

Odor Control "ABC's"

How to Compare and Evaluate Odor Control Technologies

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Introduction - The Challenge:

Odor complaints may be caused by a variety of odorous compounds that are released or generated by various wastewater processes. The major types of odors generated in wastewater treatment facilities are:

1. Amines (fishy odor quality)
2. Ammonia, NH₃ (ammoniac odor quality)
3. Diamines (decayed flesh odor quality)
4. Hydrogen Sulfide, H₂S (rotten eggs odor quality)
5. Mercaptans (skunk odor quality)
6. Organic Sulfides (rotten cabbage odor quality)
7. Skatole (fecal odor quality)

Treatment facility personnel and the consulting engineering community are generally aware of many of technologies available to treat these odors. However, these groups are often hindered in their attempts to make the proper technology selection by the lack of an effective, unbiased means to compare the relative merits of each technology.

A new standard of measurement for Wastewater Treatment Plants odor removal annoyance is in the process of being established. This new standard will be based on the intensity of detection threshold and not solely upon concentration (e.g. ppm) of certain target compounds. The new standards will include the influence of H₂S and other complex odorous compounds and a combined measurement of total odor units. Odor samples will be collected and sent to a certified odor panel testing lab. The odor panel will judge the sample for odor units to verify that the odor sample has been weakened / diluted to a predetermined detection threshold (D\T).

The information yielded by these tests will provide the municipality with an accurate picture of the odor situation at the given facility. The next step, selection of the proper technology to control the odors, is critical. This paper is an attempt to aid in that selection.

Goals and Objectives:

The primary goal of this paper is to provide unbiased technical information to the municipal wastewater community, allowing owners and engineers to compare currently commercially available odor control technologies. To accomplish our goal, we will achieve these objectives:

1. To describe the more commonly available treatment technologies
2. To discuss several of the more common odor problems present in both wastewater treatment plants as well as the collection system, and to summarize how best to apply the technologies to the particular problems.

I. Currently Available Odor Control Technologies:

There are a wide variety of odor control products available on the market today. The majority can be grouped into three distinct categories:

1. Adsorption (activated carbon and other adsorptive medias)
2. Biological Oxidation (bio-filtration and bio-scrubbing)
3. Chemical Scrubbing (acid and caustic wet scrubbing)

To these, a fourth category can be added – Combined Technologies. This would encompass the concept that often the most effective means to solve a particular odor problem is to combine one or more of the three major technologies.

Each technology has strengths and weaknesses. We have examined each technology with the following parameters in mind:

- a. General description of the technology and how it works for odor control.
- b. Odors most effectively and least effectively treated and removal efficiencies.
- c. Air flow capacities.
- d. Capital and operating costs.
- e. Operation and maintenance considerations (e.g. frequency of down time, ease of servicing, utility requirements, footprint and overhead clearance requirements).
- f. A general idea of when to and not to apply the technology.

Chemical Absorption:

A. General Description:

Chemical Absorption is defined as:

“The taking of molecules of one substance directly into another substance. It is contrasted with adsorption, in which the molecules adhere only to the surface of the second substance. Absorption may be either a physical or a chemical process, physical absorption involving such factors as solubility and vapor-pressure relationships and chemical absorption involving chemical reactions between the absorbed substance and the absorbing medium.”

This technology is widely known in the odor control industry as chemical wet scrubbing.

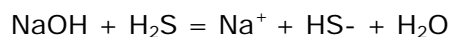
Chemical scrubbers have long been one of the most common odor control technologies used throughout the United States in the municipal wastewater industry and their performance characteristics on odorants are well documented. Chemical scrubbing has been shown to be highly effective on H₂S and ammonia odors which are the most predominant odorous compounds found in municipal wastewater treatment systems.

Chemical scrubbers achieve odor removal by mass transfer absorption via contact of the air stream with aqueous solution on random packing material in a scrubbing chamber. The liquid is typically water, adjusted to the proper pH and oxidation potential by chemicals. Two parameters define the performance of any absorption scrubbing system. These are the efficiency of gas/liquid contact and the adequacy of a chemical within the aqueous phase to promote reaction and absorption. The packing media must have a high active surface area for gas/liquid contact promoting an even liquid and gas distribution for high mass transfer rates. The wastewater treatment industry has standardized on the use of sodium hydroxide and sodium hypochlorite to control H₂S and sulfuric acid to control ammonia odors. Maintaining the chemical conditions favorable for ultimate performance is critical. The desired ORP and pH chemistry is typically adjusted at the site based on the actual gas components present.

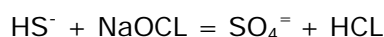
It is important to note, when necessary to remove ammonia with sulfuric acid an additional chamber will be required.

The following simplified equations illustrate the chemical combinations and typical pH/ORP settings for the removal of H₂S and ammonia in conventional chemical scrubbing systems:

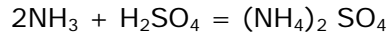
Absorption Process (caustic soda only)



Adsorption with Oxidation (caustic soda and bleach)



Absorption of Ammonia with Acid



Caustic Soda Scrubbing Settings:

pH = 11.0 to 11.5

Caustic Soda and Bleach Scrubbing Settings:

pH = 9.5 to 10 units, ORP = 600 – 700 mv

Sulfuric Acid Scrubbing Settings:

pH = 4.0 to 6.0

B. Odors Most / Least Effectively Treated and Removal Efficiencies:

When configured as a two-stage caustic/bleach system, chemical wet scrubbers can achieve 99% removal of H₂S. When a third stage (usually the first in line) is added with acid for ammonia removal, ammonia can also be removed in the 99% efficiency range. Caustic wet scrubbers are generally much less effective on organic sulfur compounds, with removal efficiencies between 20% and 70%.

OU Reduction:

As with bio-scrubbers, chemical wet scrubbers can achieve good effluent OU levels on air streams whose sole odor contributor is H₂S. However, when the air stream includes organic sulfur compounds as well as H₂S, the effluent OU levels can exceed 1,000 OU.

C. Air Flow Capacities:

Chemical scrubbers can come in a wide range of sizes, with single systems available from small 50 cfm units to massive 40,000 cfm units.

D. Capital and Operating Costs:

Chemical Scrubber O&M (10,000 cfm, 100 ppm H₂S)

Capital	\$206,000
Annual Operating & Maintenance	\$148,000
10 year Investment	\$1,686,000

E. Operation and Maintenance Considerations:

As chemical scrubbers treat air at the highest velocity of all of the odor control technologies under discussion, often around 400 feet per minute, the scrubber vessels themselves have the smallest footprint of any odor control system. However, to the footprint of the scrubber vessel must be added the space required for the chemical storage tanks (usually at least two tanks), pumps, controls, and other ancillaries. When the other hardware is added, chemical scrubbing systems will usually take up more space than activated carbon systems, although still less than any biological technology. Older chemical scrubbers used tall vertical towers, and often resulted in systems in excess of 20' tall. Newer generations of scrubbers have gone to a horizontal or low profile design, decreasing height at the expense of increasing footprint.

Chemical scrubbers require the most numerous and sophisticated controls and instrumentation of any of the odor control technologies under discussion. Instruments include pH and ORP sensors, metering pumps (sometimes linked to and controlled by H₂S monitors), recirculation pumps, level switches linked to chemical supply tanks and alarms,

and fan controls. This makes chemical scrubbers the most complex and maintenance intensive of all odor control technologies.

Chemical scrubbers require periodic replenishment of their chemical supply. Usually, this includes sodium hydroxide, sodium hypochlorite, and, if ammonia is also being treated, sulfuric acid. Often, chemicals are replenished every 30 to 60 days.

F. When and When Not to Use:

Chemical scrubbing is best suited for applications at the wastewater plant itself, as opposed to the collection system, as the high maintenance requirements of chemical scrubbers are best handled at permanently manned facilities. Caustic scrubbers are well suited to handle high H₂S levels such as those found at headworks and sludge facilities. Acid scrubbers for ammonia removal are effective on processing like composting facilities where ammonia is likely to be formed.

Biological Oxidation:

A. General Description:

Biological Oxidation is defined as:

"The process by which bacteria and other types of micro-organisms consume dissolved oxygen and organic substances in waste water, using the energy released to convert organic carbon into carbon dioxide and cellular material."

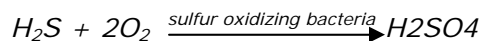
Biological oxidation has been applied to odor control for years, typically referred to (rather inaccurately) as "biofiltration". The term biofiltration is a misnomer as the process involves metabolic conversion of odorous compounds as opposed to filtration. Biological oxidation today is broken into two broad categories:

- 1) Bio-oxidation using inorganic media ("bio-scrubbers" or "biotrickling filters").
- 2) Bio-oxidation using organic media (traditionally referred to as "biofilters").

Bio-oxidation Using Inorganic Media: Bio-scrubbers:

In an effort to eliminate the high chemical and maintenance costs associated with chemical scrubbers, bio-scrubbers were developed to remove sulfide based odor off-gasses, primarily hydrogen sulfide (H₂S), utilizing a smaller footprint than a biofilter.

Bio-Scrubber[®] system components, structure and media ecosystem were designed for a corrosive environment and continuous operation during a fifteen to twenty year life cycle. Bio-Scrubber[®]'s operate similarly to biotrickling filters and wet packed chemical scrubbers. However, they contain an acid resistant inert high porosity media. Secondary effluent solution, or make-up water, containing mineral nutrients and trace elements recirculate either co-current or countercurrent to the odorous air being treated. The recirculating solution and media serve as an ecosystem to optimize the growth of thin film sulfur-oxidizing bacteria, principally thiobacilli.



Because the byproduct of biological hydrogen sulfide oxidation is sulfuric acid, the recirculation solution must have adequate blowdown rates to ensure that the acid concentration does not increase to the point that it limits the solubility of hydrogen sulfide in the water. Although the sulfur-oxidizing bacteria can survive a pH well below 1.0, an optimum balance for both the growth of the bacteria and the solubility of hydrogen sulfide is achieved in the range of 2.0 to 3.0.

The low pH blowdown water is weak in acid concentration and may be redirected into the plant process wastewater stream to neutralize acid without any effect on the process.

Compared with other hydrogen sulfide control technologies, the Bio-Scrubber®'s operational costs are very low because microbial oxidation occur at ambient temperatures, no chemicals are consumed, and a minimal amount of labor is required for maintenance.

The Bio-Scrubber® has proven cost effective as a stand-alone H₂S and ammonia scrubber and as a first-stage combination companion with biofilters and carbon adsorbers for removing VOCs and complex odor compounds, greatly extending the life of the organic media or carbon bed.

B. Odors Most / Least Effectively Treated and Removal Efficiencies:

Bio-scrubbers are most effective against H₂S. The optimum H₂S treatment range is between 10 and 1000 ppm of H₂S. Within this range, bio-scrubbers should deliver a minimum of 98% removal capacity, and often the removal capacity is greater than 99%.

Effectiveness versus organic sulfur compounds appears to be limited. The thiobacillus is less effective in consuming these compounds.

Ammonia and amines can be removed by bioscrubbers as a secondary effect of the H₂S removal process. As previously discussed, the byproduct of H₂S consumption is sulfuric acid. This allows the Bio-scrubber® to effectively function as an acid scrubber for ammonia and amine reduction. Removal efficiencies in the high 90% ranges are typical.

OU Reduction:

While bio-scrubbers have high removal efficiency for H₂S, their lower efficiencies on other compounds means that while their average odor unit (OU) effluent level for H₂S -only air streams can be very good, it can be as high as 1,000 OU for a mixed contaminant air stream.

C. Air Flow Capacities:

Bio-scrubbers are supplied in a range of sizes, from small 50 cfm units to individual vessels designed to treat 10,000 cfm. Larger flows than 10,000 cfm can either be handled by multiple "standard" vessels or by large "custom" vessels erected on site.

D. Capital and Operating Costs:

Bio-Scrubber® O&M (10,000 cfm, 100 ppm H₂S)

Capital	\$383,000
Annual Operating & Maintenance	\$10,200
10 year Investment	\$485,000

E. Operation and Maintenance Considerations:

Bio-scrubbers require a fan, flow control dampers, and a recirculation pump. Media life is generally 10 years or longer. It is even possible that bio-scrubbers might never require a media change-out. Bio-scrubbers generally do not require instrumentation or controls beyond a simple pH meter and a fan control panel.

Bio-scrubbers tend to be tall vessels, often 20 to 30 feet in height. Footprint requirements are similar to carbon systems.

F. When and When Not to Use:

Bio-scrubbers are best used for removal of moderate to high levels of H₂S (concentrations from 5 to 1000 ppm). As secondary effluent is the ideal source of irrigation water for bio-scrubbers, these systems are best employed at wastewater treatment plants, although they can be used in the collection system with supplementary nutrient supplies. Applications that have ammonia as well as hydrogen sulfide are also well suited for bio-scrubbers.

Bio-scrubbers are not recommended for H₂S concentrations that are low or highly variable, as the bio-colony will not respond quickly to changes in concentration. As with any biotechnology, intermittent applications such as CSO's are also not effectively treated by bio-scrubbers, as the colony will either die off or become dormant during times when there are no odorous compounds present.

Bio-oxidation Using Organic Media: Biofilters:

What is a biofilter? Filter suggests a physical mesh that removes particles from the air, but that is misleading. Bio-filtration is actually an air treatment process based on processes that are literally as old as dirt. Nature has provided bacteria and fungi that are capable of using almost any organic material as a food source. These microbes are plentiful in organic soils and decaying vegetable matter (e.g., the farm compost pile). Biofilters are a controlled environment where the organic odors and VOCs are brought in contact with the natural microorganisms that can use them as a food source. The concept is to pass the contaminated air-stream through a biological matrix material, such as compost, where the microbes will capture and eat the VOCs and odors simply finishing what nature started.

Traditional biofilters have successfully used these principles for decades, with more widespread use in Europe than the United States. They have typically been very large, in-ground, single-layer units that rely on a loose bed of organic media, on top of a crude air disbursement system, utilizing a sprinkler type irrigation to control conditions for treatment. Such systems are typically open-topped, with the top of the media bed exposed to the elements. In recent years engineered biofilters have been developed with a variety of advances to increase their efficiency of treatment and reduce their footprint. The contaminated air stream is conditioned to maintain temperature and humidity levels ideal for the metabolism of the microbes. The compost or organic media that supports the microbes is structured (sometimes combined with inorganic structural elements) to increase the effective surface area and allow treatment throughout the depth of the beds.

Biofilters can handle the removal challenge of a diverse mix of complex odors and VOCs better than any other odor control technology available. However, there are significant limitations in handling levels of hydrogen sulfide (H₂S) loadings above 5 ppm. The high levels of H₂S loading in biofilters will create an increase in the thiobacillus colony causing an overproduction of acid. This will destroy all biodegrading microorganisms and fungi that feed on the more complex odor compounds that are not capable of surviving in a low pH environment. A loss of treatment efficiency, compaction and channeling of the organic media will occur. In addition to these drawbacks, sulfur accumulation in the bed from partial oxidation of H₂S can also affect performance by coating the media and increasing the head losses. Alkalinity may be added, but this is soon exhausted by sulfuric acid production. The spent minerals will often form small particles which also contribute to biofilter clogging and premature replacement of media.

B. Odors Most / Least Effectively Treated and Removal Efficiencies:

Organic compounds are very effectively treated with biofilters. This includes the class of reduced sulfur compounds typically found in municipal wastewater air streams. Amines and ammonia are also effectively treated with bio-filtration.

In contrast with activated carbon, bio-filters prefer higher concentrations of organic compounds, as these compounds constitute a food source for the biology – the higher the concentration, the larger and more robust the biological colony. As discussed, hydrogen sulfide in low to moderate levels (up to roughly 10 ppm) can also be effectively and economically treated by bio-filters. However, higher loadings will cause a loss of capacity for the other odorous compounds and a host of other problems as previously noted above.

Efficiencies and OU Reduction:

Biofilters tend to have lower efficiencies than the other odor control technologies, achieving removal efficiencies ranging from 50% to 95% of all incoming contaminants. The older generation of open-top, in-ground biofilters often tend towards the lower end of this spectrum, as compaction, channeling, and deterioration of the exposed media contribute to the loss of effectiveness. Engineered biofilters are much more capable of achieving the 90% and above efficiencies often required at municipal wastewater facilities. Removal efficiencies are also dependent upon the contact times used. Biofilters generally operate with contact times between 15 to 60 seconds, with higher contact times resulting in higher efficiencies. Biofilters typically achieve an average odor unit (OU) effluent level between 200 and 400 OU.

C. Air Flow Capacities:

In-ground biofilters are limited in air flow capacity only by the amount of real estate available to the user. However, as most in-ground biofilters can only process air at a rate of 5 feet per minute, the real estate requirements can be vast. A 10,000 cfm in-ground biofilter can require a footprint of 2,000 square feet, or in other words, a 45' x 45' space. By contrast, a 10,000 cfm activated carbon system would require a footprint of only 166 square feet. Engineered biofilters, which often process air at rates between 25 and 50 feet per minute, greatly reduce the footprint required. Engineered biofilters are available in single vessel sizes up to 8,000 cfm, with larger flows handled either with multiple vessels or large field-erected vessels.

D. Capital and Operating Costs:

Biofilter O&M (10,000 cfm, 5 ppm H₂S)	
Capital	\$355,000
Annual Operating & Maintenance	\$65,000
10 year Investment	\$1,005,000

E. Operation and Maintenance Considerations:

All properly designed biofilters require fans and dampers to provide and regulate odorous air supply to the biofilter. Additionally, biofilters must be kept hydrated, so an irrigation system is also required. Normal fan and pump maintenance must be performed. Some biofilters also require the addition of nutrients and/or buffering chemicals, requiring additional storage tanks and pumps. In-ground biofilters can require media change-outs every two to three years, while engineered biofilters, with their structured media protected from the elements, can often go five years or longer without a media change.

In-ground biofilters require access for heavy equipment such as front-end loaders and dump trucks to perform media change-outs. Such change out operations can take up to two weeks, including excavating and hauling away spent media, repairing or replacing the air distribution piping, installing new media, and reassembling the irrigation system.

Engineered biofilters are much simpler to service, requiring only access to remove spent media and refill fresh media into the vessel.

Unloading is usually accomplished by means of vacuum extraction of spent media through a manway in the vessel, while loading is accomplished by dumping media in through the same manway. Such operations take several days at most.

F. When and When Not to Use:

Biofiltration is best used to treat odor streams that contain a mixture of organic compounds in concentrations in the ppm range. Low levels of H₂S (10 ppm and less) are also effectively treated. Applications where odor loadings are generally constant are also well suited for biofiltration.

Biofiltration is not recommended for applications with high (greater than 10 ppm) loadings of hydrogen sulfide. Biofilters are also not recommended for applications with either intermittent or highly variable loadings.

Adsorption:

A. General Description:

A common textbook definition of adsorption reads:

"(1) The adherence of ions or molecules in solution to the surface of solids. (2) The adherence of a gas, liquid, or dissolved material on the surface of a solid. (3) The attraction and adhesion of a layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact. An example is the adsorption of organic materials by activated carbon. Not to be confused with Absorption."

In terms of odor control, adsorption typically refers to the use of activated carbon to adsorb odorous compounds into the activated carbon material. This is usually accomplished by passing the odorous air across a bed of activated carbon, allowing the adsorptive process to occur, and releasing the now clean air into the atmosphere.

Adsorption, again primarily in the form of activated carbon (other adsorptive materials used include zeolite, potassium permanganate, and activated alumina) has been used in odor control at least since the mid-1970's. Activated carbons for odor control are not all created equal, but can be broken down into several classes:

1. Standard Activated Carbon Utilizing Physical Adsorption
2. Caustically Impregnated Carbon Utilizing Chemisorption
3. Blended Medias Utilizing Chemisorption
4. Catalytically Enhanced Carbons

Standard activated carbon works by capturing hydrogen sulfide and various organic molecules within the graphitic platelet structure of the carbon granules. Activated carbon has a specific capacity for each of these compounds; once this capacity is reached, subsequent incoming compounds "breakthrough" untreated.

Caustically impregnated carbons using sodium hydroxide or potassium hydroxide were introduced in the late 1970's to improve activated carbon's hydrogen sulfide removal performance. While standard carbons have a generally poor H₂S removal capacity, the addition of caustic soda produced an activated carbon with a greatly enhanced H₂S capacity. With caustically impregnated carbons, the H₂S molecule is first physically adsorbed and then converted to sulfur through a chemical reaction with the caustic, hence the term "chemisorption". Activated carbon has much greater capacity for sulfur than for H₂S and as a result, caustically impregnated carbon's H₂S capacity was usually on the order of five to seven times greater than standard carbon.

This enhanced performance did not come without a price, however. The impregnated carbon sacrifices capacity for all compounds other than H₂S, and has a lower ignition temperature than standard carbon, which greatly increases the chances of experiencing a carbon bed fire.

Blended carbon medias are close relatives to caustically impregnated carbons. In this case, the metal oxide (typically magnesium oxide) is added in solid form at the beginning of the manufacturing process, rather than sprayed on in liquid form at the end of manufacturing process. As with caustically impregnated carbons, blended medias attempt to enhance the carbon's H₂S capacity by promoting a chemical reaction between the H₂S and the metal oxide to form elemental sulfur. Blended carbon medias, like their impregnated cousins, also have relatively depleted capacity for organic compounds since the magnesium oxide is a non-adsorptive material that does not contribute to adsorption of organic compounds. However, blended medias do not exhibit the lowered ignition temperatures that are a characteristic of impregnated carbons.

Catalytic carbons are the newest class of activated carbons for odor control. These carbons also exhibit an enhanced capacity for H₂S, but achieve this increased capacity differently than do caustically impregnated or blended carbons. Catalytic carbons convert adsorbed H₂S into sulfuric acid and sulfurous acid, which is stored more efficiently on carbon than is H₂S (but not as efficiently as elemental sulfur). A key advantage of catalytic carbons is that the converted acids are water soluble, allowing the carbon to be regenerated in place by simply washing it with water. Catalytic carbons do not have impregnants and therefore do not exhibit the reduced organic odor capacity nor increased bed fire potentials of the impregnated carbons.

B. Odors Most / Least Effectively Treated and Removal Efficiencies:

Hydrogen Sulfide:

As discussed in the general description of adsorption, activated carbons can exhibit a wide range of H₂S capacities, depending upon the type of carbon used. An industry standard test, ASTM D-6646, was adopted years ago in an attempt to provide a common measuring stick for activated carbon H₂S capacities. This test yields a H₂S capacity measured in grams of H₂S removed per cubic centimeter of carbon utilized. The following table allows for a simple comparison of the carbons discussed:

Carbon Type	H ₂ S Capacity	Notes
Standard Carbon	0.01 – 0.03 g/cc	1
Impregnated Carbon	0.12 – 0.14 g/cc	
Blended Carbon	0.14 – 0.27 g/cc	2
Catalytic Carbon	0.09 – 0.63 g/cc	3

Notes:

1. Coconut carbons tend towards the higher (0.03 g/cc) capacity; while direct activated coal based carbons tend towards the lower capacity.
2. Based on multiple test results for various samples of magnesium oxide blended carbon.
3. 0.09 g/cc figure is for initial capacity only, while 0.63 g/cc described ultimate capacity with water washing factored in.

What this means for designers is that standard carbons should only be used to treat low levels (1 to 2 ppm) of H₂S, while impregnated, blended, and catalytic carbons can be economically used to treat H₂S levels as high as 20 to 30 ppm.

Organic Sulfur Compounds:

This class of compounds is the most prevalent in wastewater odor control after hydrogen sulfide. Typical compounds include methyl mercaptan, dimethyl disulfide, and carbonyl sulfide.

In all cases, these compounds will be removed by activated carbon via physical adsorption. Caustically impregnated carbons and blended medias do not provide added capacity for these compounds and in fact, the presence of the metal oxides in or on the carbon decreases the physical adsorptive capacity of the carbons. As these compounds are removed via physical adsorption, there is no way to regenerate the carbon in situ. Carbon can economically treat organic sulfur compounds up to the low ppm (1-5) concentration level. Higher concentrations than these will typically exhaust the carbon so frequently that carbon exchanges will represent an unreasonable expense and operator headache.

Amines:

Activated carbon can provide useful capacity for most amine compounds found in municipal wastewater. However, as with the organic sulfur compounds, carbon has a limited capacity for such compounds and cannot be regenerated in place.

Ammonia:

Most activated carbons are ineffective for ammonia removal. The ammonia molecule adsorbs very poorly on carbon and breakthrough occurs rapidly. Carbon is not typically recommended for ammonia removal. One exception involves the use of acid-impregnated carbon. However, this is usually not as cost effective as other means of ammonia reduction.

Efficiencies and OU Reduction:

Activated carbon has perhaps the highest removal efficiency of any technology described, typically removing 99.9% of all incoming contaminants. Activated carbon also has the lowest average odor unit (OU) effluent level at around 100 OU.

C. Air Flow Capacities:

Carbon adsorption systems come in a wide range of sizes, from small point source units designed to treat air flows from 5 to 50 cubic feet per minute (cfm), to large systems designed to treat up to 30,000 cfm. Higher flows require the use of multiple vessels.

D. Capital and Operating Costs:

(10,000 cfm, 5 ppm H ₂ S)	Unimpregnated	Catalytic
Capital	\$100,000	\$140,000
Annual Operating & Maintenance	\$315,800	\$30,100
10 year Investment	\$3,258,000	\$441,000

E. Operation and Maintenance Considerations:

Activated carbon systems have the fewest moving parts of any of the major odor control technologies. The carbon system itself has no moving parts; the fan and dampers are the only components with moving parts. Carbon systems generally do not require electronic sensors or instruments and generally do not require controls, other than fan motor starters and start-stop buttons.

All carbons except catalytic carbons must be physically removed from the vessel and replaced when the carbon becomes spent. This operation requires that the system goes off line for several days. A service team is called in to vacuum out the spent carbon and haul it to a landfill. The same crew then installs the new carbon (usually contained in 200 pound drums or 1,000 pound sacks) and restarts the system. Overhead clearance of at least 6 feet is usually required to allow for carbon loading and unloading.

Catalytic carbon systems can be water washed to restore H₂S capacity and thereby greatly decrease the frequency of physical change-outs required. The water washing is usually accomplished by municipal personnel and takes about 1 to 2 days.

Standard carbon systems (when not treating H₂S) are usually designed to run for one year before requiring carbon exchange. Impregnated carbons are designed to treat hydrogen sulfide for about a year before requiring replacement. Blended medias provide two to three years of life under normal H₂S loads, while catalytic carbons often provide five years or more of service before requiring replacement.

Activated carbon systems generally have the smallest overall footprint of any of the odor control technologies.

F. When and When Not to Use:

Standard activated carbon systems are best used to treat low levels of organic compounds (generally in the ppb range) and as a polishing system behind another OC technologies. Caustically impregnated carbons are going out of use due to the inherent safety issues with bed fires. Blended media and catalytic carbons are suited for moderate to high levels of hydrogen sulfide, with specialized catalytic systems capable of treating 50 ppm or more of H₂S. All carbon systems are ideal for intermittent flow / loading applications, as carbon provides instantaneous response to changes in odor concentration, and is immediately effective upon start up. Collection system and CSO/SSO applications are ideal for carbon.

Activated carbon is generally not well suited economically for treatment of high loadings of organic compounds (5 ppm and greater). Carbon, regardless of type, is also not recommended for H₂S loadings greater than 200 ppm.

Combination Technologies:

Each of the previously described technologies has distinct strengths and weaknesses. There is some overlap, but there are also many areas where one of the technologies is clearly better than the others. Just as clear, there are often odor control challenges that consist of a combination of odorous compounds. These odor scenarios often cannot be solved with a single system or technology. As an example, it is possible to have an odor stream containing both high levels (30 ppm or more) of H₂S and significant levels of organic sulfur compounds (perhaps 5 ppm of methyl mercaptan). There is no one technology that is going to solve this problem. A carbon system might handle the H₂S if catalytic carbon is used, but the mercaptans will quickly fill up the available adsorption sites and breakthrough. A bio-scrubber likewise could easily handle the H₂S but would not be very effective against the mercaptans; the same would be true of a caustic chemical scrubber. A bio-filter would handle everything for a time, but the high H₂S levels would eventually result in a kill-off of the bacteria that consumes the mercaptans as well as a breakdown in the organic media. In a case like this, a combination system, comprised of two technologies, is going to be the only viable solution. For this particular instance, a first stage system such as a bio-scrubber or catalytic carbon system might be used for removing the H₂S. A second stage bio-filter system would then be ideal to treat the mercaptans and any remaining H₂S, which at this point would be at a very low level.

Another situation that often requires a combination approach is that of odor control in sensitive areas. There are times when the odor source is quite close to the facility fence line. Some odor control technologies have an odor unit level at their discharge that might not be acceptable if the neighbors are close to the fence line. For example, bio-filters typically have an effluent odor unit level between 200 and 400 OU. This level may represent a considerable reduction of odors prior to the bio-filter but may still be too high for the neighbors. In this case, a solution would be to add a second stage activated carbon system to further reduce the OU level to 100 or less.

This odor control technique is known as polishing and is nothing new, having been practiced since the early 1980's. Bio-scrubbers and chemical wet scrubbers are also good candidates for polishing since while they typically remove 98% or more of the H₂S and / or ammonia coming in, they do not do nearly as well on the organic sulfur compounds, leading to OU effluent levels as high as 1000 on some applications. Again, the addition of carbon polishing systems can provide a total odor reduction system with an OU effluent level of around 100.

Related to polishing is the use of activated carbon on chemical scrubbers and biological systems for odor containment when concentrations peak or spike.

There are numerous potential combinations.

Efficiencies and OU Reduction:

As can be imagined, combination systems are designed to provide the highest removal efficiencies and greatest OU reductions possible. Removal efficiency of targeted compounds should exceed 99% at the exhaust of the second (or third) stage, and OU effluent levels should be no greater than 200 to 400 if a biofilter is used as a second stage and 100 OU if carbon polishing is utilized.

II. Common Odor Scenarios and Potential Solutions:

Odors can be produced at a number of points within the wastewater collection system as well as within the wastewater treatment plant (WWTP) itself. These odors can be caused by a combination of inorganic and organic compounds. We have chosen to examine three common odor scenarios in greater detail. These are:

1. Collection System – Pumping Station
2. WWTP - Headworks
3. WWTP – Sludge Dewatering

Looking at each scenario in greater detail, we describe the typical odor conditions, such as types of odorous compounds present, how they are generated, and their relative intensity. The paper then recommends the best technology or combination of technologies to solve the problem.

1. Collection System – Pumping Station:

The collection system which brings wastewater to the central wastewater treatment facility can be a major source of odor generation. Especially with collection systems that include long flat runs, the wastewater has the opportunity to go septic as it lays in the pipe for perhaps days at a time. When this happens, H₂S is formed. When the wastewater reaches a pumping station, the water is agitated and the H₂S liberated from the liquid phase to the vapor phase, and odors result. H₂S concentrations in the air can range from 2 ppm to several hundred. Commonly, the average H₂S concentration can be assumed to be 10 ppm. Other odorous compounds may be present, but typically only in very low concentrations.

Contaminant	Descriptive	Typical Level
H ₂ S	High	50 – 100 ppm
Ammonia (NH ₃)	Low	< 10 ppm
Reduced Sulfur Compounds	Low	<0.1 ppm
Other Organics	Low	<0.1 ppm
Odor Units	Rotten Egg H ₂ S	500 – 5,000 OU

How to Solve this Odor Dilemma:

The predominance of H₂S combined with the lack of significant organic odorous compounds allows this application to be effectively solved with a single stage technology. At the lower end of the hydrogen sulfide range (10 ppm and less), an engineered biofilter or catalytic carbon system would be a good choice. At higher H₂S levels, the biofilter becomes less of an adequate solution but a bio-scrubber might now become an acceptable alternative. The particulars of pump stations include proximity to neighbors and limited footprint space. For these additional reasons, the preferred choice of technology is activated carbon.

2. WWTP - Headworks

Wastewater from the collection system is brought into the treatment plant at the headworks. Hydrogen sulfide is typically the most prevalent odorous compound at the headworks and can be present in concentrations from 5 ppm up to 50 ppm and beyond. Reduced sulfur compounds are usually also present, from 50 ppb to several parts per million. This application is often a candidate for combination systems.

Contaminant	Descriptive	Typical Level
H ₂ S	High	5-100 ppm
Ammonia (NH ₃)	Low	<1 ppm
Reduced Sulfur Compounds	Low	<0.1 ppm
Other Organics	Potentially High	>1 ppm
Odor	High Intensity	500 – 3,000 OU

How to Solve this Odor Dilemma:

The combination of significant levels of H₂S and reduced sulfur compounds requires a combination system for a truly effective solution. There are several alternatives. First among these is a two-stage system consisting of a first stage bio-scrubber for H₂S removal, followed by either an engineered biofilter (should organic compounds register in the low to moderate ppm range) or an activated carbon system (should the organic compounds register in the ppb to very low ppm range).

3. WTPP – Sludge Dewatering:

Solids processes present some of the most intense odor challenges of all wastewater operations. Commonly, the average H₂S concentration can be assumed to be 10 ppm.

Contaminant	Descriptive	Typical Level
H ₂ S	High	1 – 25 ppm
Ammonia (NH ₃)	High	50 – 100 ppm
Reduced Sulfur Compounds	High	1 - 5 ppm
Ammonia/Amine Compounds	Fishy Smell	1 – 10 ppm
Odor Units	Very persistent, travels far	500 – 10,000 OU

How to Solve this Odor Dilemma:

This challenging odor application is best solved with a combination technology. In this case, the significant loadings of all major types of odorous compounds would argue in favor of a Bio-Scrubber® first stage (assuming the H₂S levels are 20 ppm or better) to treat both hydrogen sulfide and ammonia, followed by a biofilter second stage to reduce organic odors as well as to polish any remaining H₂S or NH₃. If average H₂S levels are below 20 ppm, a first stage biofilter followed by a carbon polisher is a good choice.

Closing:

It would be impossible to cover every possible odor scenario and its possible solutions in anything less than a textbook. This paper is simply an attempt to provide some insight into how municipal managers and consultants might approach solving odor challenges that they may encounter.

Thank you:

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