control requirements as well as improving safety.

It was also learned that most of the odor emissions from a primary clarifier often occur at the turbulent effluent launders. Covering and treating the air from the primary effluent launders was found to be a cost-effective approach for many facilities.

Treating Odorous Air

Fifty years ago, there were two major technologies used for treating odorous air at wastewater treatment plants: chemical scrubbers and activated carbon adsorbers. Chemical scrubbers worked well on sewage odors, but they required continuous addition of hazardous chemicals (sodium hydroxide and sodium hypochlorite). These chemicals were difficult to handle and costly, and the scrubbers needed significant operator attention and maintenance. Activated carbon worked well for many odors but had limited capacity to adsorb H_2S. Carbon adsorbers were often applied to the strongest odors, resulting in rapid exhaustion of the media and breakthrough of foul odors.

The development of biological systems to treat odorous air greatly reduced the cost and maintenance requirements of odor control systems. Biofilters, using wood-based media, became extremely popular in the 1990s, but the footprint was often quite large. Improvements in our knowledge of biofilters, as well as developments in nondegradable media, have made biofilters a common sight at wastewater treatment plants.

Another major technological development was in bioscrubber systems. Also known as biotrickling filters, these devices use naturally occurring bacteria to achieve 99% H_2S removal in a much smaller footprint than a biofilter. Operation and maintenance costs of biological systems are only a fraction of the costs of conventional physical-chemical scrubber systems and do not require hazardous chemicals.

Activated carbon has seen its own improvements, not the least of which is media designed to remove hydrogen sulfide. Chemically modified media may have an H_2S capacity an order-of-magnitude higher than virgin carbon. For some situations requiring a very high degree of odor control, activated carbon is used to polish the exhaust from a biofilter or other odor control system. Development of radial-flow adsorber vessels increased air flow capacity in the same footprint. Various vendors have developed packaged hybrid systems that include two stages of treatment.

Processing Wastewater

Improvements in wastewater processing equipment has helped reduce odor emissions, either by better containment of the odors or by more efficient treatment of the waste. Some examples are:

continued on page 20

continued from page 19

Bioscrubber odor control system. *BioAir Solutions, LLC*

Photoionization pilot unit from Ambio Biofiltration, Ltd. *Bowker & Associates*

1. Preliminary treatment – Use of enclosed screens, screenings washer/compactor/baggers, and grit washers to remove putrescible organics that cause odors.
2. Secondary treatment – Replacement of mechanical aerators and coarse bubble diffusers with fine bubble diffusers that significantly reduce the odor emission rate by reducing surface turbulence and air flow requirements.
3. Sludge thickening – Use of rotary drum or other enclosed thickeners that provide containment of the odorous air and easy withdrawal of the air for treatment.
4. Sludge dewatering – Use of screw presses, rotary presses, and centrifuges that provide odor containment and result in low air volumes for treatment.

We have had several bumps in the road along our journey. For example, nobody recognized the potential odor impact from open-air sludge composting operations, and how difficult and costly it would be to control the odors. Community odor complaints caused many composting facilities to shut down, with municipalities scrambling to find other solutions. Some advanced sludge digestion technologies, both aerobic and anaerobic, also experienced odor problems that had to be addressed. Overall, the industry recognized that odors were a major issue in the conveyance and treatment of wastewater, and responded by developing technologies that addressed the problems.

What Does the Future Hold?

Assuming that odor-free sewage is not in our future, what can we expect in the way of new developments in the next 50 years? Chemicals will continue to be used to mitigate odors and corrosion in sewers. Although we have had some significant breakthroughs in sulfide control, my crystal ball is a little hazy on whether we can expect an effective, low-cost, nonhazardous chemical to appear on the market. When I come up with that magic bullet, I will let you know.

There are three areas where new development is most likely:

- Monitoring
- Vapor-phase odor treatment
- Models

Monitoring

We can look forward to continued improvements in H_2S sensors, with greater sensitivity, datalogging capability, and other features such as telemetry and easy calibration. Is there a simple, economical and reliable electronic "odor monitor" in our future that could be used to monitor performance of odor control systems or identify upsets or odor spikes? Continued research and greater use of electronic noses is likely, including biological sensors. Other devices such as drones will assist in monitoring odors and will become valuable tools in the toolbox of the future.

Vapor-phase Odor Treatment

Can all odors be treated biologically? Biological systems do well on hydrogen sulfide, but not as well on some of the organic sulfur compounds. Can we optimize biological systems to provide 99% odor reduction at shorter detention times? Biological systems will play an important role in the future of vapor-phase odor treatment.

There are other ongoing developments in vapor-phase treatment technology, including ultraviolet light, ionization, photoionization, and new sorbent media that will provide a greater variety of tools to the design engineer of the future.

Models

There has been considerable research on improved models to predict sulfide generation, H_2S release and corrosion in sewers, but the models are complex and not user-friendly. More accurate and user-friendly sewer models are hopefully in our future. Odor dispersion models will continue to improve. Their importance as a tool in developing an odor control strategy for a wastewater treatment plant with multiple odor sources cannot be overstated. And this is from an engineer that used to joke about models, "If you don't like the results, change the assumptions."

An Odor-Free Future?

The odor control industry has made huge strides in the last 50 years, considering we started at almost zero. We are in a much better position to make sound, science-based decisions on how to prioritize odors, as well as how to control them. Sure, it may still be an inexact science and there is still a need for good engineering judgment, but the days of guessing which odor to tackle first and how to treat it are in our past. Whew! How sweet it is.

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MTA-LIRR Third Track
Ronkonkoma Hub Pump Station
Clean & Green Biosolids Processing Facility
Bergen Point WWTP
Glen Cove WPCP
FDNY
Hofstra/Northwell School of Medicine
Village of Greenport BNR
Greater Atlantic Beach Water Reclamation District
Lawrence-Cedarhurst Consolidation
NCDPW Barnes Ave SSO Correction
Sacred Heart Academy
Museum of American Armor
Baxter Pond
Courthouse Commons Pump Station
Massapequa Creek Preserve
Garvies Point
Morrelly Homeland Security
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Odor and Corrosion Problems: Two Related Issues Requiring Separate Control Strategies

by Randy Nixon

This article was based on an article previously published in the Journal of Protective Coatings & Linings (Nixon 2010).

Odor control systems are critical to handling and treating foul air in wastewater collection systems and treatment plants. However, odor control systems do not stop corrosion related to biogenic sulfide formation of sulfuric acid as many consultants would have you believe. Conversely if you have an odor problem, you also typically have a corrosion problem, and each problem requires separate control strategies.

The objective of this article is to explain why odor control ventilation does not mitigate biogenic sulfide corrosion in wastewater treatment plants or pump stations and to explain why corrosion protection is required despite the use of odor control ventilation. In fact, as this text will illustrate, odor control ventilation merely *reduces* the severity of corrosion related to the bacterial metabolism and oxidation of hydrogen sulfide (H_2S) to form sulfuric acid that damages wastewater system infrastructure. Examples will be given within this article to support these findings.

Odor Control Ventilation and Headspace Corrosion

Despite odor control ventilation, H_2S gas will continue to be released into the headspace atmosphere unless some form of chemical treatment is applied upstream to reduce sulfides in the wastewater.

Odor control systems generally pull the air from the enclosed headspaces of sewers, tanks and other structures away to one of the many types of odor treatment technologies. These treatment technologies include activated carbon adsorbers, biofilters, fine-mist wet scrubbers, packed-tower wet scrubbers and thermal oxidizers, just to name a few. There is no doubt that collecting this foul air for treatment is an essential control strategy.

By collecting the foul air and pulling it away, the concentration of H_2S gas in the headspace atmosphere can be reduced. Fresh air is brought into the headspace to account for multiple air changes per hour so that a negative pressure environment is maintained within the headspace. And while this air movement process does lower the H_2S gas levels within the headspaces of tanks, wet wells and channels, the H_2S gas is still pulled across concrete, fiberglass-reinforced plastic (FRP), and metal surfaces upon which condensation of water is generally constant. As such, the gas is dissolved or absorbed into the layers or sheets of moisture on these surfaces where sulfur oxidizing bacteria reside. Therefore, acid formation still occurs, and corrosion continues, albeit at a lesser degree.

The design of airflow patterns for odor control systems is quite involved. Care is taken to sweep the air over all the water surfaces, with greater flow over areas where wastewater turbulence occurs. Also, the design process focuses on preventing dead spots within the headspaces where air changes are obstructed or slowed due to the geometry of the structure. In doing this, an ample supply of oxygen passes over the surfaces where the sulfur oxidizing bacteria have colonized. Remember that these bacteria, mostly of the genus *Thiobacillus*, are aerobic and are healthier in an oxygen-rich environment. If the number of air changes provided does not remove the gaseous H_2S nearly as quickly as it comes out of solution, the amount of H_2S gas absorbed into the wetted surfaces will increase, as will the formation of the sulfuric acid responsible for corrosion. If dead spaces are allowed to exist, more rapid corrosion rates will occur at those locations where the higher H_2S gas levels remain for longer periods of time.

There is a further salient corrosion consideration related to the use of odor control systems. The construction materials for these systems are also subjected to biogenic sulfide corrosion. Ductwork, fans, dampers, and treatment equipment routinely degrade due to acidic exposure and associated corrosion and, as such, are typically constructed using FRP, stainless steel or other corrosion-resistant materials. These odor control components should not be constructed from unprotected concrete or carbon steel because the corrosion rates are likely to be too high. Therefore, it is prudent to protect the concrete and metallic substrates found in the headspaces of the wet wells, tanks, and channels at treatment plants or pump stations. These surfaces behave as an extension of the air collection and conveyance components (the ductwork, if you will) of the odor control system. The fact is that these surfaces are equally susceptible to biogenic sulfide corrosion. Hence, these surfaces must be properly coated or lined, or else rapid deterioration can occur.

The fact that the ductwork and headspace structures are prone to corrosion emphasizes the importance of proper material selection for FRP components as well. For FRP ductwork and odor control equipment, the right resin must be used. Refer to ***Photograph 1***, which shows FRP degradation in odor control ductwork where the resin used was not chemically resistant to the exposure conditions.

Photograph 1. In this case, a less expensive polyester resin was used by mistake in a part of ductwork fabricated for odor control in a wastewater treatment plant. The resin was attacked by sulfuric acid and the FRP laminate failed. *Randy Nixon*

H_2S Gas and the Dynamic Chemical Equilibrium

Hydrogen sulfide generation in wastewater is mostly controlled by a chemical equilibrium where first the sulfide ion ($S^=$) is produced and introduced into the liquid wastewater from the anaerobic slime layer. The sulfide ion reacts with hydrogen in

continued on page 24

continued from page 23

the wastewater to form bisulfide or hydrosulfide (HS^-), which in turn further reacts with hydrogen to form dissolved H_2S. At areas of turbulence, the dissolved H_2S is released as gas into the headspaces of tanks or structures. As this occurs, more bisulfide ions are transformed into more dissolved H_2S to replace the molecules that are lost to the headspace. More sulfide ions then react with hydrogen in the wastewater to form more bisulfide ions to replace those lost to form dissolved H_2S.

Through this dynamic equilibrium, the quantitative relationship between the four species of sulfides ($S^=$, HS^-, dissolved H_2S and gaseous H_2S) is mainly controlled by the pH of the wastewater. The sulfide ion does not exist at a pH much below 12.0. So, we know that once released into the wastewater at near neutral pH, the dominant species will be bisulfide. At the normal pH of municipal wastewater (6.8 to 7.2), this means that in a 50/50 proportional relationship, nearly half of the sulfide present will be bisulfide ions while the other half will exist as dissolved H_2S. And since *the concentration of dissolved gases tends to be directly proportional to the partial pressure of the same gas above the liquid surface* (to paraphrase Henry's Law), the dissolved H_2S can be released to exist in its free gas form.

The concentration of dissolved H_2S gas in solution is controlled by the specific Henry's Law constant for H_2S. When subjected to turbulence, the wastewater releases the dissolved gas as free H_2S, and more bisulfide ions are transformed into the dissolved H_2S form to replace the H_2S lost to the headspace.

In the aerated headspaces, the gaseous H_2S is absorbed into condensation on sewer system surfaces. Naturally occurring sulfur-oxidizing bacteria, mainly *Thiobacillus*, populate this environment. These bacteria metabolically oxidize the H_2S to form sulfuric acid through a series of chemical reactions. The sulfuric acid formed attacks alkaline concrete and metal surfaces resulting in aggressive corrosion damage.

Ideal Conditions for Mitigating Biogenic Sulfide Corrosion

So how do we create the ideal conditions to mitigate biogenic sulfide corrosion? Studies by the County Sanitation Districts of Los Angeles and others have shown that biogenic sulfide corrosion does not occur when H_2S gas concentrations are less than 2 parts per million by volume (ppmv) because the growth of sulfur-oxidizing bacteria is not possible. These studies were based on laboratory work. It would also be nearly impossible for biogenic sulfide corrosion to occur if headspace surfaces were completely dry. If no moisture from condensation was present, then H_2S gas could not be absorbed and be made available to the bacteria.

So, to mitigate corrosion by odor control ventilation, the H_2S gas concentrations would have to be kept below 2 ppmv and/or the headspace surfaces would have to be kept dry. Such ideal conditions cannot possibly be created in wastewater treatment plant or collection system tanks or structures.

The differences in temperature between the concrete structures and the liquid wastewater generally produce the condensation of moisture in the headspaces of these environments. Additionally, odor control ventilation exacerbates this situation by introducing air that is either warmer or cooler than the wastewater or the concrete surfaces depending on the time of year. Keeping such headspaces completely dry using dehumidification equipment is simply not an economical alternative.

Creating conditions in the wastewater collection system to ensure that H_2S gas concentrations remain below 2 ppmv is also both impractical and not economical. The National Fire Protection Association recommends that a minimum of 12 air changes per hour be provided at a minimum negative pressure of 0.1 inch of water column to maintain H_2S gas concentrations below 10 ppmv. This is a typical air change rate used for odor control systems in wastewater treatment plants. Even air change rates up to 20 air changes per hour are not typically able to reduce H_2S concentrations much below 10 ppmv.

The costs associated with reducing H_2S gas levels to below 2 ppmv or maintaining dry headspace surfaces would be prohibitively high. Much larger motors, fans and ductwork would be necessary to achieve such high-volume air flow requirements. And such equipment costs would be much higher than the costs for proven linings for corrosion protection of the headspaces.

Real World Experience

Inspections of wastewater treatment plant covered tanks with operating odor control systems consistently show corrosion losses

continued on page 27

Photograph 2. Primary clarifier headspace with odor control. Deterioration of coatings and concrete after six months of service exposure. *Randy Nixon*

Photograph 3. Pump station wet well headspace with the beginning exposure of rebars with operable odor control. *Randy Nixon*


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continued from page 24

and active (ongoing) corrosion of concrete and metallic substrates. ***Photographs 2, 3*** and ***4*** show headspace concrete corrosion problems in treatment plant and pump station wet wells where odor control ventilation has operated routinely for several years. By contrast, ***Photograph 5*** shows corrosion damage that has developed in a structure's headspace where an odor control air flow system did not operate properly for several years.

The fact that the ductwork and headspace structures are prone to corrosion emphasizes the importance of proper material selection for FRP components as well. For FRP ductwork and odor control equipment, the right resin must be used. ***Photograph 1*** shows FRP degradation in odor control ductwork where the resin used was not chemically resistant to the exposure conditions.

Photograph 4. Pump station wet well headspace with visible surface corrosion with operable odor control. *Randy Nixon*

Photograph 5. Grit tank headspace with advanced corrosion with non-operational odor control system. *Randy Nixon*

Summary

Odor control systems do not magically make H_2S gas disappear in the headspaces of wastewater tanks and structures. Rather, odor control ventilation systems pull foul air over headspace surfaces that are wet and inhabited by sulfur oxidizing bacteria. Additionally, fresh air supply to these headspaces brings an ample supply of oxygen to the aerobic bacteria ensuring their health and proliferating sulfuric acid driven corrosion. Furthermore, dead spaces in the air flow patterns have been shown to create zones of higher corrosion rates in headspaces with operating odor control systems.

The ductwork and the other air handling and treatment equipment used for odor control systems suffer from biogenic sulfide corrosion when not constructed from sufficiently corrosion-resistant materials. The headspaces of such tanks and structures are part of the odor control air collection system. Hence, concrete and many metal surfaces in these headspaces must also be protected from corrosion. For FRP ductwork and equipment, the right resin and laminate design must be used. The Fiberglass Reinforced Plastic Institute (FRPI) provides specifications for the appropriate laminate designs for odor control ductwork and equipment.

Because there is a chemical equilibrium that occurs for the sulfide species in these wastewater environments, the free H_2S gas removed by ventilation will invariably be replaced by more gaseous H_2S. And the gaseous H_2S gas will, in turn, be replaced by the conversion of bisulfide (HS^-) to more dissolved H_2S. This means that despite ventilation, H_2S gas will continue to be released into the headspace atmospheres and pulled across the surfaces upon which it will be absorbed by moisture. Here, it will be transformed by the ever-present sulfur oxidizing bacteria to sulfuric acid.

To mitigate biogenic sulfide corrosion, two conditions would need to happen. First, the H_2S gas concentrations would have to be below 2 ppmv. Secondly, the surfaces over which the headspace air was pulled would have to be dry. Neither of these conditions realistically occurs in the subject headspaces. And when and if these two conditions exist, it would be an extremely short-lived event. Making these conditions happen through more air changes or via better air sweeping are neither pragmatic nor economical.

So, the end result is consistent with what we see in real world field applications. Ventilation associated with odor control cannot mitigate corrosion related to biogenic sulfide production of sulfuric acid. Rather, it simply reduces the severity of sulfide corrosion to our infrastructure.

Therefore, corrosion protection is required for headspace substrates despite the presence of odor control air treatment systems. Proper selection of corrosion resistant materials for odor control exposed surfaces is essential. In short, corrosion and odor are inextricably related issues that require separate control measures.

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WHEN IT COMES TO MAKING YOUR
WATER BETTER, WE NEVER SLEEP.

Getting the Best Value Out of Your Fiberglass Equipment

by Gary L. Arthur

Fiberglass-reinforced plastic (FRP) is a great material of construction. It is strong, lightweight, chemical resistant, customizable, readily available, and very cost competitive with alternative materials.

One of FRP's most outstanding features for the odor marketplace is its ability to minimize corrosion despite the extremely harsh environments characterized by the wastewater, biosolids, and chemicals used to control the odors. Accordingly, it is often the material of choice for odor control technology vessels, ductwork, stacks, covers, chemical storage tanks, etc.

Simply boasting about the material though does little to help with getting the best value out of your fiberglass equipment in the wastewater and water treatment industry. The truth of the matter, technologically speaking, is that FRP is essentially stuck in the 1970s to 1980s. The product an owner needs and believes they are paying for is too often not the FRP manufactured product that is delivered.

Understanding the FRP Market

FRP equipment prices based on nearly half-century old practices have proven to be as much as 130% lower than prices based on advanced approaches to operating modern day reliable equipment. Technology-driven FRP manufacturers have tried to advance design, engineering, laminating, and secondary bonding practices in the municipal industry. Most have been defeated when attempting to pass through higher value/cost and exited this market due to the low bid price pressure, payment retainage, contract abuse, plus off-spec equipment delivered by others.

FRP is a complicated material that generally has been very challenging for inquisitive specifying engineers and owners to master. Valuable lessons learned are routinely forgotten by specifiers due to infrequency of FRP project involvement and large FRP equipment needs as well as retirements of experienced professionals. In today's decentralized and remote specifier workplace, corporate authority over master specifications and quality assurance has given way to cost reduction. This has further fueled FRP specification development and administration challenges from design through construction.

Overall, the specifying community has inadvertently stymied advancement of FRP and too many owners are living with the ongoing cost of premature failure. Those that have lived through failure, or know others who have, understand this dilemma and pursue modern day remedies. They are the minority though, where most are not aware of premature failure let alone the underlying causes and tend to fall victim to putting themselves at risk. These circumstances, combined with forgotten lessons learned, are what continues to seed the cycle that keeps FRP stuck in the 1970s to 1980s and owners at risk.

Bringing FRP to the 21st Century

The time has come for specifying engineers to break the stalled FRP technology cycle, move FRP well into the 21st century and help owners get the best value out of their fiberglass equipment. It is long overdue. Reliability in 2022 and going forward has a whole new meaning in the wake of the COVID-19 pandemic. Trust, fact-checking, and caution have moved front and center in our minds. FRP manufacturing company advertising claims such as "Industry Leader," "Expert" and "Quality" merit a deeper level of vetting now more than ever before.

To help with getting the best value out of your fiberglass equipment, we are going to share a few discussions around results from decades of research and audit findings that will establish the foundation for FRP technology change. Data supporting findings to be presented were gathered from across the United States. It entails hundreds of FRP equipment failure situations, current standards stories, a few manufacturer databases, dozens of engineering firm master specification libraries, and tens of millions of dollars in FRP equipment submittal audits.

The facts to be presented will validate the vulnerability of FRP process equipment mechanical reliability and provide practical guidance for related risk mitigation. The extent of work to be shared includes quantifying premature failure, assessing industry standards scope, investigating supply side issues plus reviewing specification effectiveness. Conclusions to be presented will summarize lessons learned and provide guidance to help move FRP technology well into the 21st century.

Premature Failure

Premature failure is defined as any event causing unexpected cost associated with in-operation FRP process equipment, such as odor control vessels, round and rectangular ductwork, covers, exhaust stacks and aboveground chemical storage tanks. To better understand premature failure, a look at the nature of fiberglass equipment and fiberglass equipment failure studies will provide a good starting point for specifiers.

The Nature of Fiberglass Equipment

Fiberglass equipment design and manufacturing are complicated. As depicted in the background photo of ***Illustration 1***, a fiberglass laminate is made up of several plies of glass reinforcement. The type and number of plies are determined through engineering work for each equipment component. This illustration shows a cross-section of the laminate, where total structural cross-section is made up of the inner corrosion barrier, structural layer and outer corrosion barrier. These laminate sections are further subdivided into the inner surface, interior layer, structural layer, exterior layer

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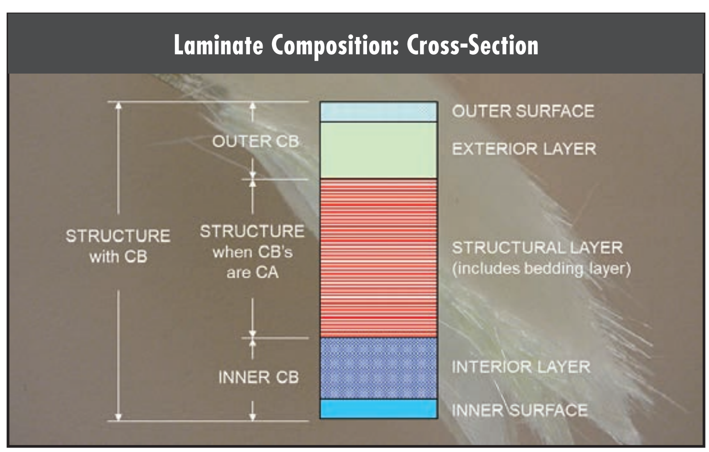


Illustration 1. Laminate composition cross-section. *FRPI*

continued from page 29

and outer surface. These layers are manually laminated one ply at a time, with cylindrical shapes typically spiral wound during the laminating process.

Fiberglass equipment fabrication is laborious. The components that make up a piece of equipment, once laminated, are demolded, trimmed, ground, drilled, fit up, secondary bonded (or welded, if you will), accessorized and finally resin finish coated. A ton of skilled labor hours goes into laminating and fabricating. As a result of being laborious, equipment quality varies directly with hired skill level variation day-to-day, month-to-month and year-to-year. Since a high level of retained skill can cost up to 50% more than entry level, skill plus labor cost is a remarkable portion of total cost. Meeting excellent specifications to achieve best value does cost significantly more.

Fiberglass equipment is not a catalog commodity like pumps, valves, pressure gauges, calibration cylinders and other related process equipment. A lot of design, engineering and specification writing is required for bid documents. It takes a FRP subject matter expert to adapt existing master specifications to a project, correct specification issues or effectively write them from scratch.

The complicated and laborious nature of equipment manufacturing combined with a wide range of specification effectiveness results in FRP equipment market price instability. The graph in ***Figure 1*** shows seven levels of specification effectiveness on the X-axis from "F" (poor effectiveness) to "A" (excellent effectiveness). On the Y-axis is the price, which ranges from $43,000 to $97,000 for a typical 12-foot diameter sodium hypochlorite tank at different levels of specification effectiveness. Price instability, resulting in bid value/cost spread illustrated by the red line, ranges up to 130% due to the market being flooded with a wide range of specification effectiveness.

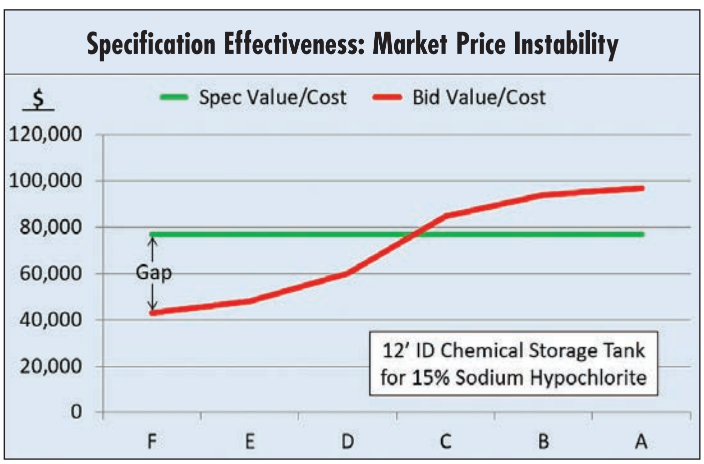


Figure 1. Specification effectiveness and market price instability, where the X-axis ranges from "F" (poor specification effectiveness) to "A" (excellent specification effectiveness). The wide range of specification effectiveness in the market results in price instability (the gap between Bid Value/Cost and Spec Value/Cost) of up to 130%. *FRPI*

Fiberglass Equipment Failure Studies

The only published FRP industry study on types and causes of premature failure in the past few decades quantifies hundreds of cases *(Arthur 1991)* and still helps define root cause for equipment reliability risk resulting from specification ineffectiveness to this day. ***Figure 2*** shows findings for 754 cases for types of failure, where 62% of types are fiberglass laminating related. ***Figure 3*** shows findings for 865 cases for causes of failure, where 73% of causes are manufacturer related.

Failure study findings are exemplified by the following case histories.

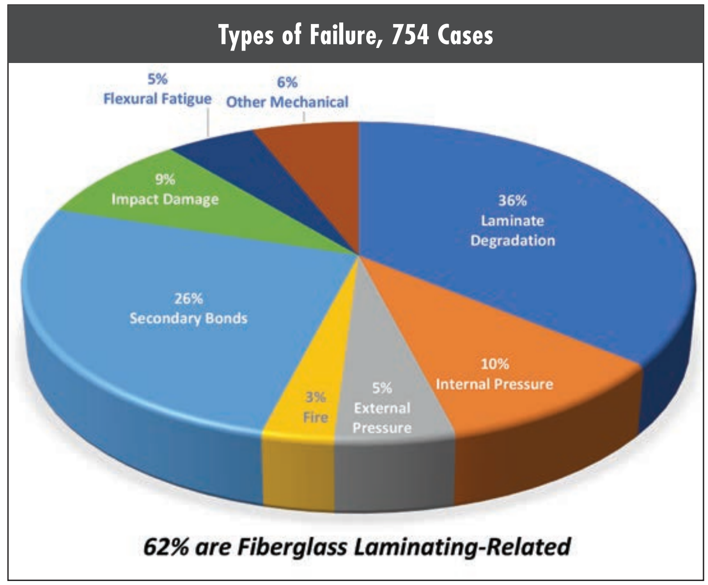


Figure 2. Premature fiberglass equipment failure by type of failure. A published fiberglass industry study *(Arthur 1991)* found that most failures were due to errors in fiberglass laminating. *Gary Arthur*

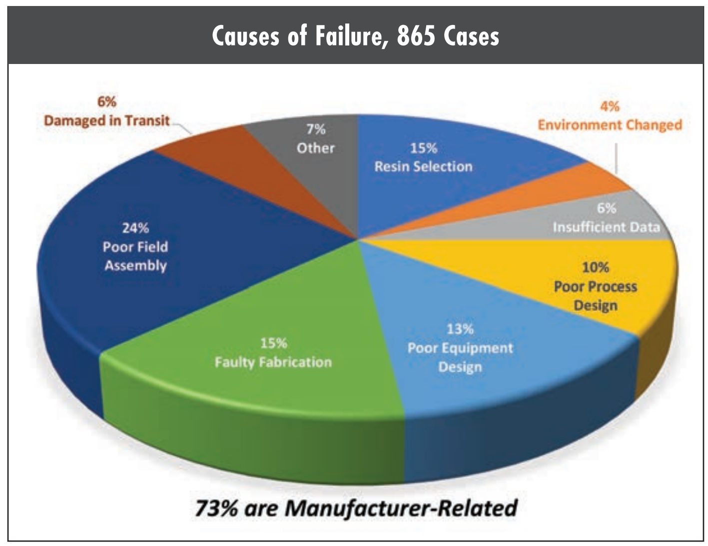


Figure 3. Premature fiberglass equipment failure by causes of failure. The fiberglass industry study *(Arthur 1991)* found that most failures resulted from manufacturing-related issues. *Gary Arthur*

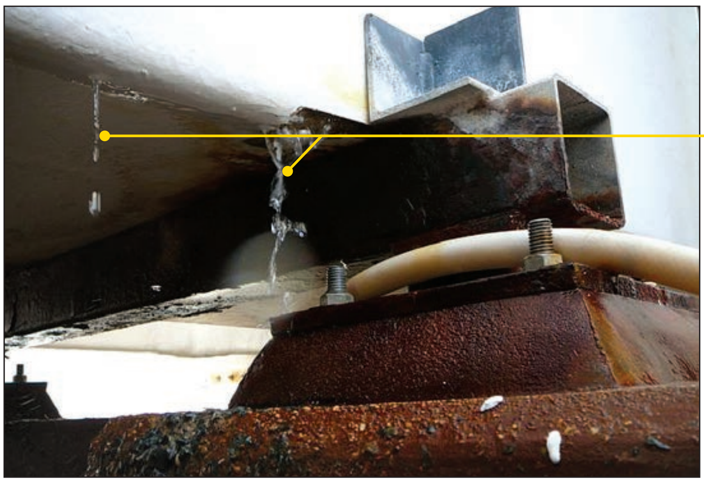
Photographs 1 and ***2*** show a carbon absorber operating at 10 pounds per square inch that failed catastrophically within five days of startup, where the anchor system failed, and bottom blew out. ***Photographs 3*** and ***4*** show a repaired vertical scrubber duct section that was improperly supported, cracked, and continuously leaked hazardous corrosive condensate beginning 12 years after startup. ***Photographs 5*** and ***6*** show a pair of sodium hypochlorite tanks that were replaced after seven years of service due to excessive FRP deterioration and through-wall leakage. A 20- to 30-year, maintenance-free equipment life was presumably expected and should have been realized for each of these case histories.

Costs and Risks

Let us now look at estimated cost and risk of premature failure. According to the most current American Composites Manufacturers Association (ACMA) report on fiberglass market segment performance *(ACMA 2011)*, the total fiberglass industry market is composed of the electrical, consumer, aircraft, marine, transportation, construction and corrosion market segments. The

Photograph 1. A carbon absorber failed catastrophically within five days of startup, when the anchor system failed, and bottom blew out. *Gary Arthur*

Photograph 2. Close-up of the blown-out carbon absorber. *Gary Arthur*



Photograph 4. Close-up of the cracked, leaking area of the vertical scrubber duct section. *Gary Arthur*

corrosion segment covers fiberglass process equipment, which accounts for 22% of the market. This equates to $5.1 billion in corrosion equipment purchased in 2016, a $3.86 billion average in purchases per year over the past 30 years and a $115.8 billion installation base that gets to a premature failure cost of $357 million per year or 7% of purchases.

Let us now compare the top 10 insurance claims for small business reported a few years back *(Insurance Journal West Magazine 2015)* to FRP equipment premature failure risk of 7%. Interestingly, FRP is as much of a risk exposure as other perils, such as burglary or vehicle accidents ***(Figure 4)***, which we all know well and for which we are usually insured.

Top 10 Insurance Risks

- Burglary and Theft (20%)
- Water and Freezing (15%)
- Wind and Hail Damage (15%)
- Fire (10%)
- Customer Slip and Fall (10%)
- Vehicle Accident (<5%)
- Product Liability (<5%)
- Struck by Object (<5%)
- Reputational Harm (<5%)
- Customer Injury and Damage (<5%)

Figure 4. Top 10 Most Common Property and Liability Claims, as published in April 2015. *Insurance Journal West Magazine*

Photograph 3. A repaired vertical scrubber duct section that was improperly supported, cracked and leaked hazardous corrosive condensate. *Gary Arthur*

Industry Standards Scope

Committees of ASTM International (ASTM) and the American Society of Mechanical Engineers (ASME) promulgate FRP industry standards covering tanks, vessels, ductwork, flanges and materials of construction. While they are very good for content published,

continued on page 33

Clear Waters Winter 2021 31

continued from page 31

Photograph 5. Pair of sodium hypochlorite tanks that were replaced after seven years of service due to excessive FRP deterioration and through-wall leakage. *Gary Arthur*

these standards are significantly lacking on their own merit. They have incomplete design scope; multiple decisions are required with no guidance and important details are missing for a complete design specification. They do not include other common structures such as grease filters, exhaust stacks and cover applications plus are deficient for odor and air pollution control systems.

The FRP industry's very first voluntary product standard – PS 15-69 published by the U.S. Department of Commerce National Bureau of Standards – and a Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) construction manual published by the sheet metal industry are other standards often referenced by specifiers. PS 15-69 was published in 1969, never updated, delisted in 1996, superseded by ASTM standards and had a less conservative design than ASTM and ASME. Yet it is still specified, and manufacturers continue to claim they build in accordance with it. On the other hand, the SMACNA manual some also claim compliance with conflicts with ASTM and ASME, compromises safety factors, is less conservative plus has a narrow and shallow industry review. Other ASTM pipe standards are also misapplied when specifying tank and vessel internal piping plus ductwork.

Supply Side Issues

Out there in the sea of fiberglass equipment supply lies a convoluted chain of vertical and horizontal integration. As one can see in ***Illustration 2*** for example, a general contractor has three options to buy an odor control system:

1. From a system supplier Type A, who does turnkey design/build systems.
2. From a system supplier Type B, who does process design only.
3. From mechanical or HVAC contractor that pieces together their own system or provides purchased ductwork only.

Then the Type A supplier can either manufacture inhouse or outsource manufacturing, while the Type B supplier and mechanical or HVAC subcontractor outsources manufacturing. Then the FRP inhouse or outsourced manufacturer may use an inhouse or outsourced professional engineering service who often relies on

Photo 6. Close-up of FRP deterioration on one of the sodium hypochlorite tanks. *Gary Arthur*

outsourced pipe stress or finite elemental analysis when required.

About 80% of the time there are four suppliers involved in delivering fiberglass odor control equipment to the owner. This convoluted chain of supply creates remarkable risk for specifiers and owners to receive reliable FRP equipment. It is a significant underlying root cause of off-spec equipment and premature failure. Reliability risk includes but is not limited to control of FRP supplier expertise and capabilities, professional engineer scope of engineering performed, limited drawing disclosure for specification compliance auditing, manufacturing and quality control, technical and commercial tactical cost maneuvering plus cracks and loopholes throughout the entire procurement process.

Another discovery in the convoluted chain of supply that was uncovered during Fiberglass Reinforced Plastics Institute (FRPI) auditing is manufacturer's licensed professional engineer (PE) ethics and stamp risk. As the licensed community of engineers know, their oath of ethics requires them to only practice in an area of demonstrated expertise, have and exercise responsible charge over their work and not to apply their stamp where such has not occurred. With nearly all specifications requiring a FRP PE stamp in the state where equipment will be installed, manufacturers need to outsource licensed engineering on most if not all projects. The risk in this is many engineers hired may have over five years of experience, but their depth and breadth of experience over those years may have been very minimal. This limited experience leaves them ill equipped to provide a thorough, accurate design report, especially at a level of pipe stress or finite elemental analysis when required.

Beyond manufacturer's outsourced PE expertise though, the biggest issue with outsourcing the FRP PE is equipment selling price pressure. This causes the manufacturer to limit their outsourced PE's scope and responsible charge over work to a bare minimum for equipment approval. Cases of simply plan-stamping without PE design and responsible charge were also uncovered during FRPI auditing.

Specification Effectiveness

Informal engineering firm specification audits have been conducted for dozens of regional and national engineering firms over the past 30 years. This support evolved into formal engineering firm risk audits based on a 21-point score card as shown in ***Figure 5***.

continued on page 34

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The Sea of Supply: A Convoluted Chain

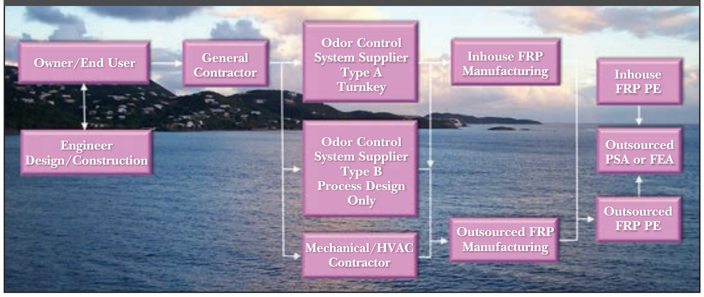

Illustration 2. In the sea of fiberglass equipment supply lies a convoluted chain of vertical and horizontal integration. *FRPI*

These points follow Construction Standards Institute specification formatted subjects. A series of 106 questions centered around the 21-point card were raised to arrive at a risk score. Scores from 1 to 5 were determined given answers to questions raised for each of the points, where 1 is low risk and 5 high. The benchmark for scoring was FRPI master specifications developed by a balanced team of industry experts.

As you can see on the card bottom in ***Figure 5***, this firm's specification scored a 4.2, representing high risk of premature failure. This score is typical of most, if not all, specifications audited. The top 10 general audit findings include improper use of industry standards, unsatisfactory audit trail established, poor manufacturer and PE prequalification, incomplete product and laminate design, deficient fabrication details, inadequate use of sample submittals, limited quality verification, insufficient installation guidelines, ineffective use of third-party subject matter expert and/or certification programs plus errors, omissions and conflicts.

FRPI auditing has shown specification effectiveness is usually poor for FRP equipment, establishes a very low industry price floor and puts equipment at risk. The graph in ***Figure 1*** shows the FRP equipment market price instability findings presented earlier, where "F" (poor effectiveness of specifications) and a price floor of $43,000 are represented by the red line. The green line on the graph represents the price ceiling during bid time, with improved reliability afforded by a specification approaching the value of "C" at a cost of $78,000. The value/cost gap to police from floor to ceiling is now 80%. With this size gap, audit findings show that one in three to three in five bids are off spec, and this equates to a 30 to 60% risk exposure for specifiers to uncover during submittal review. Findings also show this value/cost gap creates too great of a technical challenge for non-FRP subject matter experts to specify and police effectively, especially within the timeline of construction schedules.

Conclusions

The research and audit results presented validate the vulnerability of fiberglass equipment reliability. Industry standards are lacking, supply side convolution is challenging, specifications are generally poor and resulting premature failure is reality. Dozens of reliability risk issues presented exist throughout the project lifecycle. From drawings and specs developed during design, through construction including submittal approval, manufacturing and installation. Together these issues necessitate moving away from poor, performance-oriented specification language that leaves reliability to chance covered by a limited manufacturer warranty, and compels moving toward comprehensive, prescriptive specification language supported by a specific process that assures compliance with stringent requirements and reliability.

Specification Effectiveness: Engineering Firm Risk Audit

CONTENT	RISK SCORE
SPECIFICATION Scope:	**4.2**
Notes to specifier	4
Tank Configuration Range	5
Wastewater and Drinking Water	4
Number of Chemical Services	5
Non-Fire Retardant and Fire Retardant	3
PART 1 General:	**4.1**
Reference Standards	4
Definitions	4
Submittals	3
Quality Assurance	4
Delivery, Storage and Handling	5
Sequencing	5
Warranty	5
Tolerances	2
Manufacturers Representative	5
PART 2 Products:	**3.8**
Fiberglass Tanks	4
Laminate Materials	4
Accessories	4
Manufacturer's Quality Control	3
PART 3 Execution:	**4.7**
Installation	4
Inspection and Testing	5
Cleaning	5
RISK RATING	**4.2**

Figure 5. Engineering firm specification risk audit 21-point score card. *FRPI*

The final objective of this research and audit findings story is to provide practical guidance for reliability risk mitigation, so best value can be consistently obtained. The place to start is to write a new great prescriptive specification, rolling in lessons learned. As we know, standards, an audit trail, pre-vetted suppliers, design, fabrication details, sampling, quality control, installation, third party certification programs plus error, omission and conflict free specifications are hot topics. Be sure to budget for and engage a FRP subject matter expert in specification development, as opposed to salespeople, starting with the specification in design and keep the expert engaged through construction. Engaging a FRP expert is not a matter of if, but rather when and where. A third-party FRP equipment reliability risk assessment is a good place to start.

There are three FRP subject matter expert selection options to choose between or that can be leveraged simultaneously during stages of the project lifecycle:

1. Hire an inhouse expert.
2. Contract a third-party specialty FRP consultant.
3. Specify industry standard certification programs.

If contracting a consultant, be sure they are not otherwise hired by the contractor or manufacturer, have no manufacturer and PE conflict of interest, are vetted to specific expertise criteria, have a complete detailed scope of work plus mandatorily perform the scope they have been contracted for. Engaging industry certification programs assures a bona fide auditing process is in place. There are five certification programs to choose from, where four are industrial consumer protection agencies and one is a standards organization. Each serves a different purpose and has from one to nine listed suppliers prequalified. They include Underwriters Laboratories, Factory Mutual, Air Movement and Control Association, FRPI and ASME.

FRP is a highly specialized engineering material that requires special attention to assure getting the best value out of your fiberglass equipment. When this value is achieved, lowest owning and operating lifecycle cost is realized.

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Fiberglass Reinforced Plastics Institute, Inc.

The FRPI is a nonprofit group that was founded in 2003 by a group of wastewater and water treatment industry owners, engineers, FRP manufacturers and FRP consultants to address the issues plus opportunities validated by research and audit findings presented in this article. The Institute's SP9000 Manufacturer Certification industry standard, coupled with the SP9100 Equipment Certification standard, were developed by this group to cover risks from specification development in design through equipment installation during construction. These certification programs also include submittal, manufacturing, and installation auditing on a project-by-project basis. Under federal guidelines, FRPI is a Professional Trade Certification Organization that holds U.S. Patent and Trademark Office registered certification marks governing its auditing practices.

Properly specifying Fiberglass Institute SP9000 and SP9100 standards is like obtaining insurance coverage required for other perils. These standards provide protection against risk of premature failure by setting the value/cost price ceiling higher for expected reliability while policing the resulting gap for specifiers. They also enable great FRP equipment manufacturers to compete on a level playing field and get fairly paid to deliver the design life specifiers expect.

Odor Control Starts with Odor Sampling

by Ryan McKenna

Odors associated with wastewater are considered objectionable, and odor mitigation is important for all phases of wastewater collection, treatment, and the transport and disposal of biosolids and other residuals. This article discusses the types of odors and odorous compounds that can be formed, and methods for sampling, including liquid-phase and vapor-phase techniques, as well as advancements in sensor technology.

You may ask why we would sample liquid-based compounds when our focus is odor or vapor phase. The answer is that it is important to understand the liquid-based concentrations to assess the potential of the liquid/wastewater to strip out odors, as well as to recognize possible control scenarios starting with reducing surface turbulence to minimize odor stripping and/or adding chemicals to reduce odorous compounds in solution.

Sample Methods

Sampling typically begins with a walk-through of the area of interest to survey potential odor sources. Based on the results of the odor survey, as well as collection and analysis of relevant background data and information, a sampling plan is developed to provide the proposed framework for field sampling efforts related to both liquid-phase and vapor-phase data collection. The sampling plan includes:

- Sampling locations
- Type of samples and data to be collected
- Sampling equipment required
- Sampling frequency and duration
- Sampling timing

Data gathered as part of sampling activities are used to assess the liquid- and vapor-phase conditions leading to the potential generation and release of odors from wastewater collection, treatment and disposal. The data are used to develop recommendations in an effort to mitigate the potential for off-site odor impacts to the surrounding community.

Liquid-Phase Data Collection

Wastewater characteristics provide information on the potential for the generation of sulfides from the anaerobic transformation of sulfate. Liquid-phase samples also provide information on the concentration of sulfides present in the wastewater, the speciation, and the potential for release into the vapor phase.

Liquid-phase grab samples are often collected to measure dissolved/total sulfide concentrations, dissolved oxygen (DO), pH, temperature and oxidation-reduction potential (ORP). ORP, for example, is a measurement of the wastewater conditions present and the potential for various biological reactions. Sulfide formation in wastewater occurs when the ORP is between -50 to -250 millivolts (mV) *(WEF 2020)*.

Total and dissolved sulfides can typically be measured with various field kits available in the marketplace today. The LaMotte sulfides test kit ***(Figure 1)***, for example, uses the methylene blue method as described in Standard Methods for the Examination of Water and Wastewater *(APHA, AWWA* and *WEF 2017),* while the other liquid-phase parameters are typically measured with handheld water quality probes.

Figure 1. LaMotte sulfides test kit, which uses the methylene blue method as described in Standard Methods for the Examination of Water and Wastewater. *Courtesy of LaMotte Company*

Vapor-Phase Data Collection

For vapor-phase sampling, data for the following parameters are often collected:

- Continuous hydrogen sulfide (H_2S) monitoring
- Instantaneous H_2S sampling
- Sensory sampling
- Sulfur speciation sampling
- Ammonia and amines sampling
- Pressure monitoring
- Airflow measurement

Continuous H_2S Monitoring

Hydrogen sulfide is the most common odorous compound in wastewater collection and treatment systems. Its characteristics are well known, and concentrations of H_2S in air are easily measured using portable instruments. H_2S is generated from the biological reduction of sulfate (SO_4^{2-}) or thiosulfate under anaerobic conditions *(WEF 2020)*.

OdaLogs and Acrulogs are common examples of intrinsically safe, portable, battery-powered devices that are used to measure and record H_2S levels over a continuous period of time. The detection range of H_2S depends on the model of the unit utilized. The units are usually hung in or near certain H_2S area sources for accurate monitoring of process areas.

For point source locations where negative pressures or high-humidity conditions are present, such as the inlet duct of an existing odor control system (upstream of the fan). The unit is often housed in a sampling system enclosure, whereby tubing transfers the foul air from a duct tap through a moisture trap on the outside of the enclosure to the OdaLog/Acrulog unit, by way of an air pump located within the enclosure.

Instantaneous H_2S Sampling

For instantaneous H_2S sampling, devices such as the Jerome 631-X Hydrogen Sulfide Analyzer or the PortaSens II can be used.

The Jerome 631-X is a hand-held ambient air analyzer with an H_2S range of 0.003 parts per million by volume (ppmv) to 50 ppmv. The device operates by use of a thin gold film, which in the presence of H_2S undergoes an increase in electrical resistance proportional to the mass of H_2S in the sample that plates out on the gold film. The standard units display instantaneous measurements that can be recorded by the user. Data loggers can also be purchased or rented as an optional accessory to the unit. The data loggers record and store H_2S values that can be downloaded onto a computer for storage and analysis.

The PortaSens II is a hand-held device used to detect H_2S, toxic gases, or oxygen levels by attaching the desired gas sensor module. The device utilizes a battery powered intake pump with a flexible wand for sampling *(Analytical Technology, Inc. 2014)*. Readings and settings are displayed on a backlit graphics LCD, which may be recorded and/or transferred to a computer.

Portable personal gas devices used for monitoring atmospheric hazards often contain an H_2S sensor. These monitors are generally operated to measure ambient instantaneous gas concentrations but can also be equipped with a sample pump and data logger. The available range, resolution and accuracy of personal gas monitor sensors are typically less than equipment designed specifically for testing purposes. It is important to consider how the collected data will be used, anticipated concentrations, and regulatory enforcement standards when selecting an H_2S sampling device.

Sensory Sampling

Odor sensory samples are collected in individual 10-liter inert Tedlar plastic bags and shipped overnight to an odor laboratory where the odor samples are analyzed within the required 24-hour holding period. A trained odor panel uses the "dynamic dilution, triangular, forced-choice test" following ASTM International (ASTM) method E679-04 *(2011)* and method EN 13725 *(British Standards Institution 2003)*. Sensory samples can be collected for both point and area sources to determine threshold dilution levels as well as odor intensity, characterization and persistency ***(Table 1)***.

Table 1. Definitions of Sensory Odor Metrics.

Metric	Definition
Odor Detection Threshold (D/T) and Odor Recognition Threshold (R/T) dilution levels	The number of times an odor sample is diluted with odor-free air before the average person does not detect/recognize that an odor exists.
Odor intensity	The perceived strength of an odor (e.g., strong, moderate, weak, faint).
Odor characterization	Describes the odor perceived using descriptors (e.g., rotten egg, chemical, musty).
Odor persistency	The ability of the odor to maintain its intensity as it is diluted (e.g., skunk odor).

For the area sources, an isolation flux chamber is used ***(Figure 2)***. This is a U.S. Environmental Protection Agency (USEPA)-sponsored device that is designed to capture otherwise fugitive emissions from soil/solids and water surfaces, like open channels, tanks or sedimentation basins, to determine the emission rate of odors and/or volatile organic compounds (VOCs). The standard

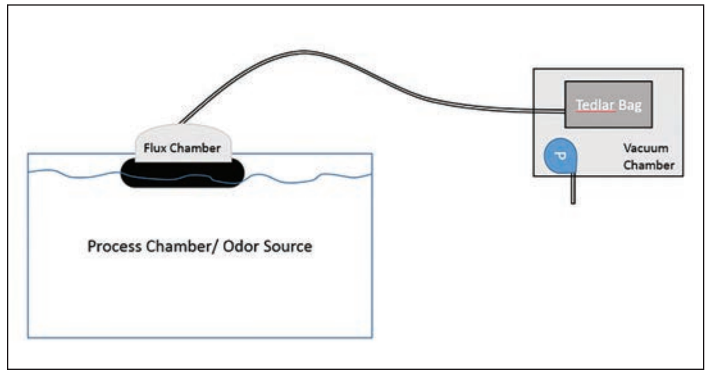

Figure 2. Area source sensory sampling. *Hazen and Sawyer*

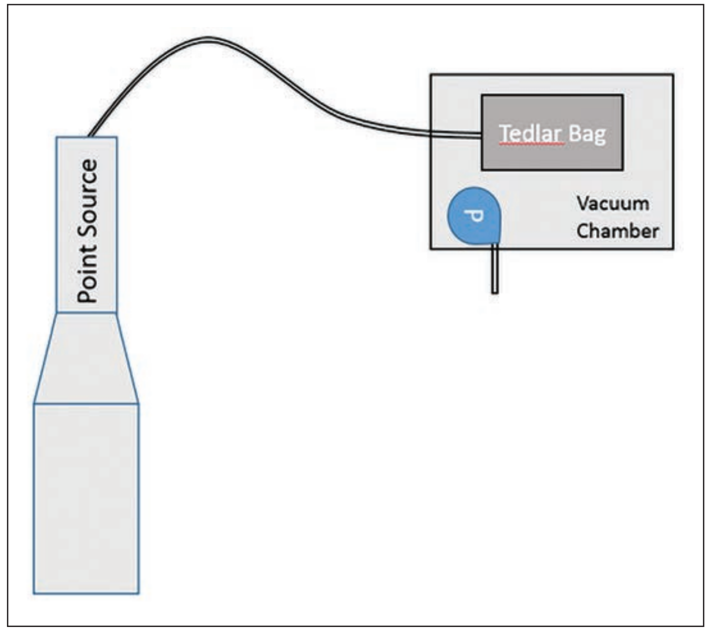

Figure 3. Point source sensory sampling. *Hazen and Sawyer*

design is approximately 18 inches in diameter by 11 inches high and is used to isolate a portion of the emission surface, enabling air samples to be collected without interference from the effects of wind, other odors in the area, and other environmental factors *(Klenbusch 1986)*.

For point sources, such as a stack or vent, samples are collected using a vacuum chamber and inert Tedlar bags ***(Figure 3)***. A small battery-operated vacuum pump removes air from the airtight vacuum chamber to create negative pressure, causing the Tedlar bag, connected by tubing to the desired point source, to inflate with odorous air. This setup avoids having the sample pass through the pump where odors could be added to the sample.

The sensory data collected from the selected point and area sources can be used to determine the odor emission rate (OER) for each source. The OER is the odor mass emission rate and is a product of the D/T times the exhaust rate. This key parameter can then be used to preliminarily rank the odor sources or, more importantly, as input for air dispersion modeling. The data are modeled to determine the theoretical transport distances for each of the individual odor sources, or multiple sources to determine their combined impact from the site to the surrounding communities.

Sulfur Speciation Sampling

Biological matter in wastewater subjected to anaerobic conditions often results in the generation of reduced sulfur compounds, which

continued on page 38

continued from page 37

can contribute to the characteristic odor *(WEF 2020)*. Removing just H_2S from these emissions may result in only marginal odor reduction if the reduced sulfur organic compounds are present at elevated concentrations. Some of these compounds are less soluble than H_2S and can be difficult to treat *(WEF 2020)*.

Tedlar bags or glass-lined SilcoCan/Silonite canisters are used for collecting samples for analysis at an independent certified laboratory able to test for method ASTM D5504-12 *(ASTM 2012)*. This laboratory procedure is used to analyze for 20 sulfur/reduced sulfur compounds that include many of the sulfur-based, odor-causing compounds prevalent in a wastewater collection system and/or treatment plant, such as:

- H_2S
- Mercaptans
- Dimethyl sulfide
- Dimethyl disulfide
- Carbonyl sulfide
- Carbon disulfide

A benefit of SilcoCan/Silonite glass-lined canisters is that they have a seven-day hold time for laboratory processing versus the 24-hour hold time required for regular stainless steel Summa canisters or Tedlar bags. SilcoCan/Silonite canisters are also provided in a vacuum state, and therefore do not require the use of sampling pumps, evacuation chambers or other additional equipment.

Ammonia and Amines Sampling

Wastewater and its residuals contain various forms of nitrogen, much of it present as ammonia or organic nitrogen. The small quantity of ammonia in wastewater that off-gases in neutral pH conditions contributes little to no odor emissions, and these odors are typically less detectable than the sulfur-based compounds. However, ammonia and nitrogen-based compounds such as trimethylamine typically appear in the dewatering processes, in the solids created from dewatering, or in subsequent solids processing such as composting. When wastewater solids are treated in a high-pH process, such as lime stabilization, or a high-temperature process, such as composting, the release of ammonia and other nitrogen-based odorants can become the significant factor in odor emissions. Anaerobic digestion and autothermal thermophilic aerobic digestion can also cause the generation and release of ammonia and compounds such as amines.

Sorbent detection tubes are often used to sample for nitrogen-based odor compounds such as ammonia and amines. Ammonia can be sampled using Draeger or other vendor tubes and associated hand pumps. Amine compounds can be sampled with the use of lab-provided sorbent tubes and battery-powered air pumps.

Pressure Monitoring

If a process area is not adequately ventilated to maintain a negative air pressure within the enclosed space, positive pressure from the space can be the source of fugitive odor emissions, leading to nuisance odor complaints, corrosion and safety issues. Smoke candles can be used to provide visual confirmation of positive or negative pressure for selected process areas. Acrulog differential pressure monitoring units are intrinsically safe sensors that can be hung in a covered process area to determine the differential pressure between the atmosphere and an enclosed process space. These units are deployed to continuously record air pressure to determine if the process areas remain under negative pressure during all operating conditions indicating effective containment of the odors.

Airflow Measurement

A hot wire anemometer is used to measure the air velocity in a duct or wall ventilation fan associated with existing odor control and HVAC systems. The anemometer's probe is inserted in a sample tap hole and the flow rate of air is calculated using the velocity measurement and the cross-sectional area of the conduit. The velocity measurement is taken at multiple points across the diameter of the duct or fan opening to account for variations in the velocity due to friction along the side walls. The velocity is then determined by averaging the measurements of the multiple data points collected. The airflow measurement results can also be used to determine if an existing system requires rebalancing to achieve design airflow rates.

Electronic Odor Monitoring

Advancements in sensor technology have led to the development of electronic odor monitoring devices ***(Figure 4)***, commonly referred to as electronic noses or "E-Nose." These devices typically consist of one or more sensors targeted to specific odor compounds. The devices are generally calibrated to odor causing compounds that are known to be associated with odor emissions for a specific application. The calibration is based on the relationship between the observed odor compound concentration measured by the sensor for a given sample compared to the measured odor threshold value for that same sample. Once calibrated, the concentration of a particular odor causing compound can be correlated to an odor threshold value. Today these devices are most commonly used to provide real-time odor exceedance alerts, often in combination with dispersion modeling.

Figure 4: Electronic odor monitoring system. *Courtesy of Odotech*

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Odor Dispersion Modeling: An Effective Design Tool to Help Facilities Meet Standards, Be a Good Neighbor *and* Save Money

by Phyllis G. Diosey

Dispersion modeling to evaluate the air quality impacts of new and modified emission sources, such as wastewater and sewage sludge treatment facilities, has been used for many years. New facilities and modifications of such potential sources of air pollution are generally mandated by the Clean Air Act, other federal and state regulations, and local municipal codes. Using dispersion modeling for air permitting and environmental assessments can demonstrate compliance with air quality standards and criteria. These techniques were adapted for modeling odorous emissions and continue to track closely with the regulatory tools. However, though odor modeling is an extremely valuable tool to evaluate both new and modified odor sources, it is often overlooked or avoided by facilities, often citing time or cost constraints.

Resolving Odor Issues with Modeling

A wastewater treatment facility has a higher nuisance visibility to the public, but actually may have less impact within the community compared to other facilities in the same community. Determining a facility's odor issues and the best solutions to resolve these issues can seem simple, but they are often multifaceted and complex. It is a common occurrence to find that there are still odor complaints from the surrounding community after putting controls on a single odorous process. For example, digester gas emitting from a relief valve, while highly odorous, may actually have much less odor impact in the surrounding community than the lower concentration emitted from the open final settling tanks.

Unfortunately, attempting to "solve the problem" through trial-and-error fixes often misses the mark altogether and can frustrate the surrounding community. Planning for upgrades and long-term improvements generally requires significant capital cost. But having to redo and revise these improvements because they resulted in unanticipated odors will add significantly to the project cost and can also result in regulatory fines along with generating unwanted ill will within the impacted community. Odor modeling is one of the best tools that can be used to identify potential problems in advance and assist in the design of cost-effective solutions.

Modeling the spread of contaminants in the atmosphere emitted from stacks and chimneys has been performed for over 60 years. It has evolved from the use of simple equations to estimate the gaseous concentration from a specific stack at a single receptor for a given set of meteorological conditions, to complex computerized programs that simulate the physics and chemistry governing the transport, dispersion, and transformation of pollutants in the atmosphere. Atmospheric dispersion modeling has become the primary tool for regulatory agencies and industries alike to estimate impacts from new and modified sources, and to predict whether air quality standards and other regulatory criteria will be met.

Similarly, these same air quality dispersion models and modeling techniques have also been successfully applied to the assessment of odors. And while differences between the modeling of contaminant-specific pollutant emissions and complex odors do exist, use of air quality dispersion models for odor emissions provides the same opportunity to predict the odor impacts from existing facilities, newly proposed facilities, or future upgrades and/or proposed modifications in equipment or operations at existing facilities – all before "putting a shovel in the ground."

Wastewater facilities, for example, generally have a variety of different source types with different exhaust parameters. Trying to assess the hydrogen sulfide (H_2S) concentration impacts of these varying sources by collecting samples alone cannot provide the answers needed. We need to better understand how emissions from each stack spread as they travel downwind, mixing with atmospheric air, and then potentially combining with the emissions emitted from other nearby sources, and then determine the impacts from these emissions at specific receptor locations. This is an extremely difficult, if not impossible task. However, by using computerized dispersion modeling, the impacts of both the individual H_2S sources, as well as the H_2S impact of the combined sources can be determined. Once determined, the opportunity to investigate alternative controls and design options to either eliminate exceedances or reduce impacts to acceptable levels is easily accomplished with all the "trial and error" work done efficiently and effectively by computer.

Three valuable uses of project odor modeling include:

1. Demonstrating compliance.
2. Improving design and selecting an appropriate technology.
3. Determining culpability.

Compliance

While there are currently no federal odor regulations, many states and localities have odor standards or criteria. Some are pollutant-specific, some are in terms of dilution-to-threshold ratio (D/T, a measure of the number of dilutions needed to make the odorous ambient air nondetectable), and some are in terms of general nuisance (i.e., that unreasonably interferes with the proper enjoyment of the property of others). ***Table 1*** is a list of odor standards and criterion in various states and localities.

One difference between regulatory air quality standards and a number of odor standards/criteria is the averaging time. This difference often depends upon whether the goal of the criterion is to protect against health effects (generally the criteria with the longer time frames, as with many other pollutants), or protect against potential nuisance odors (the shorter timeframes). The shortest averaging time for federal and most state air quality standards is one hour. In the case of odors, criteria averaging times are often much shorter (as low as five seconds in Hong Kong), recognizing the fact that odors can be detected in a much shorter time, and that the typical odor-related goal is to *protect against unreasonable interference with the enjoyment of life or property*. In other words, they are nuisance-odor based and not health-risk based.

In general, odor regulations (or criteria), like air quality regulations, are based on odor levels in *ambient air;* defined as that region beyond a facility's fence line, where the public has access. This area of ambient air can include the fence line of the facility, but it can also include a school or park several blocks away from the facility, or an apartment balcony several stories up in a nearby high-rise. Assuring that a facility's odorous emissions always meet

continued on page 42

continued from page 41

Table 1. State and Local Odor Regulations and Criteria.

Location	Standard or Criterion	Averaging Time	Source/Receptor
Bay Area, California	5 D/T	Five or more confirmed complaints per year averaged over three years	Fence line
Colorado	7 D/T	Scentometer	Residential/Commercial
	15 D/T	Scentometer	Other
	7 D/T; 2 D/T	Scentometer	Combined Animal Feeding Operations (CAFO); Offsite
Connecticut	0.0045 ppmv H_2S	15 minutes	Ambient air
	7 D/T	Three samples	Ambient air
Illinois	8 D/T	Scentometer	Residential, recreational, retail sales, institutional, educational premises
	24 D/T	Scentometer	Industrial premises
	16 D/T	Scentometer	All other premises
	Pollutant-specific	3-5 seconds	Ambient air
Maricopa County, Arizona	0.03 ppmv H_2S	30 minutes	Any occupied place beyond source
Missouri	7 D/T	Nasal Ranger	Outside source property line
New York State	10 ppbv H_2S	One hour	Ambient air
New York City	1 ppbv H_2S	One hour	Sensitive receptors
Texas	0.08 ppmv H_2S	30 minutes	Residential, business or commercial
	0.12 ppmv H_2S	30 minutes	Industrial property, vacant tracts, range lands – normally unoccupied

Notes:
1. A number of these jurisdictions also have general quality-of-life regulations that restrict the emissions of odors, toxics, or other substances that would affect human health or well-being, or unreasonably interfere with the enjoyment of property.
2. *D/T:* dilution to threshold = a measure of the number of dilutions needed to make the odorous air nondetectable.
3. *ppmv:* parts per million by volume.
4. *ppbv:* parts per billion by volume.

the required odor criteria over this wide area would either be a huge monitoring effort or a complaint-based, trial-and-error study that could, as a worst-case, lead to monetary fines for failing to meet the regulations, or at minimum, result in long-lasting ill will from the surrounding community.

Determining compliance with these standards and criteria can be done relatively quickly in the field with devices such as the Scentometer and/or the Nasal Ranger ***(Figure 1)***. These two devices are used in the field to assess D/T. In 1958 the U.S. Public Health Service sponsored the development of the Scentometer instrument and procedure for field olfactometry (ambient odor strength measurement). The Nasal Ranger was developed by St. Croix Sensory in 2002 based on the same principles used by the Scentometer but updated to provide a simpler user experience. Short-term and longer-term monitoring of H_2S can be performed using devices such as a Jerome meter or Acrulog monitor ***(Figure 1)***.

Design

Odor modeling is an extremely useful and cost-effective design tool. For a proposed or planned facility, modeling is the best way to evaluate whether odor levels from the facility sources are likely to meet or exceed odor criteria for the facility as designed, or whether modifications or additional controls will be required. Likewise, a facility proposing changes or upgrades can use odor modeling to determine if these changes meet the required odor criteria or if modifications are needed. In both cases, odor modeling can be used to evaluate "what-if" alternative designs to determine which design offers the best control for cost-effectiveness or for assessing varying operating conditions to make sure that under the proposed operating scenarios, the facility will be in

continued on page 44

a. Scentometer Field Olfactometer *Barnaby-Sutcliffe Corp.*

b. Nasal Ranger Field Olfactometer *St. Croix Sensory Inc.*

c. Jerome H_2S Analyzer *Arizona Instrument LLC*

d. Acrulog H_2S Portable Gas Monitor *Acrulog PTY LTD*

Figure 1. Odor monitoring instruments.

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continued from page 42

compliance. All of this can be accomplished with odor modeling in the early, upfront design phase at a far lower cost than trying to remedy odor problems from an already-built process or facility.

Culpability

When there are multiple sources of odors, whether due to different processes at a single facility or in an area where there are a number of potential odor sources, odor modeling can be used to identify which sources are the potential problems. Due to the complex nature of odor dispersion, simply assigning culpability to the source with the strongest odors, while seemingly logical, can often fail to identify the actual problem source. This is especially important in areas where there are other facilities that may be contributing to or might be the actual source of community odors. All too often, higher visibility facilities, such as wastewater treatment facilities, are assumed to be the source of community odors. Using dispersion modeling to simulate the various odor sources, those sources that are the greatest contributors to off-site impacts can be identified, and appropriate mitigation measures developed and put into place.

Screening-Level or Refined Modeling?

There are different types and levels of modeling, basically related to the amount of input information required, and the purpose of the analysis. Different models serve different purposes. Screening-level modeling generally requires the least amount of input data and can run the gamut from spreadsheets and simple nomographs to computer-based models, such as SCREEN3 and AERSCREEN, two U.S. Environmental Protection Agency (USEPA) regulatory screening-level models that are also approved for use by most state and local regulatory agencies *(USEPA 1995, 2016)*. Often, these screening approaches were developed from simplifications of more advanced models.

Screening-level models generally include assumptions with respect to wind data designed to provide worst-case odor impacts directly downwind of a source. Most screening-level models are also simple and inexpensive to run, so that the analysis itself is quick and relatively easy; however, these models are generally limited to evaluating a single odor source, such as a single stack, with simple straight-line receptors and conservative assumptions to provide worst-case impacts from the source.

Refined models, such as USEPA's AERMOD *(USEPA 2021),* require more detailed, site-specific input data than screening-level models, but in return, they provide much more useful output information with a much greater degree of site-specificity and realism. Models like AERMOD are generally run with five years of local hourly wind data collected and stored by government-based organizations, such as the National Weather Service (NWS). Alternatively, on-site meteorological data can be used if these data have all the detail and formatting required by the model. Similarly, the detailed terrain data are generally available online.

Because refined models can evaluate multiple source types within a single run, they can help identify which source or sources are the key contributors to off-site odor impacts. This allows the facility operator to focus critical resources on the most important processes. Refined modeling will also help to determine the level of control necessary for each source so that collectively, they will meet regulatory and project goals. Where there are multiple options with respect to proposed designs or modification, refined modeling is the most effective tool to compare the cost versus benefit of each design.

Refined models are also more useful and efficient for projects located in developed areas, such as cities and towns, where there are a variety of receptor locations, such as balconies and hilly terrain. Refined models can predict impacts at these discrete locations in addition to a receptor grid, which then allows for presentation of the impacts in the form of isopleths, or lines of constant concentration, downwind of a release. Such a graphic representation illustrates the extent of the odor impacts beyond the fence line.

Figure 2 presents an isopleth showing the extent of the off-site D/T impacts (in terms of odor units per cubic meter) in the community from the combined odor sources at a municipal wastewater treatment facility. This type of graphic is extremely valuable not only for the project team, but also when discussing the project with regulatory agencies as well as communicating with local community boards about the odor impacts from facility sources beyond the fence line.

Model Input Parameters

Input parameters for odor dispersion models include the following:

- Source parameters
- Meteorology
- Topography
- Building downwash
- Receptor location

Source Parameters

Whether screening or refined approaches are selected, key inputs are the source parameters ***(Table 2)***.

Table 2. Source Parameters.

Source Type	Examples	Input Parameters
Point	Stacks Chimneys	• stack height • inside diameter • emission rate* • flow rate • exhaust velocity • stack exhaust temperature
Area	Tanks Ponds	• dimensions–length and width, or radius • emission flux** • release height
Volume	Building vents Open doors Relief valves	• release height • initial vertical and horizontal dimensions • emission rate

Notes:
* Emission rate = pollutant-specific mass or odor units per unit time
** Emission flux = pollutant-specific mass or odor units per unit time per unit area

Since concentration/odor impacts downwind are directly proportional to the emission rate (assuming no chemical reactions), accurate measurement of the emission rates for existing sources and defensible estimates of the emission rates for proposed sources is critical. In the case of odors, it is important to correctly characterize worst-case conditions, both in emissions and operations, in order to assure that the modeled impacts are not likely to be exceeded.

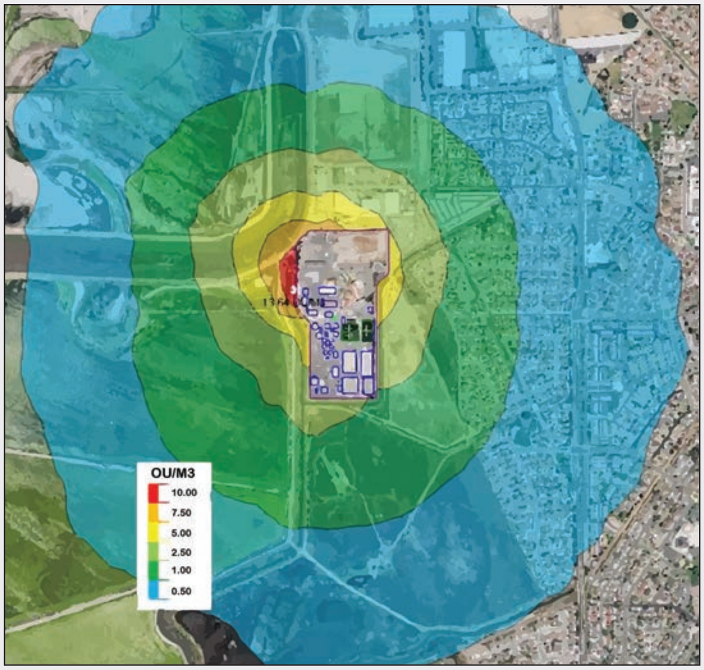

Figure 2. Odor isopleth (one-hour D/T) for municipal wastewater treatment facility. *Hazen and Sawyer*

Figure 3. Odor control rain cap. *Hazen and Sawyer*

continued on page 46

Figure 4. Mountain-valley flow. *BayAreaMonitor.org*

Figure 5. Sea breeze fumigation. This rare image, taken from an airplane leaving JFK International Airport, captured this phenomenon as it happened in the real world. *Y. Ogawa (1973)*

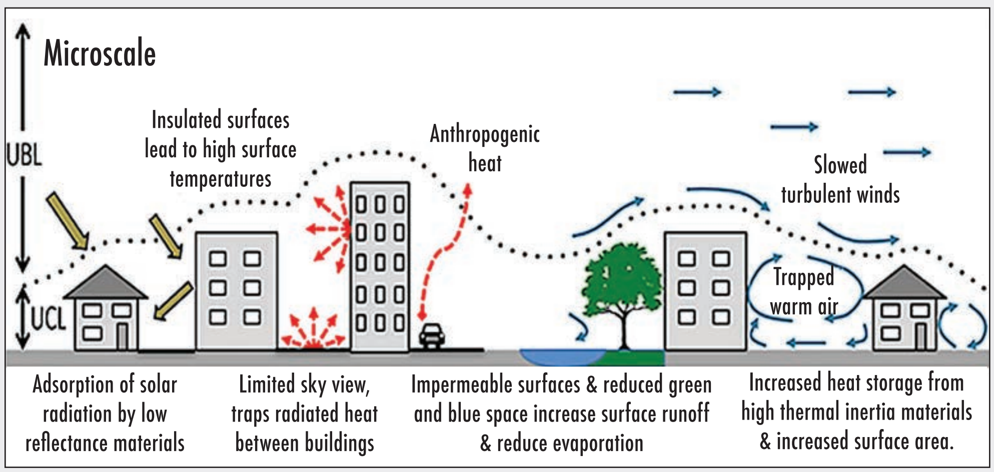

Figure 6. Urban heat island. *T. Kershaw (2017)*

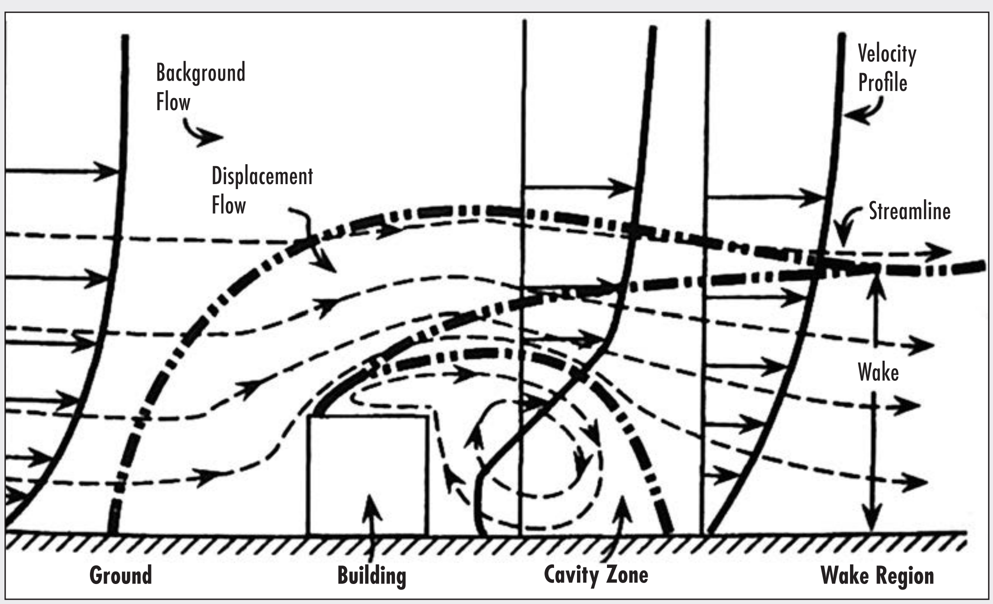

Figure 7. Building downwash. *Liu and Liptak (1997)*

continued from page 45

Point sources (stacks and chimneys) generally have greater dispersion potential than most area or volume sources (tanks and vents) due to their elevated location, their momentum and their buoyancy. Momentum refers to enhanced upward movement that generally results in reduced impact, while buoyancy refers to the temperature differential between the stack gases and surrounding atmosphere that can also enhance upward movement of gases leading to lower impact downwind. However, these beneficial effects assume that there are no obstructions to this upward momentum, such as a rain cap ***(Figure 3)***, which can actually inhibit the dispersion of the exhaust odors from the stack, often leading to high concentrations in the vicinity of the stack.

Open-area sources, such as aeration tanks and sedimentation tanks, generally have higher ground-level concentrations directly downwind of the source edge that then tend to drop off fairly rapidly traveling further downwind.

Meteorology

Wind speed, atmospheric temperature, stability (a measure of the turbulence in the atmosphere), and wind direction will each play a role in the dispersion of odors and will affect the dispersion process in different ways depending upon the source characteristics, and the topography. Weather conditions with very low wind speed and strong stability are often associated with higher impacts because the severely reduced turbulence offers very little opportunity for the plume to disperse. However, stronger winds and more turbulent conditions can also lead to intermittent high concentrations on the ground as a plume tends to "loop" up and down in the turbulent atmosphere.

Topography

The topography and terrain in the vicinity of an odor source will affect the flow patterns, and in turn, affect the dispersion characteristics. Topography modifies both wind and temperature. Air flows up, over, around, and down hills and mountains carrying exhaust gases emitted with it. Likewise, thermal effects due to uneven heating of hilly or mountainous terrain may lead to *mountain-valley flow* where emissions are carried downslope and collect in the lower valley resulting in high concentrations ***(Figure 4)***.

Sources located near a large body of water may be significantly affected by sea or lake breezes that can result in high downwind concentrations due to the differential in surface temperatures and roughness between the land and water leading to a phenomenon known as *fumigation* ***(Figure 5)***.

Sources located within or nearby large metropolitan areas ***(Figure 6)*** will be affected by the enhanced turbulence due to the surface roughness from the buildings themselves, and the higher temperatures due to the heat-adsorbing urban surface *(urban heat island)*.

Building Downwash

Nearby buildings can distort the oncoming local airflow pattern, changing both the velocity and the pressure fields around the building (***Figure 7)***. As the airflow approaches and flows up, over and around the building, a highly turbulent region, called the cavity wake, is created directly downwind of the building. High concentrations within the cavity wake are typical.

Receptor Location

In the case of regulated pollutants, receptor locations apply to all areas beyond a facility fence line where the public has access. In the case of odor modeling, additional receptors are generally placed at special locations, such as parks, schools and hospitals (so-called *sensitive receptors*).

Conclusions

Dispersion modeling has been shown to be one of the most effective, and at times, the only way to evaluate odor impacts from existing and proposed facilities before any physical changes are made. Depending upon the complexity of the source under investigation, the modeling can apply a simple conservative approach using a screening-level model, or a more realistic and data-driven approach (refined modeling).

Both approaches require good and accurate information about the source itself – in particular, the emission rate of the odorous exhaust – and refined modeling requires additional site-specific data in order to correctly characterize the site. However, with the appropriate setup and data input, modeling is an extremely powerful and cost-effective tool that can be used to:

- *Identify* those odor sources likely to impact the surrounding community
- *Assist* in designing better odor control approaches
- *Demonstrate* the effectiveness of the proposed controls and compliance with local project odor and air quality criteria
- *Compare* the cost/benefit of current and proposed future projects
- *Provide* the documentation that will be required for the environmental review and permitting processes

Most importantly, odor modeling can be used to correct for existing odor problems and eliminate the potential for post-construction odor problems that generate odor complaints from the community, fines from the local regulatory agencies, and very costly trial-and-error fixes.

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Reflect. Protect. Connect. … RESPECT
Women of Water Summit: Water Leaders Growing Stronger Together
by Lauren Livermore

As president of NYWEA, I was so honored to welcome over 50 in-person and virtual attendees to the very first Women of Water Summit at the Renaissance Marriott hotel in Albany in October, 2021. There were the familiar faces of our dedicated NYWEA volunteers and new NYWEA friends to network with, a welcome sight after months of virtual meetings. There were young professionals and experienced professionals in attendance, from a wide range of water industry careers, including operators, consultants, regulators, utility managers, and other water sector representatives. I was delighted to have our President-elect Khris Dodson, Vice President Donna Grudier and Vice President-elect Lisa Derrigan in attendance to share in this momentous occasion.

On to the Stats

When the announcement to hold this conference came out, people may have asked: Why do you need to have a Women of Water conference? Our answers would most certainly include:

- The number of females on the executive board today is the same number of women who have been president of NYWEA over its nearly 100 year history. With myself being the third after Gale Wolfe in the 1994, and Janice Jijina in 2006.
- Only 25% of NYWEA's members are women.
- In the ENTIRE state of New York, only 5% of licensed operators are women.

We can all say with confidence that these numbers have improved in the past 20 years, so we are making progress. We also know the industry can do better and that's why we all came together at the Women of Water Summit, growing stronger together as water leaders. At the conference, when the question of when there will no longer be a need for a Women of Water Summit was posed, Rosaleen Nogle quickly replied, "When 50% of NYWEA's members are women."

What Makes Everyone a Leader in the Water Sector

One take away from the conference was we all have the capacity to be leaders in the water sector, regardless of our title. As operators, engineers, scientists, academicians and vendors in the industry, we all serve in a leadership role teaching those in our lives the importance of protecting public health and the environment. This could be in our own organizations or as an informal water sector ambassador in our communities. We are the experts!

Our Amazing Line-up of Women

Our panelists, presenters and keynote speaker are some of the most accomplished and inspiring people in the water sector. I was starstruck introducing them! These women are nothing short of water sector royalty.

- Pam Elardo, the deputy commissioner for the New York City Department of Environmental Protection's Bureau of Wastewater Treatment.
- Carol Lamb-LaFay, who was promoted to assistant division director for the Division of Water at New York State Department of Environmental Conservation the day after the conference.
- Kianna Laurin Tralongo, who leads a company that works to stimulate personal growth in individuals and help groups excel.

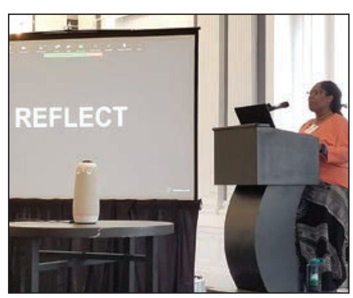
NYWEA President Lauren Livermore, left, and panelists Jean Malafronte, Kianna Laurin Tralongo, Carol Lamb-LaFay and Pam Elardo.

- Jean Malafronte, an engineering and facilitating dynamo who had opened up her own WBE consulting firm.
- Claire Baldwin, who announced the creation of the Avril D. Woodhead Grit Scholarship honoring her mother who was a pioneer in the field of science.
- Nicole Brown, the keynote speaker and an associate vice president at AECOM, who rounded out our day with a little R-E-S-P-E-C-T aimed at our fellow female colleagues.

Thanks to the planning team and many others who helped make our inaugural Women of Water Summit a reality: Jean Malafronte, Pam Elardo, Lisa Derrigan, Michelle Hess, Claire Baldwin, Khris Dodson, Patricia Cerro-Reehil, Sana Barakat, Kara Pho, Angela Delillo, Donna Grudier, Michelle McIntire, Silvia Marpicati and Danielle Hurley. Many thanks also to Madison Quinn for her technical assistance on site that help bring the meeting to those who couldn't be with us in person!

Of course, we have to also thank our sponsors for helping to make this conference happen, including: Andris Consulting, Arcadis, Barton & Loguidice, Carollo, CT Male and Jacobs. NYWEA would not be the amazing organization it is today without the generous support of our sponsors.

Kianna Laurin Tralongo conducted an Impact Leadership workshop.



Nicole Brown set the tone as keynote speaker.

Photos: Madison Quinn

Pam Elardo provided inspiring closing remarks.

What's That Smell?!? Chemical Treatment for Odor Control Applications

by Calvin Horst

What do expensive cheese, fine wine and wastewater have in common? To the initiated, the olfactory experience can tell you a lot about the qualities of each. Unlike cheese and wine though, wastewater odors do not typically elicit feelings of decadence and affluence. They do, however, remind us of the vital role our wastewater treatment and conveyance systems play in ensuring public health and quality of life. But where do these odors come from, and how can we ensure that fugitive emissions don't adversely impact the life experience of our constituents? This article will answer these questions and more!

Hydrogen Sulfide

There are a variety of odorous compounds that exist in wastewater systems, but the most impactful is hydrogen sulfide. Hydrogen sulfide is a soluble, corrosive and colorless sulfur-based gas that smells of rotten eggs. In addition to the corrosion impact hydrogen sulfide can have on infrastructure and equipment, it is detectable by the human nose at extremely low concentrations and becomes increasingly dangerous to human health as the concentration of the gas increases.

Hydrogen sulfide is formed in wastewater conveyance systems when the biologically active wastewater runs out of dissolved oxygen to support cellular respiration of aerobic bacteria. This is most evident in pressurized lines that don't allow for oxygen exchange but can also occur in long, quiescent, gravity lines, or lines with excessively high biochemical oxygen demand (BOD). In these situations, the sulfate-reducing bacteria become dominant in the wastewater. These bacteria use the oxygen on sulfate molecules for respiration, stripping them off the sulfate, which results in sulfide. This is where hydrogen sulfide comes from.

Sulfide can exist in any one of three forms in wastewater. We have already mentioned hydrogen sulfide, which has the chemical formula H_2S and sulfide, which has the chemical formula $S^{=}$. The third form is bisulfide (HS^-) that, like sulfide, is not volatile, meaning it cannot be directly released into the atmosphere to create odor issues and contribute to corrosion.

Of course, not all hydrogen sulfide odor issues are the same. There are certain characteristics that are favorable for the formation of sulfide. Some of these characteristics are immutable, like the physical dimensions of a collections system, while others can be changed or influenced in some way. For example, the influent stream to a pump station that is known to contain sulfide will be more problematic if the wet well level is kept too low, allowing the influent stream to cascade in, creating excessive turbulence. In this scenario some amount of hydrogen sulfide release could be mitigated simply by raising the wet well level to allow for a gentler entry and reduced turbulence.

Other variable characteristics that contribute to the formation and release of hydrogen sulfide are shown in ***Table 1***.

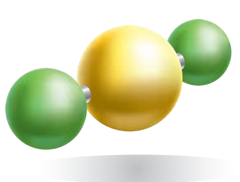


Table 1. Variable Characteristics That Contribute to the Formation and Release of Hydrogen Sulfide.

Characteristic	Contribution to H_2S Formation/Release
Wastewater BOD	Provides extra food for the biology.
Temperature	Higher temperatures reduce the solubility of water and increase biological activity.
Wastewater flow rate	Lower flow rates allow wastewater to spend more time in pressure mains.
pH	Three forms of sulfide (H_2S, $S^{=}$ and HS^-) exist at various equilibriums with one another depending on pH.
Baseline dissolved oxygen	Used by microorganisms to break down wastes; once depleted, organisms use oxygen bound to sulfate, releasing sulfide.

Most of these parameters can be easily measured or manipulated to help control wastewater odors with chemical treatment, but before discussing how to approach an odor control problem we should establish some basic odor control principles to help us think about our approach.

Basic Odor Control Principles

Following are four basic principles to remember when developing an odor control solution:

1. Odor control chemicals treat the water they are metered into, not water that went before or is coming after.
2. The amount of odor control chemical required is dependent on the amount of sulfide being generated.
3. The amount of sulfide generated in a fixed volume of wastewater is dependent on how quickly new wastewater enters the pipe afterward.
4. Wastewater flow patterns and chemistry are repeatable and follow fixed patterns.

These principles are generally true, but there may be exceptions based on application-specific conditions.

Designing an Odor Control Program

There are a few basic dosing strategies generally used when designing a chemical odor control program. The first and simplest is to set a sufficiently high, continuous chemical dose rate to achieve odor control. Due to the diurnal nature of wastewater flows and the resulting sulfide generation rates, this approach necessarily results in either periods of chemical overfeed (wasted dollars) or underfeed (poor performance). The argument for dose rate optimization is clear and the repeatable pattern of wastewater flows may make other dosing strategies clear, but before discussing those, let's talk a bit more about how to approach chemical dose rate optimization.

Dose Rate Optimization

To optimize a chemical dose rate, one first must establish a goal. Simply put we need to know what we are optimizing against. The two most common factors are budget and hydrogen sulfide concentration. In most cases the goal is not simply to optimize against budget or hydrogen sulfide, but rather to strike the best balance between those (and possibly other) parameters. For simplicity we will assume that we are only optimizing against the two parameters

continued on page 50

continued from page 49

of budget and hydrogen sulfide and nothing else. For example, we are assuming a practitioner has unlimited time available to devote toward optimization and therefore labor time is not a factor.

The next step is to figure out what it is that we hope to accomplish exactly; in other words, what is our odor control goal? Is the utility concerned about infrastructure preservation? Or do we need to address a particularly sensitive odor control application? Odor control targets should align with the outcome the practitioner is trying to achieve.

Let's consider infrastructure preservation. The USEPA has indicated that the corrosion rate of wastewater infrastructure is not directly proportional to the amount of dissolved sulfide in the wastewater, but rather it is proportional to the flux of hydrogen sulfide from the wastewater to the sewer walls (*USEPA, 1991*). Therefore, a minimum target of dissolved sulfide in wastewater may not be adequate for achieving corrosion control objectives. However, a study conducted by Evoqua Water Technologies in partnership with Sanitation District 1 in Kentucky (*Goossens et al., 2016*) revealed that concrete coupons maintained in a treated portion (3.6 parts per million by volume [ppmv] H_2S) of the evaluated collection system had a 22% higher compressive strength after 24 months than those maintained in an untreated portion (68.5 ppmv H_2S) of the collection system. It may be obvious, but this indicates that an atmospheric concentration target for hydrogen sulfide, rather than a wastewater concentration target, is better suited for corrosion mitigation purposes.

Atmospheric hydrogen sulfide is what causes odor issues and is therefore a perfect measurement for odor mitigation as well. Remember, the human nose can detect hydrogen sulfide at levels as low as 2 parts per billion by volume (ppbv). If we are looking at an odor control application with a sizable buffer area before the first odor receptor (nose), then perhaps 75 ppmv is an appropriate target.

Taking it a step further, budget should also be a consideration when establishing a target. It will cost more to treat to 10 ppmv than 100 ppmv in the same application using the same chemistry.

Now that we have defined our parameters for optimization and know we are optimizing against two factors, we've introduced the opportunity for variability based on individual sentiment. What I mean is that depending on who is optimizing, they may favor slightly better odor control over a slightly lower spend or vice versa. Fortunately, the repeatable pattern of wastewater flow rates makes it simple to optimize one time and then make seasonal adjustments up or down. What this looks like in practice depends on which other dosing strategy the practitioner has elected to use, the other two most common being dosing proportionally to the wastewater flow rate when a flow signal is available and dosing on a known dose curve developed leveraging the repeatable pattern of wastewater flows.

The Problem with Direct Feedback Control

The question often comes up about optimizing chemical dose rates through a feedback loop with measured hydrogen sulfide concentration. This may be marginally effective for a narrow set of applications where the odor control chemical is added at the point where the odor issue exists (i.e., point source applications) if the chemical treatment is very fast acting; however, most odor control applications do not work this way. Once odor comes out of the wastewater, it is difficult to get it back in. In other words, odor control chemicals are generally added upstream from the odor issue.

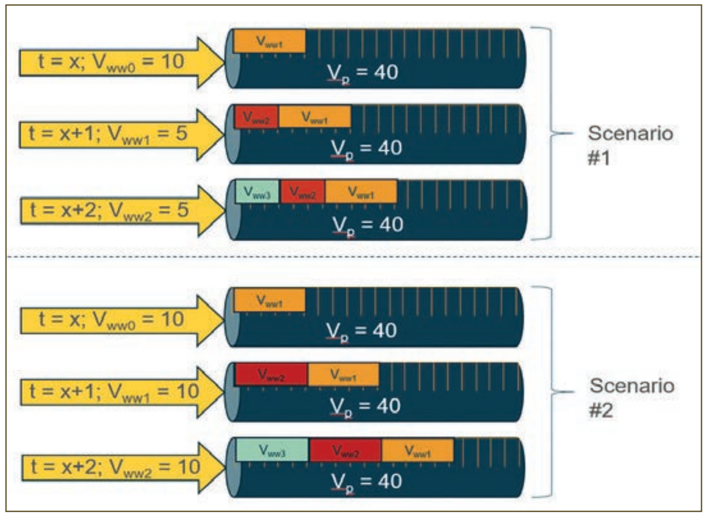


Figure 1. Odor control chemical demand is dependent on how quickly wastewater comes in after the chemical is added. *Calvin Horst*

To understand why direct feedback control with measured hydrogen sulfide concentrations does not work, it is helpful to remember the four odor control principals from earlier while referencing the simplified pressure main image depicted in ***Figure 1***.

In Scenario #1, a wastewater volume of 10 units (V_{ww0} = 10) enters the system at time index 1 (t = x). The amount of time this wastewater spends in the pipe, and therefore how much odor control chemical is required, depends on how quickly more wastewater comes in afterward. In Scenario #1 the 10 units at time index 1 are followed by five units at time index 2 and another five units at time index 3. In this case the first wastewater to enter the pipe is 20 volume units (10+5+5) into the 40-unit pipe at time index 3.

In Scenario #2, 10 volume units enter the pipe at time index 1, followed by another 10 units at time index 2, and another 10 units at time index 3. In Scenario #2 the first wastewater to enter the pipe is 30 volume units (10+10+10) through the 40-unit pipe at time index 3 and is closer to exiting the pipe in the same amount of time as Scenario #1.

In the example in ***Figure 1***, if the pattern were to continue and assuming all other wastewater characteristics were the same, the wastewater in Scenario #1 spends more time in the pipe, allowing more time for the biology to consume the dissolved oxygen and then the oxygen bound to sulfate, ultimately generating more sulfide. Put more plainly, the amount of odor control chemical that needs to be fed at time index 1 depends on how much wastewater comes in at time index 2, time index 3, and so on until it exits the pipe.

Again, thank goodness for repeatable wastewater flow patterns! Given the technical knowledge required to determine an objective, evaluate a collection system for the variety of odor control solutions available, and then effectively optimize the system to balance budget and control, it is no wonder the answer to many odor control issues is to "turn up the chemical."

Monitoring and Control

Optimization is only one aspect of an odor control program. Ongoing monitoring and control can be just as dicey of a proposition. Collection systems are complex and manifolded arrays of piping with wastewater coming from many different directions into a common point.

I have run across multiple odor control applications where high hydrogen sulfide concentrations in the air space were measured while wet samples revealed no sulfide and high treatment chemical residuals. In each of these cases an unknown and untreated line was feeding into the monitoring point. It took a bit of detective work (and time) to solve those problems, by systematically sampling the wastewater over the course of many hours to confirm the suspicion.

Advances in technology have made this type of work a bit easier. Imagine sitting at a desk monitoring a stream of hydrogen sulfide concentration data on your computer or manipulating chemical dose rates on a smartphone in response.

That is just what the Village of Wolcott, New York, was able to achieve in the following case study.

Case Study: Village of Wolcott

The Village of Wolcott is a rural town in upstate New York with a particularly interesting odor control application. The village previously maintained and operated their own wastewater treatment plant. In an effort to centralize wastewater treatment and better utilize resources, the village developed an agreement to shift treatment to a neighboring utility.

The Village of Wolcott converted their treatment plant into a large pump station, sending 200,000 gallons of wastewater per day, 5.7 miles to the neighboring utility, which allowed plenty of time for the wastewater to go anoxic and generate odors. Hydrogen sulfide concentrations up to 1,000 ppmv were measured at the last air relief valve (ARV 7) before the treatment plant. Ultimately ARV 7 and a section of pipe had to be replaced due to corrosion. Because of this, the receiving utility required that the Village of Wolcott's flows be treated for odors and corrosion prior to entering their plant.

Of course, it is not that simple. Eventually, plans were made for the receiving utility to tie into the Village of Wolcott line. To resolve the odor issues, the Village of Wolcott installed an advanced dosing system – the Versadose LT by Evoqua Water Technologies ***(Figure 2)*** – at their pump station to meter odor control chemicals. In addition, a remote hydrogen sulfide monitor was installed at ARV 7, the last air release valve before the treatment plant. This configuration allowed the Village of Wolcott to effectively optimize their own wastewater flow while visualizing odor issues coming in from other untreated flows!

The Village of Wolcott's advanced dosing system is a programmable logic controller (PLC) that automatically adjusts dose rates proportionately to changes in wastewater flow rates, adjusts dose rates for changes in wastewater temperature, and reduces the chemical feed rate when significant inflow and infiltration is measured. Any of the setpoints for these adjustments can be made remotely from any internet-enabled device, saving the village valuable labor-time resources and preventing corrosion at the ARV 7! The remote hydrogen sulfide monitor continuously measures the hydrogen sulfide concentration at ARV 7 and will notify service providers if the concentration exceeds configurable average or high concentration setpoints. This combination allows the Village of Wolcott to operate as a good neighbor to the receiving utility and residents living around ARV 7, while ensuring they do not exceed their budget targets!

Figure 2. Village of Wolcott advanced dosing controller. *Todd Gaignat*

Calvin Horst is a veteran of the U.S. Navy's nuclear power program having served aboard a fast attack submarine. After completing his education in chemical and nuclear engineering Calvin began working for Evoqua Water Technologies in 2013. Calvin has eight years of experience developing and optimizing chemical and capital odor control solutions. He may be reached at calvin.horst@evoqua.com.

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Vapor-Phase Odor Control

by Chris West

The wastewater discharged through our city sewer systems contains a variety of material that is either inherently odorous or will breakdown through (anaerobic) bacterial action into chemical compounds that are odorous. While these compounds remain in solution or in airtight sewers, we often ignore them (sometimes to our later regret). It is when these odors escape through maintenance holes, vents, hatches or from uncovered process areas at the wastewater treatment plant that our neighbors become more aware of odors and demand treatment. This is when vapor-phase odor control is frequently applied, to treat these odors that annoy neighbors.

Historically vapor-phase treatment of odors, or more simply, treatment of odors in the air, has fallen into one of three categories:

- adsorbent media filters
- wet chemical scrubbers
- biological systems (e.g., biofilters, bioscrubbers, biotrickling filters)

Adsorbent Media Filters

Adsorbent media filters ***(Figure 1)*** remove odors through physical adsorption of the odor compounds to the media. These filters are used to remove a wide range of odors, and the media is most often activated carbon. As the odors pass through the media, they simply attach to the media surface through a process known as adsorption. At some point, the surface of the media is saturated and the media "spent," after which the media is either regenerated or replaced with new media.

The longevity of the media – and therefore the overall operation and maintenance (O&M) cost – determines the long-term viability or desirability of adsorption media filters. Media change out can be laborious and "unpleasant" (dirty and dusty) and it may require special disposal considerations. Use of alkali-impregnated activated carbon for the removal of hydrogen sulfide (H_2S) has led to instances of carbon bed fires and associated safety concerns. Overall process simplicity and high odor removal efficiency are some of the main advantages associated with adsorption media filters.

Figure 1. Carbon filter treating 17,000 cubic feet per minute (cfm).
Rob Firestone

Figure 2. Chemical scrubber. *Rob Firestone*

Wet Chemical Scrubbers

Wet chemical scrubbers ***(Figure 2)*** have been utilized for odor control for more than 40 years. The scrubber vessel is the reaction chamber where the chemical reaction occurs that results in the removal of the odorous compounds from the air. Different chemicals are used depending on the type of odorous compounds to be treated. For example, caustic is used to remove H_2S by increasing the scrubber water pH, while acid is used to remove ammonia by reducing the scrubber water pH. Caustic and hypochlorite (bleach) are often used together to remove odors and oxidize them to odorless compounds.

Benefits of chemical scrubbers include high odor removal efficiency, considerable flexibility in treating varying types and odor concentrations, and relatively small footprint. Disadvantages include the need to purchase, store and handle hazardous chemicals and associated risk mitigation procedures; the potential for very high operating costs due to high chemical consumption; and intensive maintenance. Chemical scrubber maintenance is much more involved than that of activated carbon filters since it requires frequent calibration of sophisticated instruments and cleaning of the media through acid washing.

Biological Systems

Biological treatment of odors relies on naturally occurring, aerobic bacteria to consume (oxidize) offending odorous compounds in the presence of oxygen and produce odorless compounds as

continued on page 54

continued from page 52

Figure 3. Biofilter treating approximately 7,000 cfm. *Matt Johnson*

Figure 4. Biotrickling filter treating 25,000 cfm. *Rob Firestone*

a result. This process is referred to as an aerobic process, and it essentially reverses the action of the anaerobic bacteria in the sewer collection system that created the odors in the first place. Biological treatment is becoming more appealing due to the perceived naturalness of the process since it is considered both sustainable and environmentally friendly. Furthermore, it does not consume any carbon or chemicals since the treatment utilizes naturally occurring bacteria, *and* the "bugs" work for free!

Biofilters

Biofilters ***(Figure 3)*** represent the oldest form of biological odor control and have been in use for more than 40 years. Biofilters may utilize wood chips, lava rock or specially engineered inorganic media for the bacteria to grow on. It is used mostly where odor concentrations are low and large land areas are available. Biofilters provide a good odor control solution in moderate climates and are often designed and built in-house by utilities with the support of consultants.

The downside of biofilters is that they require a large footprint to treat a certain airflow, and, based on the inlet odor concentration, the media may require more frequent replacement, which can be labor intensive.

Biotrickling Filters

Biotrickling filters ***(Figure 4)*** represent the latest development in biological odor control. Since the late 1990s, biotrickling filters have mostly used synthetic media, and the odor removal efficiency is optimized through sophisticated process controls. Since the media is synthetic, the life expectancy of the media is more than 20 years, and the media requires zero maintenance.

Biotrickling filters are very versatile in their ability to treat many different kinds of odorous compounds at varying concentrations. For example, industry installations include applications where H_2S concentrations range between 1 part per million by volume in air (ppmv) to more than 4,000 ppmv ***(Figures 5*** and ***6)***. These filters can remove ammonia, reduced organic sulfur compounds (ROSCs) such as mercaptan, dimethyl sulfide and the like, and many different types of volatile organic compounds (VOCs) and volatile fatty acids. Treatment of VOCs such as benzene, toluene, ethyl benzene

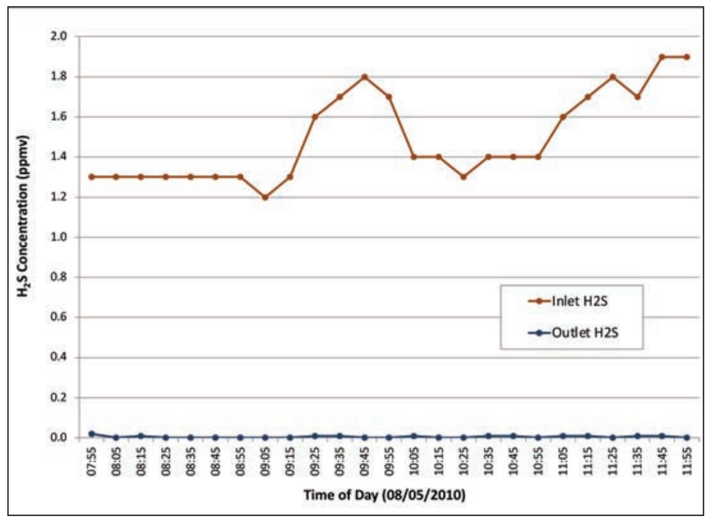

Figure. 5. Performance of low concentration H_2S treatment using the EcoPure Mini System biological section. Austin Water Utility, Davenport Lift Station. *BioAir Solutions, LLC*

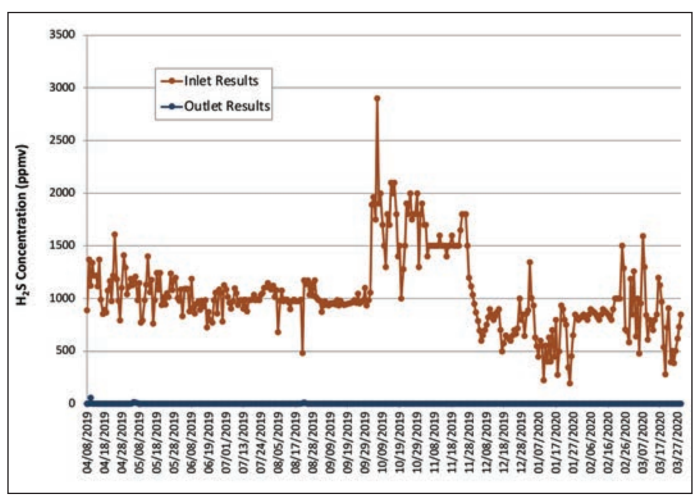

Figure 6. Performance of high concentration H_2S treatment using the three EcoFilter EF134 Biotrickling filters. Jebel Ali Sewage Treatment Plant, grit and primary settling tanks. *BioAir Solutions, LLC*

and xylene (BTEX) are often required due to their carcinogenic nature, and they have been successfully treated with biotrickling filters.

The latest generation of biotrickling filters provides for the smallest footprint requirements of all the biological odor control technologies available on the market.

Benefits of Biological Systems

Because biological odor control systems are considered environmentally friendly, have a low O&M cost, have a media that lasts more than 20 years, and are suitable for use in cold climates, their use and popularity has increased substantially over that of carbon and chemical systems in recent years. Furthermore, significant research has been conducted by specialist biological solution suppliers to improve the media performance and life, and to reduce system size *(le Roux et al 2010a, le Roux and Johnson 2010b)*. In particular, the development of uniform and structured, synthetic media systems for more technologically advanced biotrickling filters has led to significant reduction in system size, while at the same time improving the odor removal efficiency. For example, the biotrickling filter shown in ***Figure 4*** is treating more than three times the airflow than the biofilter in ***Figure 3*** in less than 5% of the footprint!

For footprint-restricted applications where a biofilter simply would not fit, there is now a very efficient, low O&M, environmentally friendly biotrickling filter option available where a carbon filter or chemical scrubber may have been the only option in the past.

With the wide range of different media types available in the market for bioscrubbers and biotrickling filters, it is important that biological systems be designed according to the media type. Different media types will result in different performance and different system sizes. Similarly, media life expectancy, and performance guarantees vary by manufacturer.

When your neighbors call to complain about odors, there are many good options – many of which are time tested and some of which are still in the evaluation phase. Do your research and connect with an expert in the field to help you identify the odor problem and design the right odor or air emissions control system for the specifics of your application.

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Can Biological Systems Treat Reduced Organic Sulfur Compounds and/or VOCs?

With the increased interest in biological odor and air pollution control, one of many recurring questions is: can they treat reduced organic sulfur compounds and/or VOCs?

This Superfund cleanup project, located in Bridgewater Township, New Jersey, was added to the National Priorities List in 1983 after contamination was found in the groundwater at the site. Prior owners used the site for numerous chemical and pharmaceutical manufacturing operations for more than 90 years, resulting in the contamination of waste disposal areas, soil and groundwater with VOCs and other compounds. In 2009 a large pharmaceutical company acquired the site and assumed responsibility for its long-term cleanup, which is ongoing.

Biotrickling filter for VOC treatment, Superfund site, Bridgewater Township, New Jersey. *Rob Firestone*

The major portion of the site cleanup deals with groundwater remediation. The first step in the treatment process is pumping of the groundwater into two large equalization tanks. BioAir Solutions provided a biological air pollution control system to eliminate the VOCs that are emitted from these equalization tanks, which hold the groundwater prior to treatment. The VOC removal system is designed to treat foul air that contains benzene, carbon disulfide, chlorobenzene and toluene. The system removes greater than 90% of the VOCs, thus ensuring compliance with the New Jersey Department of Environmental Protection air permit requirements ***(Table 1)***.

Table 1. VOC Removal Performance Data for the Biological Air Pollution Control System, Superfund Site.

Compound	Inlet Concentration (ppbv)	Outlet Concentration (ppbv)	Removal Efficiency (%)
Benzene	85,000	1000	98.8
Chlorobenzene	2500	130	94.8
Toluene	560	89	84.1

Notes:
ppbv = parts per billion by volume in air

This installation presents an exciting step forward in the use of biotechnology to treat VOCs and solve challenging environmental problems in a sustainable and environmentally friendly manner.

Activated Carbon Adsorption of Hydrogen Sulfide: Adsorption Mechanisms, Carbon Properties and Design Considerations

by Chester M. Morton

Introduction

Activated carbon has been used as a vapor-phase adsorbent since the mid-19th century when it was used in London to scrub odorous air from sewers. Its use as a vapor-phase adsorbent was accelerated when it was used in gas masks during World War I. Activated carbon has been used extensively in the wastewater industry for over 50 years where it has served to remove hydrogen sulfide (H_2S) and other odorous compounds with low olfactory threshold concentrations from exhaust air streams. But what do you really know about activated carbon?

This article discusses the activated carbon manufacturing process, the removal mechanisms associated with H_2S, the properties of activated carbon, and the activated carbons offered by manufacturers. Factors to consider in the design of activated carbon systems and carbon adsorber vessel types are presented.

Activated Carbon Manufacturing, Removal Mechanisms and Carbon Types

Activated Carbon Manufacturing

Activated carbon is manufactured from a number of raw materials including coal (anthracite, bituminous, lignite), coconut shells, peat and wood. The raw material is first crushed and sieved to the desired particle size distribution. It is then thermally treated in a high-temperature carbonization process that volatilizes material from the substrate, begins the formation of the pore structure and results in a carbon-rich solid fraction called char. In the following activation process, the micropore network is further developed where the char is oxidized with steam, carbon dioxide or air. The result is a carbon material with an extensive pore structure and surface area, which are key to its performance and adsorption capacity.

Activated carbon is available in powdered and granular forms. Powdered carbon is used in liquid-phase applications. The granular carbon form is more typically used in vapor-phase applications. It has a particle size of 1 to 5 millimeters. Granular carbon can be unshaped or shaped. The shaped carbon is produced in an extrusion process in the form of pellets. The advantage to pellets is that they have a greater porosity due to their consistent shape, higher hardness than unshaped non-pelletized carbon, and generally a lower pressure drop, which is associated with that greater porosity *(Menendez-Diaz and Martin-Gullon 2006).*

H_2S Removal Mechanisms

Adsorption on activated carbon is a physical process in which nonpolar compounds are preferentially adsorbed. In general, compounds of a higher concentration, with a higher molecular weight and lower volatility, are adsorbed preferentially. The adsorption process involves first the adsorption of a gas molecule to the carbon surface driven by van der Waals forces. The molecule is then stored in the carbon's pores. Physical adsorption is reversible, i.e., there is the potential that an adsorbed H_2S or other gas molecule can be replaced by heavier compounds with a greater adsorption affinity for the carbon. The typical H_2S capacity of virgin carbon is given in ***Table 1***.

The adsorption of H_2S can be enhanced via chemisorption, by impregnating the carbon with an alkali such as sodium hydroxide or potassium hydroxide. The adsorbed H_2S dissociates in part to hydrosulfide, the soluble form of H_2S. The higher the pH of the water film the greater the fraction of hydrosulfide present. The hydrosulfide is then oxidized by oxygen to sulfur and sulfuric acid and is stored in the pores of the carbon. Adsorption of the H_2S proceeds until the alkali is consumed or the pores are filled.

The H_2S capacity of alkali impregnated carbon ***(Table 1)*** exceeds the capacity of a virgin carbon. While impregnated carbon provides a greater H_2S adsorption capacity, the alkali on the carbon lowers the ignition temperature of the carbon. If the operation of a carbon system using impregnated carbon does not strictly adhere to recommended operating procedures and is not carefully monitored, the carbon in the system can auto-ignite, potentially resulting in extensive equipment and facility damage *(Bandosz and Ania 2006).*

Hydrogen sulfide adsorption can be enhanced with a catalytic carbon. With a catalytic carbon the adsorption process involves absorption of the H_2S gas molecule into a water film on the carbon surface. The source of the water is the humidity of the air stream being treated. Catalytically enhanced carbon contains alkali earth metals such as calcium and magnesium. These metals form oxides, which have limited solubility. The metal oxides impart a hydroscopic nature to the carbon, which is otherwise hydrophobic, promoting the presence of a water film on the carbon's surface. The metal oxides are present in the carbon as a solid phase, are coated with a thin film of hydroxides or carbonates and provide an elevated pH at the carbon-oxide water film interface, providing the environment for the dissociation of H_2S to hydrosulfide. The hydrosulfide is oxidized on active sites on the carbon surface to sulfur and sulfite, which then migrate to pores making the oxide sites available for additional sulfide oxidation. Similarly, carbons can also contain iron, which forms an oxide (ferric sulfide). The sulfide is oxidized to sulfur and then migrates to the carbon's pores *(Bandosz and Ania 2006, Bagreev and Bandosz 2005).* The H_2S capacity of catalytic carbons is given in ***Table 1***.

When injected into an air stream containing H_2S, ammonia has been shown to improve the adsorption capacity of H_2S on virgin carbon as compared to potassium hydroxide impregnated carbon. The capacity for alkali impregnated carbons is 0.12 grams per cubic centimeter (g/cc). In bench scale tests the capacity for virgin carbon with an inlet concentration of approximately 500 parts per million by volume (ppmv) H_2S and an ammonia concentration of 50 ppmv ranged from 0.86 to 0.94 g/cc. In full-scale tests the capacity of the carbon was 0.21 g/cc (*Turk, Sakalis, et al. 1989).* Ammonia injection in full-scale systems containing caustic impregnated carbon demonstrated increasing the H_2S capacity of the carbon up to two to four times the capacity of impregnated carbon in some cases *(Turk, Mahmood and Mozaffari 1993).* Despite the observed increased capacity, operating issues with ammonia storage, injection, and pass through have prevented this approach from becoming a viable option.

continued on page 58

continued from page 57

Carbon Properties

Parameters that describe the properties of activated carbon are described below. The properties of virgin, impregnated, and catalyzed carbons provided by various manufacturers are summarized in ***Table 1***. Carbon is available in non-pelletized and pelletized forms, although there is less non-pelletized carbon available. It is believed this is because pelletized carbon typically has a lower pressure drop than non-pelletized carbon and that is less subject to breaking apart and resulting in fines that fill in voids in a carbon bed.

H_2S adsorption capacity

This is expressed as mass adsorbed per unit volume, in grams per cubic centimeter (g/cc). Refer to method ASTM D6646 *(ASTM 2014)*.

Ash Content

Ash content is indicative of the inorganic matter in a carbon, e.g., metal oxides and carbonates. While there is a general correlation between ash content and H_2S capacity, it is this author's experience that there is not a strong correlation between these parameters, indicating other parameters are also factors, such as pore volume and surface. If there is a need to verify a carbon's capacity this can be determined by testing the carbon using the H_2S capacity test, method ASTM D6646 *(ASTM 2014)*.

Butane Activity Number

This parameter is an indicator of a carbon's capacity to adsorb organic compounds. It is a measure of the mass of butane adsorbed per unit weight of carbon expressed as a percentage. The Butane Activity No. has replaced the Carbon Tetrachloride (CCl_4) No. because of the adverse effect of carbon tetrachloride on the ozone layer. The relationship between CCl_4 and butane is:

CCl_4 No. = 2.52 x Butane No.

Refer to method ASTM D5742 *(ASTM 2016a)*.

Ball-Pan Hardness

Hardness is the resistance of a granular carbon to be broken down to smaller particles after being shaken with steel balls. Refer to method ASTM D3802 (*ASTM 2016b*).

Pressure Drop

Carbon manufacturers typically represent the pressure drop of their carbon graphically with pressure drop in inches water gauge (inch-WG) per foot bed depth plotted on the y-axis versus superficial velocity (feet/minute) on the x-axis.

Odor Control System Design

Adsorption Process

Hydrogen sulfide and compounds in general are adsorbed onto carbon in a mass transfer zone. As the capacity of the carbon is consumed, the mass transfer zone moves progressively in the direction of air flow through the carbon and is referred to as a wavefront. When the carbon is exhausted, the wavefront reaches the end of the carbon bed and the exhaust and inlet air concentration become equal. This is referred to as breakthrough.

It is noted that all the carbon in the bed is not utilized uniformly over time and as a result the wavefront concentration is not uniform along the bed depth and cross section. There are typically lower concentrations breaking through before the exhaust concentration equals the inlet. As a result, depending on the acceptable breakthrough concentration, which is typically based on a maximum concentration that will not cause an odor impact on the closest receptor, the full mass of the carbon bed may not be utilized.

To account for this lack of full carbon utilization, the adsorption capacity of a bed is often discounted by 20 to 25% when determining carbon life. Sample ports are typically located on the wall of the carbon vessel along the length of the carbon bed that enable the air passing through the bed to be sampled in order to track the wavefront progression. This enables the carbon to be replaced before breakthrough occurs.

Design Basis

Activated carbon is highly effective adsorbing H_2S and other compounds. It can be used as the sole treatment technology or as a polishing technology in an odor control system. However activated carbon has a finite adsorption capacity. As a result, the inlet design loadings relative to the capacity of the carbon being used needs to be determined so that the service life and cost of a carbon system in the proposed application is acceptable.

Determining the inlet compound mass loading involves determining the air flow rate and the concentration of the compounds being treated. The design air flow rate is based on providing an adequate air flow to capture odor emissions and/or providing the minimum air change rate for the spaces being exhausted. The design velocity for the carbon adsorbers will determine size (surface area) and quantity of carbon adsorbers required.

Table 1. Activated Carbons and Properties.

Carbon	Type	Particle Type (4-mm Pellets)	H_2S Capacity (g H_2S/cc Carbon)	Ash Content %	Butane No.	Hardness	Pressure Drop at 50-ft/min Bed Velocity (inch-WG/ft Bed)
P60/P70 – Evoqua	Virgin	Coal	0.01 to 0.02	-	23.5/27.5	95	0.5
STIX -Waterlink-Barnaby Sutcliffe	Impregnated	Coal	0.14	12	-	95	–
MIDAS-Evoqua	Catalyzed	Coal	0.3	28	26	95	1.0
Adsorb Sulfox-Jacobi	Catalyzed	Coal	0.2	20	19.6	95	0.2
NCB2-NICHEM	Catalyzed	Coconut	0.2	16.4 a	26.7 a	95	1.8
Darco BGH - Norit	Catalyzed	Coal	0.17	32 a	13.5 a	86	1.3
W-HS 1000 – Carbon Activated	Catalyzed	Coal	0.3	20	-	99	1.3
COC – H2 80	Catalyzed	Coconut	0.3	17	-	98	1.5

Notes:
The source of all parameters was manufacturers' carbon data sheets unless indicated otherwise.
a – Values from laboratory test work.

The velocity will drive the pressure drop through the carbon adsorber and the power requirement for the fan that will move air through the adsorber and associated ducting. The design velocity for an adsorber typically ranges between 50 to 75 feet per minute (ft/min), however velocities as low as 30 ft/min and as high as 90 ft/min have been used. At velocities above 90 ft/min with an upflow bed, the use of a plastic grid (bed limiter) on top of the bed should be considered to prevent the carbon from fluidizing.

The design inlet concentration is determined by measuring the concentration of the air stream that is to be treated. Grab samples or continuous monitors can be used to characterize the air. Continuous monitors are preferred because they can be deployed for an extended period of time and will provide the range of concentrations the treatment system will see as opposed to relying on grab samples. In the case of H_2S there are continuous monitors available at a reasonable cost that can be deployed for up to two to three weeks. Ultimately an average design inlet concentration needs to be established, which is used to determine the mass loading to the carbon system. A rule-of-thumb is that the design inlet H_2S concentration to a carbon system should be less than 10 ppmv for a carbon system to be cost effective. However, the loading to a carbon system and the carbon cost should be determined to verify its cost-effectiveness.

The carbon usage rate is determined using the capacity of the selected carbon. Typically, the carbon replacement rate should not be more frequent than once per year. The H_2S capacity of carbons is included in ***Table 1***. These capacities tend to be elevated as compared to the capacities most carbons will provide when treating air streams with concentrations of 1 to 10 ppmv. This is because the capacity values are based on ASTM 6636, which uses a humidified air stream containing 10,000 ppmv. A higher inlet concentration to a carbon tends to increase its loading capacity. There may also be other compounds present in the air being treated that will compete for space on the carbon and impact carbon life. Physical attrition of the carbon can result in a higher pressure drop and require a carbon to be replaced before breakthrough. As a result, these published capacities should be discounted to estimate carbon life. Selection of the carbon type to be used in a design can be informed by determining the annual carbon cost. This would be based on the estimated carbon usage rate and unit carbon cost.

The number of carbon vessels in a treatment system should consider standby vessels for when a vessel is taken offline for carbon replacement. In some cases, two vessels in series are used, which enables more complete utilization of a vessel's carbon by allowing breakthrough to progress in the first vessel. This is referred to as a lead-lag configuration. The lag vessel would adsorb the breakthrough from the lead vessel. At some point the lead vessel is taken offline, its carbon replaced, and the lag vessel would become the lead vessel. The vessel that had been the lead vessel and had its carbon replaced is then put back online as the lag vessel. A lead-lag vessel configuration requires dampers in the interconnecting ducting to allow switching the service positions of the vessels.

Ultimately, the cost-effectiveness of a carbon system is determined based on its present worth cost as compared to the cost of other potential odor control technologies. The present worth is based on the number and size of the required carbon vessels and the annual carbon cost along with the labor and costs necessary to remove, replace and discard the used carbon.

Pretreatment

Activated carbon is a relatively fine media. Odor control at wastewater treatment plants is typically provided at headworks, primary sedimentation, biosolids handling facilities and treating off-gas from covered activated sludge systems. In these applications the exhaust air may contain particulate, grease and excessive moisture, which may blind the carbon. To protect the carbon and odor control fan from these materials, a grease filter/mist eliminator (GFME) that contains filter elements such as stainless steel or plastic chevrons plates and/or mesh pads is provided upstream of this equipment.

Pressure versus Passive Carbon Adsorber Operation

In most cases designing a carbon system to operate under a positive or negative pressure is preferred as compared to a passive system. The design of a system operating under a positive or negative pressure involves determining the pressure drop required to pull the odorous air from the multiple odor sources, and to move it through the ducting, GFME, carbon vessel and exhaust stack. A fan is sized to provide the driving force to move air from the most distant upstream point through the exhaust stack. A positive pressure system has the advantage of providing a positive pressure within the carbon vessel that facilitates sampling a carbon adsorber's inlet and exhaust sample ports without the need for a pump to fill air sample bags.

Passive systems suffer from failure because there is often not adequate pressure to push the odorous air through the carbon bed, and/or the vessel is not adequately sealed, which allows the air that is supposed to be treated to leak out of the vessel or the inlet ducting untreated.

Carbon Adsorber Vessel Types

Carbon adsorber vessels can be provided in many shapes and configurations but are typically found in the following configurations:

- Vertical vessel
- Radial flow vessel
- V-bank vessel

Vertical Vessel

A vertical vessel is typically circular and contains one or two horizontal carbon beds. With a one-bed vessel, air enters through a nozzle in the vessel wall below the bed. Air passes upward through the bed and out through an exhaust nozzle in the roof of the vessel. With a two-bed vessel, air enters through a nozzle in the vessel wall located between the two beds. Half the air flow goes through each of the bottom and top beds. Each bed has its own exhaust stack with a damper that enables the air flow to be balanced between the two beds. The beds are typically 3 feet deep. ***Figure 1*** is a schematic of two-bed vertical vessel.

Radial Flow Vessel

Radial flow vessels are vertical circular vessels. The carbon bed is configured vertically and is located so that there is an annular space between the vessel wall and carbon bed. Looking down from the top of bed, there is a void in the middle of the bed from the top of the bed to the vessel floor. Air flow enters the vessel through a nozzle in the vessel wall, enters the annular space, passes through the carbon bed into the void space in the middle of the bed and exhausts through a nozzle in the center of the vessel roof.

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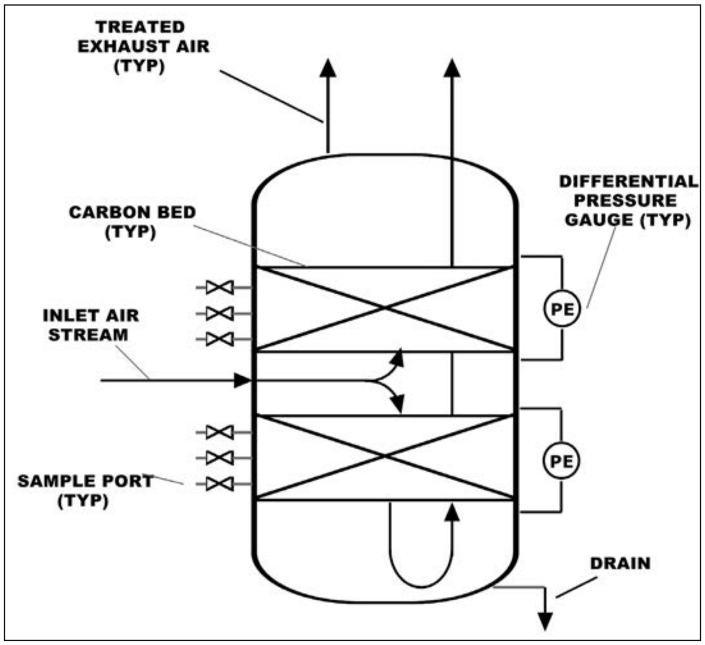

Figure 1. Vertical Vessel Dual Bed Carbon Adsorber *Chester M. Morton*

V-bank Vessel

V-bank vessels are rectangular. A V-bank vessel contains two carbon beds positioned vertically, almost the full length of the vessel. When viewed from above, the beds are configured in a "V" shape. Air enters the vessel through a nozzle at one end of the vessel, passes into the wide end of the V (middle of the beds), passes through the beds, then into a space between the bed and vessel wall, and moves to the exhaust nozzle located at the other end of vessel. An advantage of V-bank vessel is their capacity to treat large air flow rates. This minimizes the number of vessels and interconnecting ducting that would be required with multiple smaller vessels. The rectangular shape requires less space when laying out equipment. ***Figure 2*** is a schematic of a V-bank carbon adsorber.

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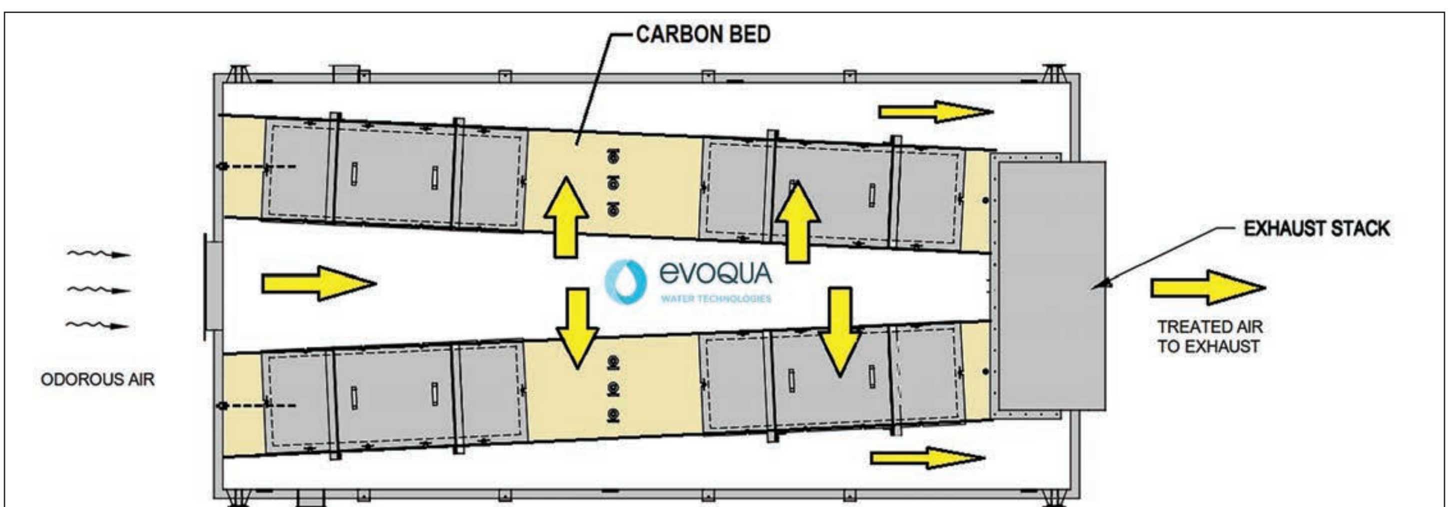

Figure 2. V-bank Carbon Adsorber – Plan View Schematic. *by permission of Evoqua*

Operator Quiz Winter 2021 – Odors

The following questions are designed for individuals/trainees pursuing certification 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 process of wastewater treatment. Good luck!

1. The main cause of most odors in wastewater systems is due to:
a. Hydrogen sulfide
b. Hydrogen peroxide
c. Hydrogen gas
d. Nitrous oxide

2. Chlorination of waste streams is an effective means of odor control because:
a. Chlorine is very reactive and oxidizes many chemical compounds in water.
b. Chlorine can destroy bacteria that can convert sulfate to sulfide.
c. Chlorine can destroy hydrogen sulfide at the point of application.
d. All of the above.

3. Odor complaints are increasing at the WRRF. The operator finds most odors seem to be coming from the primary clarifiers where bubbles and chunks of solids are found on the tank surface. What should be done to correct the problem?
a. Cover the secondary clarifiers.
b. Increase the pretreatment chlorine dosage.
c. Increase the sludge withdrawal from the primary clarifiers.
d. Add potassium permanganate or hydrogen peroxide to the upstream lift station.

4. A mechanical ventilation system for the wet well portion of a lift station that operates continuously should be able to exchange the air in the wet well _____ times an hour
a. 6
b. 15
c. 30
d. 60

5. When wastewater remains in the collection system for an extended period of time it becomes:
a. Organic
b. Inorganic
c. Septic
d. Toxic

6. One method used to minimize odor generation in sewer lines is to prevent solids deposition by designing a system with a high-flow velocity. What is the recommended design flow velocity to minimize odors?
a. Greater than 1.0 ft/sec
b. Greater than 2.0 ft/sec
c. Greater than 3.0 ft/sec
d. Greater than 5.0 ft/sec

7. Hydrogen sulfide gas is released most rapidly from wastewater at what pH range?
a. Greater than 9
b. 7 to 9
c. 5 to 7
d. Less than 5

8. Healthy activated sludge has what type of smell?
a. Mild, musty
b. Antiseptic
c. Sharp, acidic
d. Rotten egg

9. When odors are emitted to the atmosphere, the area downwind of the release point that contains the odor is called the ____ .
a. Plume
b. Eddie
c. Wake
d. Wind shear

10. A "rotten egg" odor near a trickling filter generally indicates:
a. Anaerobic conditions within the filter
b. The presence of the *Psychoda* fly
c. A too-high DO level in wastewater being applied to the filter
d. Too much recirculation

Answers below.

For those who have questions concerning operator certification requirements and scheduling, please contact Carolyn Steinhauer at 315-422-7811 ext. 3, carolyn@nywea.org, or visit www.nywea.org.

Answers: 1. (a) Hydrogen sulfide **2.** (d) All of the above **3.** (c) Increase the sludge withdrawal from the primary clarifiers **4.** (a) 6 times an hour **5.** (c) Septic **6.** (b) Greater than 2.0 ft/sec **7.** (d) Less than 5 **8.** (a) Mild, musty **9.** (a) Plume **10.** (a) Anaerobic conditions within the filter

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