

Liquid Stream Fundamentals: Odor Management and Control

Odor control is an operational strategy utilized at water resource recovery facilities (WRRFs) and in the wastewater collection system to mitigate nuisance odors in the surrounding communities. Depending on the design criteria, odor control can assist with worker health and safety considerations, as well as decrease the production of corrosive conditions that impact the useful life of treatment system infrastructure.

Odor Generation

Odors are generated from every phase of wastewater management including collection, treatment, and disposal. Just as the character of the wastewater changes as it progresses through the treatment process, so do the odors released from that wastewater. All odor emissions from wastewater are considered objectionable, but some processes release larger odor volumes and more objectionable odors than others and are capable of impacting the communities near WRRFs. The following three elements are required to create an odorous emission:

- Odorous compounds in the source wastewater
- Exposed surface area, from which compounds can be emitted; and
- A driving force that causes the compound to pass from the facility to the surroundings.

Odors from WRRF's are a complex combination of a wide variety of compounds; however, for the designer, there are certain compounds and groups of compounds that contribute significantly to wastewater odors and thus affect the selection of a treatment technology. These include the following:

- Hydrogen sulfide (H₂S);
- Organic reduced sulfur compounds;
- Ammonia and other nitrogen compounds; and
- Volatile organic compounds (VOCs).

Hydrogen Sulfide

H₂S is generated from the biological reduction of sulfate (SO₄) or thiosulfate under anaerobic conditions (Figure 1). Factors such as the concentration of sulfate compounds, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, temperature, and detention time (especially for long forcemains) impact H₂S formation. H₂S is a colorless gas with a characteristic rotten-egg odor, and can pose health risks as well as cause corrosion of wastewater infrastructure. H₂S is generally the most prevalent odor causing compound in wastewater and is the design-driving contaminant for most odor control strategies, but other compounds must sometimes be considered as well. H₂S is able to be detected at very low concentrations, with a published detection threshold value of less than 1 part per billion (ppb).

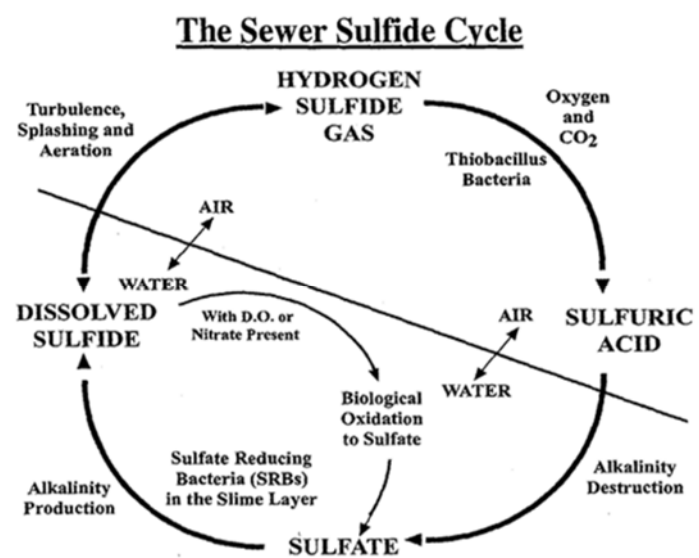


Figure 1—The Sewer Sulfide Cycle

Organic Sulfur Compounds

Organic-sulfur compounds include odorous compounds such as mercaptans, dimethyl sulfide, and dimethyl disulfide. Biological matter in wastewater subjected to anaerobic conditions often results in the generation of reduced sulfur compounds, which can contribute to the characteristic odor. While removing H₂S can often result in significant odor reduction, the organic-reduced sulfur compounds become much more prominent. Removing only the H₂S from these emissions may result in only marginal odor reduction if the reduced sulfur organic base odorants are dominant. Some of these compounds are less soluble than H₂S and can be difficult to treat.

Ammonia and Organic Nitrogen Compounds

Wastewater and its residuals contain various forms of nitrogen. Much of it is present as ammonia or organic nitrogen. The small quantity of ammonia in wastewater that off-gasses in neutral pH conditions contributes little to 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 and in the solids created from dewatering. 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 a dominant and significant factor in odor emissions.

Other Wastewater Odorants

Although most odor characterization and control efforts focus on sulfur-based compounds and, to a lesser degree, nitrogen-based compounds, there are many other compounds present in wastewater that contribute to its odor. Other classes of odorous compounds include, but are not limited to: carboxylic acids, VOCs, and aldehydes and ketones. Although these compounds may somewhat contribute to the odor of wastewater and sludge, they are not typically the dominant odor or the target of odor-control efforts.

Odor Management Strategy

Unlike most operational aspects of a WRRF, odor emissions from the facility can have a direct, immediate, and most importantly, noticeable effect on the surrounding community. Odors from WRRFs are often perceived by the public as a nuisance and foul odors affect quality of life and can potentially affect property values.

Since odor emissions are nearly impossible to prevent, a management strategy must be developed to mitigate the impacts of the odor emissions in the surrounding community. The following framework is the typical management strategy employed at WRRFs:

- Testing and characterization;
- Mitigation of odor generation;
- Containment and ventilation; and
- Odorous compound treatment and discharge

The community surrounding a facility is both the ultimate regulator and the arbiter of the success or failure of any odor-control strategy. Thus, a vital part of an odor-control strategy should be working with the public and keeping them informed about what odors are being emitted and what measures are being taken to mitigate the odors' release.

Testing and Characterization

Wastewater odors are typically sulfur- or nitrogen-based compounds, organic acids, aldehydes, and/or ketones. The odors most associated with WRRFs are H₂S, reduced-sulfur organic compounds (mercaptans, dimethyl disulfide, and dimethyl sulfide), and to a lesser degree, nitrogen-based compounds. Odor sampling, measurement, and modeling are useful in the determination of which odorous compounds are causing, or for new designs, could cause, the most significant issues at specific process areas within the WRRF.

Sampling and Measurement

Quantifying odorous emissions and understanding the air stream's odor profile is an essential part of any odor management strategy and odor-control system design. It allows the designer to prioritize odorous compounds and select the optimal treatment technique. To accomplish these goals, samples of the emission must be collected and analyzed.

There are standardized scientific methods for collecting these samples, and the method selected depends on the source of the emission and the desired data to be collected. Odorous air samples can be collected from point emission sources (e.g., stacks or vents) and from surface-area emission sources (e.g., liquid or solid surfaces). Hydrogen sulfide can be analyzed real-time, on a grab or continuous basis, in the field. Other odorous compounds require that samples be sent to a laboratory for analysis. Air samples for laboratory odorous compound testing are typically collected in Tedlar gas-sample bags or glass-lined stainless-steel canisters for transport to the odor-testing laboratory.

Point, area, and volume emission source samples can also be sent to a laboratory for odor panel testing of odor parameters (i.e., odor concentration, intensity, persistence, and descriptors). Odor also can be measured and quantified directly in the surrounding air, at the property line, and in the community using standard intensity and field olfactometry practices.

Atmospheric Dispersion Modeling

It is important to understand how air emissions are potentially carried from WRRFs to the surrounding community. When odorous compounds are emitted to the atmosphere, they are carried away from the emission source by wind transport and dispersion with ambient air. Topography, meteorological conditions, and source characteristics all influence odor concentrations at ground-level receptors. Dispersion models define the relationship between the emission source and the downwind receptor, and are also useful for predicting the risk of impacts of future sources of odors.

Several computerized dispersion models are available from the U.S. EPA's Support Center for Regulatory Air Models (SCRAM) website (<http://www.epa.gov/scram001/>) and from various dispersion model software vendors. Model selection should be based on the particular installation. Most odor modeling can be done with simpler Gaussian plume models such as AERMOD. More complex applications may require the use of more intricate models such as CalPUFF.

Mitigation of Odor Generation

The first step to controlling odors at a WRRF is the reduction of odor generated from the wastewater. Some reduction can often be accomplished through operational and housekeeping measures such as minimizing septic conditions, reducing turbulence, keeping access covers closed, managing sludge blanket depths, or adjusting activity times to minimize odor impacts. There are also a range of liquid-phase treatment technologies available for prevention of odorous compound generation and release, including:

- Air or Oxygen Injection;
- Nitrate Addition;
- Chemical Oxidation;
- Iron Salts; and
- pH Adjustment.

Air/Oxygen Injection

The presence of dissolved oxygen (DO) can have a significant impact on reducing odor generation, as sulfate reducing bacteria preferentially use oxygen, then nitrate, and then sulfate. Also DO can directly oxidize odor-causing compounds and allow aerobic bacteria to biologically oxidize these compounds through metabolic processes. Maintaining a dissolved oxygen concentration of 0.5 to 1.0 mg/L or more can prevent most odors from being produced in wastewater.

Air injection is an attractive option as it is a readily-available resource for oxygen supply. However, odor release can be increased based on the injection method, which can potentially increase turbulence. Since pure oxygen is five times more soluble in water, it can be beneficial to use over air as the injection rate is much lower. A drawback of pure oxygen is that it requires equipment for on-site generation or needs to be delivered regularly.

Nitrate Addition

Nitrate can also be used to mitigate the release of odorous compounds. Similar to the addition of DO, nitrate is a common electron acceptor preferred over sulfate by facultative and obligate anaerobic bacteria (the bacteria are responsible for odor generation due to the conversion of sulfate to sulfide). The addition of nitrate will also remove sulfides through biochemical reactions which convert sulfide back into sulfate. Nitrate is added in a soluble form as a liquid solution, which can provide for a simpler application than air or oxygen injection.

Chemical Oxidation

Chemical oxidants convert sulfide to sulfate or elemental sulfur, depending on pH, through oxidation-reduction reactions. These reactions reduce the concentration of dissolved H₂S that can transfer to the gas phase. Commonly used oxidants include chlorine, hydrogen peroxide, and less commonly, potassium permanganate. Due to rapid reaction times, oxidizing agents are best used when immediate odor control is required. However, oxidizing agents can also react non-discriminately with other compounds present in wastewater, requiring a larger amount of chemical (above the stoichiometric amount required) to be effective. These products are also typically designated as hazardous and have safety, storage, and handling considerations.

Iron Salts

Another method of liquid-phase H₂S control involves dosing iron salts into the wastewater upstream of a WRRF. The iron salts bind with sulfide and form iron sulfide precipitates, which settle rapidly in quiescent conditions. This process can also provide treatment benefits by removing phosphate. While oxygen, nitrate, and chemical oxidation provide control of sulfide and other compounds (particularly reduced sulfur organic compounds), iron salts are limited to treating sulfide. A variety of iron salts can be used including ferric chloride, ferric sulfate, ferrous chloride, and ferrous sulfate. Iron salts are corrosive, can stain infrastructure, and can affect treatment systems such as UV disinfection. Care should be used when storing and handling these products.

Adjustment of pH

The release of odorous compounds, particularly sulfide, is a pH-dependent process. As shown in Figure 2, at a pH of 7.0, approximately 50% of the sulfide in wastewater is present as dissolved hydrogen sulfide gas (H₂S) and the other 50% is present as dissolved sulfides (HS⁻ and S₂⁻). At a pH of 8, the percentage as H₂S gas is only 10% and the remainder is ionic – only the H₂S form will be stripped to air. Continuous pH

adjustment can be utilized to mitigate the release of odorous compounds from the wastewater using chemicals such as magnesium hydroxide, calcium hydroxide, sodium hydroxide, and lime. Additionally, periodic pH spiking (or slug dosing) can temporarily kill the anaerobic bacteria that generate sulfide. A drawback of pH spiking is that reduction in sulfide generation only lasts days to weeks and the very high increase in pH can have negative effects in the downstream treatment processes at the WRRF.

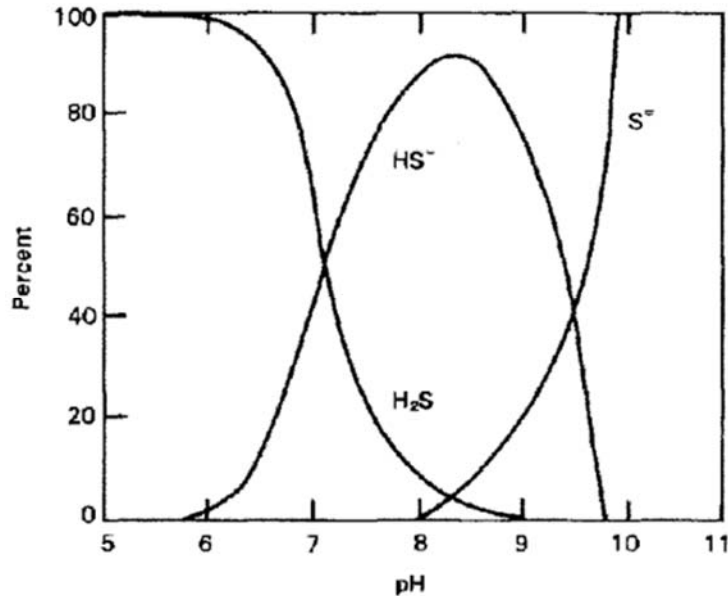


Figure 2—Sulfide Speciation Curves

Table 1 provides a summary of advantages and disadvantages for the liquid phase treatment options.

Mode	Chemical	Advantages	Disadvantages
Prevention	<ul style="list-style-type: none"> > Oxygen > Nitrate > Caustic (slug dose) 	<ol style="list-style-type: none"> 1. Can be cost effective for low sulfide concentrations and high flows 2. Non-hazardous and safe to handle (except for slug dosing) 3. No disruption of downstream treatment (except slug dosing if close to WWTP) 	<ol style="list-style-type: none"> 1. Less cost effective for higher sulfide concentrations and low flows 2. Requires 30 to 60 minutes of HRT 3. Slug dosing is temporary (days to weeks)
Oxidation	<ul style="list-style-type: none"> > Hydrogen Peroxide > Hypochlorite > Potassium Permanganate 	<ol style="list-style-type: none"> 1. Indiscriminate – can be effective for H₂S, as well as other odor compounds 2. Fast acting, no retention time 	<ol style="list-style-type: none"> 1. Can be costly compared to other options 2. High doses can be required 3. Safety and storage/handling issues
Precipitation	<ul style="list-style-type: none"> > Ferrous Sulfate > Ferrous Chloride > Ferric Sulfate > Ferric Chloride 	<ol style="list-style-type: none"> 1. Can aid solids settling and dewatering 2. Aids in phosphate removal 3. Can be economical 	<ol style="list-style-type: none"> 1. Corrosive/hazardous 2. Can cause staining 3. Initial pH drop and H₂S off-gassing 4. Can impact treatment systems such as UV disinfection
pH Adjustment	<ul style="list-style-type: none"> > Magnesium Hydroxide > Calcium Hydroxide > Caustic > Lime 	<ol style="list-style-type: none"> 1. Economical for high sulfide concentrations or lower flows 2. Can provide alkalinity 3. Can be non-hazardous (magnesium hydroxide) 	<ol style="list-style-type: none"> 1. Dilution from downstream flows 2. Can require freeze protection and mixing 3. Dosing can be difficult to control 4. Can be hazardous (caustic)

Table 1 – Summary of Liquid Phase Treatment Options

Containment and Ventilation

A key factor for the success of any vapor-phase odor control system is the efficacy of the containment and ventilation equipment. Proper containment and ventilation includes structures and equipment, such as covers, ductwork, and fans, that maintain negative air pressure in the contained air space to ensure emissions are captured and conveyed to the odor control system. Typically, a fan is designed to create this negative air pressure by venting the odorous air at a rate that is greater than the supply of air to the same air space cavity.

The ventilation rate refers to the volume of air removed from the space over time. Ventilation rates for odor control may be lower or higher than the ventilation requirements for other purposes such as compliance with electrical code requirements (such as NFPA 820), the presence or absence of workers (health and safety), and other considerations. The ventilation rate required to contain odors, reduce corrosion, provide for a safe and comfortable worker environment, and minimize the volume of air to be treated can be selected based on experience with designing similar systems. Designers often rely on building codes, which include mechanical, fire protection, and electrical codes, leakage rates, and other industry standards as the basis of their ventilation designs.

Odorous Compound Treatment

Once the foul air has been captured and conveyed by use of covers, ductwork, and fans, the air is treated to remove odorous compounds. Vapor-phase odor treatment technologies commonly fall into one of four categories:

- Chemical Scrubbers;
- Biological Treatment;
- Media Adsorption Units; and
- Ionization Systems.

Chemical Scrubbers

Using chemicals like sodium hydroxide and sodium hypochlorite, chemical scrubbers convert odorous compounds (e.g. sulfur-based) to a non-odorous salt either by acid-base or oxidation-reduction reactions. Chemical scrubbers can also employ different chemicals for the varying odorous compounds they are treating. For instance, ammonia and trimethylamines are absorbed with an acid recirculation liquid (pH 1.5 to 5) using sulfuric acid. Odorous compounds to be treated in scrubbers can include H₂S; organic sulfides, such as methyl mercaptan, dimethyl sulfide, and dimethyl disulfide; and ammonia. While VOCs, can be treated in chemical scrubbers, it is often more desirable to use carbon adsorption or thermal oxidation for VOC control.

Biological Treatment Systems

Biological systems provide efficient odor treatment naturally by promoting bacterial cultures to oxidize sulfides with metabolic processes. Biological systems rely on a combination of three basic biochemical processes—autotrophic, heterotrophic, and biological-uptake

processes. Two categories of biological treatment systems are commonly utilized for odor control, including biofilters and biological trickling filters (BTFs).

Biofilters

Biofilters pass odorous air streams through an organic or inorganic bed of media. The media in biofilters is used to promote bacteriological growth that can be used to break down odorous compounds biologically. The primary design criteria for biofilters is the empty-bed contact time (EBCT), which varies based on the odorous compounds being treated and the type of media utilized. *Thiobacillus*, for instance, requires 15 to 25 seconds to oxidize H₂S. Alternatively, heterotrophic organisms require more contact time – around 30 to 60 seconds – for larger organic molecules such as mercaptans and dimethyl sulfide.

Biofilter media can be organic (compost, bark, wood chips) or inorganic (sand, gravel, volcanic rock, oyster shells, clay-based media, or synthetic media). The selection of the media depends on the nutrient requirement and corrosion resistance needed. Inorganic media, for instance, is typically more resistant to acid and corrosion byproducts but requires the addition of nutrients, to promote bacteriological growth.

Biological Trickling Filters

As with biofilters, biological trickling filters (or biotrickling filters, BTFs, bioscrubbers), use biochemical processes to oxidize odor compounds. A BTF functions much like a conventional chemical packed-bed scrubber, except that the chemical solution has been replaced by a bioactive solution. The bioactive solution is distributed over the top of a synthetic packing media in a vessel, while the odorous air is forced upward. While most of the biomass in biofilters is attached to media (fixed film), some of the biomass in BTFs is suspended in the bioactive solution.

With BTFs, odorous compounds are absorbed or dissolved into the bioactive solution, where the microorganisms can oxidize them partially. Nutrient supplement is commonly required to promote heterotroph biomass growth.

Dry Adsorption Systems

Activated carbon (AC) has been used to control odors for over 100 years. AC is typically made by thermal decomposition of high-carbon content materials such as coal, wood, peat, and coconut shells. Presently, both AC and specialized media are used to remove odors from air using a naturally occurring phenomenon called adsorption, in which molecules in the air stream are trapped by cavities in the media's surface (both internally and externally). The performance of the media will vary based on the surface area, pore size, and oxidation properties. The main design factor for dry adsorption systems is the media face velocity, which is also a function of bed residence time. Dry adsorption systems, are best suited for low loading rates.

Virgin Carbon

Virgin bituminous and coconut-based activated carbons adsorb volatile and odorous organic compounds, but they have a relatively low capacity to adsorb inorganic H₂S. For this reason, WRRFs don't typically use virgin carbon for high H₂S applications. Virgin coconut shell carbon is effective for reduced sulfur organic compounds. Virgin carbon can also be thermally reactivated allowing it to be regenerated to near to its original adsorption capacity. Each subsequent regeneration process further reduces the available adsorption capacity, however. Due to the infrastructure required, thermal regeneration is typically not performed at the WRRF. Unless the carbon is shipped off-site for regeneration, once this media capacity is used and the media is spent, it has to be replaced.

Impregnated Activated Carbon

Chemicals, such as caustic, can be impregnated into activated carbon to promote higher H₂S removal efficiencies and capacities. A drawback of this method is that the impregnate reduces the carbon's adsorption capacity for VOCs and organic compounds. Additionally, the impregnated carbon can be reactive with oxygen, which can cause smoldering or spontaneous combustion without sufficient airflow to dissipate the heat. On-site regeneration is typically not a recommended option due to the hazards and complexity involved. Caustic impregnated carbon was initially introduced in an attempt to increase H₂S capacity compared to virgin coconut shell carbons.

High H₂S Capacity Catalytic Carbon

Catalytic carbon is a bituminous AC with finer pores, giving it a higher density. It's capable of higher adsorption rates than virgin activated carbon and promotes a reaction between H₂S and oxygen from the airstream to produce sulfate (nearly 90% of sulfide), instead of elemental sulfur. While elemental sulfur cannot be removed from the AC after adsorption, sulfate is water-soluble and can be washed out of the carbon. In general terms catalytic carbons will have a higher H₂S capacity than virgin coconut shell carbon but they may be less effective on the reduced sulfur organic-based odorants.

Specialized Adsorption Media

Specialty adsorptive media is commercially available, including products such as permanganate-impregnated zeolite and permanganate-impregnated activated alumina. These media function by way of both adsorption of odorous compounds and oxidation/neutralization of the odors. Specialty, non-carbon, media has a lower capacity than carbon for H₂S, but presents advantages with respect to the ability to treat reduced sulfur compounds such as mercaptans and dimethyl sulfide. Thus, an initial layer of high H₂S-capacity activated carbon followed by a polishing layer of permanganate-impregnated media can provide for a broader range of odorous compounds removal from a foul air stream.

Ionization Technologies

Ionization technologies are an emerging group of processes that use oxygen (O₂) and water vapor in the air to create highly-reactive oxygen molecules such as ozone O₃, OH⁻, O₂⁻, O₂⁺, and O[•]. These technologies use the highly-reactive molecules to oxidize odorous compounds produced by the WRRF and include:

- Electro-oxidation;
- Photoionization; and
- Ionized air oxidation.

Electro-oxidation

With electro-oxidation units, a side-stream of fresh, ambient air is passed through an electrical field and the electrical current splits oxygen (O₂) molecules into highly-reactive molecules, including ozone and hydroxyl radicals. This air stream is combined with the odorous air stream to oxidize the odorous compounds present.

Photoionization

Photoionization uses UV light and a catalyst to oxidize odor-causing compounds in a treatment chamber outside of a wet well, channel, or process tank. Like electro-oxidation, UV light creates oxidizing agents from air that oxidize H₂S and other odor-causing compounds (i.e. ozone and hydroxyl radicals). Compounds not treated in the UV light compartment, proceed to the catalyst, in the treatment chamber, where they are trapped and oxidized by the constant stream of oxidizing agents through various reactions including catalysis.

Ionized Air Oxidation

Instead of pulling odorous air out of a contained area to be treated, air ionization is a process by which air with positive and negative oxygen ions are introduced into the contained area to react with odorous compounds. Ambient air is filtered and then passed over ionization tubes, creating an electromagnetic field, or corona. The reactive oxygen ions form ion clusters, which are used to oxidize odorous compounds by blowing air into a contained area. However, some forms of this technology have been known to cause corrosion of rubber materials in certain applications.

Category	Type	Advantages	Disadvantages
Chemical Scrubbers	<ul style="list-style-type: none"> > Caustic/ Hypochlorite > Acid > Other 	<ol style="list-style-type: none"> 1. High-efficiency H₂S removal 2. Can oxidize a wide range of odor compounds 3. Has been a commonly used treatment technology for decades 	<ol style="list-style-type: none"> 1. Storage/handling considerations, hazardous chemicals 2. Higher operating and maintenance costs/requirements 3. Operational attention for proper efficiency and minimized scaling 4. Additional instrumentation and controls, increased complexity
Biological	<ul style="list-style-type: none"> > Biofilter > Biological Tricking Filter 	<ol style="list-style-type: none"> 1. Green technology 2. High-efficiency H₂S removal 3. Lower operating and maintenance costs 4. No handling and storage considerations of hazardous chemicals 	<ol style="list-style-type: none"> 1. Acclimation period (up to a month) 2. Biological activity is somewhat susceptible to process fluctuations 3. Longer contact time required for odor compounds other than H₂S 4. Low pH blowdown
Adsorption	<ul style="list-style-type: none"> > Virgin Activated Carbon > Catalytic Carbon > Impregnated Carbon > Specialized Media 	<ol style="list-style-type: none"> 1. High H₂S removal (at low concentrations) 2. Simple to operate and maintain 3. No continuous chemical, water, or nutrient consumption 4. No handling and storage considerations of hazardous chemicals 	<ol style="list-style-type: none"> 1. Periodic media replacement can be labor and equipment-intensive process 2. Rapid breakthrough of media depending on odor loading 3. Difficulty removing compounds other than H₂S (layered specialty media)
Ionization	<ul style="list-style-type: none"> > Electro-Oxidation > Photoionization > Ionized Air 	<ol style="list-style-type: none"> 1. Can oxidize a wide range of odor compounds (ozone/hydroxyl radicals) 2. No chemical, water, or nutrient consumption 3. Low maintenance requirements 4. No handling and storage considerations of hazardous chemicals 	<ol style="list-style-type: none"> 1. Less commonly used historically 2. Less proven technology 3. Response time to fluctuations in odor 4. Potential for excess ozone in exhaust stream

Table 2—Summary of Vapor Phase Treatment Technologies

References

- Manual of Practice 8, Design of Municipal Wastewater Treatment Plants (WEF, 2017)
- Manual of Practice 25, Control of Odors and Emissions from Wastewater Treatment Plants (WEF, 2004)
- Biosolids and Residuals Management Fact Sheet, Odor Control in Biosolids Management (EPA, 2000)
- Figure 1 Source: Joyce, P.E., Jim. Understanding Odor and Corrosion in Collection Systems: The State of the Science. WEF Workshop, October 2009.
- Figure 2 Source: USEPA. Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants. EPA/625/1-85/018, October 1985.

Acknowledgments

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