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Odor and air emissions control using biotechnology for both collection and wastewater treatment systems

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Abstract

Air emission controls using biotechnology is a new focus area for publicly owned treatment works (POTWs), especially now with many Federal, State, and Local air quality laws and regulations that often require significant air emission reductions for a new plant or collection system source to be permitted. CH2M HILL and others have collected biotechnology-based odor and air emissions control performance data over the last 4 years to track performance of various biofilters and biotowers as those technologies have evolved and emerged over time. Specifically, odor removal performance data have been collected from soil, organic, and inorganic media biofilters and inert inorganic media biotowers. Results indicate that biotechnology-based odor control is a viable and reliable technology capable of achieving high removal performance for hydrogen sulfide (H_2S) as well as various other broad spectrum odor-causing compounds. While control of other air emissions such as overall volatile organic compounds (VOC) and hazardous air pollutants (HAP) is feasible, typically removal efficiencies of VOC and HAP are lower than those observed for typical odorous compounds such as H_2S. In many cases, a biotechnology device is removing odors at very high levels while the same device has relatively lower removals of other air emissions. Properly designed biofilters evaluated during the testing showed high levels of removal for both H_2S and overall odor if sufficient contact time is provided. Biotower systems tested also provide high removal rates for H_2S at substantially reduced contact times compared to biofilters, but they show overall lower removal rates for other odor-causing compounds. Some lessons learned and rule of thumbs on the differences among types of biofiltration units, is also provided.

Keywords: Odor; Air emissions; Volatile organic compounds; Hazardous air pollutants; Air toxics; Hydrogen sulfide; Reduced sulfur compounds; Biofilters; Performance data

1. Introduction

Wastewater collection and treatment systems often generate offensive odors, resulting in complaints from neighbors. Collection systems transport wastewater from residences, commercial and industrial facilities to wastewater treatment plants (WWTPs) for processing. Collection systems can include force mains, through which wastewater is pumped, and gravity sewers, through which the wastewater flows without pumping. Odors from collection systems generally come from anaerobic decomposition.

Both collection and treatment systems typically emit trace amounts of air emissions. Air emissions from the wastewater treatment plant are well understood, while air emissions from the collection system are not. Two general types of air emissions are regulated by federal, state, and regional air quality agencies: criteria pollutants and hazardous or toxic pollutants. A third type of air quality indicator – odor – is not specifically addressed under air quality regulations, other than by public nuisance requirements. Most of the odors generated within the collection system are sulfur-

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based compounds, the predominant compound often being hydrogen sulfide (H_2S). Other sulfur-based compounds found in lower concentrations can also cause odor complaints because they are detectable at very low levels and tend to disperse below nuisance concentration levels relatively slowly. These compounds can also be difficult to treat. They are the family of total reduced sulfur (TRS) compounds that include methyl mercaptan, dimethyl sulfide, dimethyl disulfide, ethyl mercaptan, carbon disulfide, and carbonyl sulfide. Air emissions from the collection system results from air stripping, wastewater turbulence, and some byproducts of biologically mediated processes seen in the collection system and breakdown of volatile organic compounds. Odors and air emissions from collection systems can be released from manholes or transported in the wastewater to the WWTP, where they are released at the headworks.

In addition to sulfur-based odorous compounds, nitrogen-based compounds also can cause odors. Nitrogen-based odorous compounds include ammonia, the amine family of compounds (such as ethyl amine, trimethyl amine), indole, and skatole.

Odors are generated in WWTPs when the wastewater turns septic because of excess time spent in clarifiers, because of anaerobic decomposition of solids, or because of decomposition of nitrogen compounds, such as proteins, releasing ammonia and other nitrogen-based odorants. The same biological mechanisms and physical conditions inside the collection system can release air emissions.

Other sources of odor in a WWTP include dewatering, solids handling, and further processing, such as alkaline stabilization or composting. Each of these unit processes may release different odorous compounds; nonetheless, nuisance odors are generated. The focus of this paper is the performance of full-scale biotechnology-based odor and air emissions control systems operating at WWTPs and collection systems to treat sources of nuisance odors. Typically biotechnology has not purposefully been used to treat other air emissions, but incidental air emissions removal often occurs in these same devices as they treat odors. Some researchers have seen as great as 90% air emission reductions in units specifically designed for air emission biotechnology applications [1–3]. A bioscrubber vendor also has data that shows both high odor (>95% odor removal) and lower air emissions removals (in the range of 40–83% removal that is VOC compound-dependent) [4].

2. Background

Biofiltration has become a popular choice for treating odorous air streams [4,5]. Others believe it can be used to treat air emissions, as well. Biofiltration is becoming popular because of improving reliability of these systems, and because it is a “green” technology that uses no chemicals and creates no issues of potentially hazardous media disposal. As odorous air and air emissions pass through the biofiltration system, odorous and air emission compounds are removed and then oxidized by the microbes growing on the media. There are two main types of biological control units: biofilters and biotowers (biotrickling filters). The remainder of this paper describes design criteria and performance data collected for full-scale biotechnology-based odor and air emisisons control at WWTPs and from collection system applications. Performance data are summarized for various biofilters with different media as well as for biotower systems.

Biofilters have shown proven ability to remove hydrogen sulfide, methyl mercaptan, and other reduced sulfur compounds. VOCs also have been successfully controlled [1–4]. Torres reported VOC removal rates in organic media biofilters ranging from 73 to 82% when measured in terms of non-methane hydrocarbon reduction. Wani et al. [1] reports biofilters providing VOC removals in the range of 52–99% VOC removal for various systems. Kraakman [4] reports bioscubber air emissions from 40 to 80% with removal rates being compound-dependent. Reported hydrogen sulfide removal rates are typically high, exceeding 98 and reaching 99% or even greater [7]. Overall odor removal in terms of dilution-to-threshold reduction are often reported above 80%, with values as great as 99% [8,9]. Biofilters have been successfully tested and commercially installed in industrial applications to remove solvent VOC emissions such as toluene and ethanol [10]. Studies have indicated that biofilters may be more suitable for removing both VOC and odor emissions than other technologies, such as wet scrubbers [2].

3. Biotechnology-based odor and air emissions control design criteria

Biofilters are traditional solid media systems that use organic-based media such as compost, bark or woodchips or other proprietary vendor-supplied media. In both biofilters and biotowers, the media provides the home for the microbes that consume the odorous compounds. In a biofilter system, the media itself provides the trace nutrients such as organics, nitrogen, potassium, and phosphorous that the microbes need to thrive. In biotower systems, these nutrients are provided in the humidification make up water spray itself or by supplementing the recirculation water with trace nutrients. This is often accomplished by using wastewater plant effluent water which carries sufficient trace nutrients, but can also be provided by nutrient supplemented potable water.

Much of the following design criteria discussion can be applied to both technologies. Several parameters need to be considered when designing biofilters and biotowers to ensure that the optimum conditions are provided for efficient operations. These factors all have one main goal: to provide a suitable environment to sustain the microorganisms responsible for the biofiltration process. A number of these key factors are considered in the following paragraphs.

3.1. Sizing and contact time

Biofilters are sized to provide sufficient contact time for the odorous and air emission compounds to be absorbed, adsorbed, and biodegraded. Contact time typically is characterized as the empty bed residence time (EBRT) and is represented by:

$$\mathrm{EBRT} = \frac{AD}{Q}$$

where EBRT is the empty bed residence time (s), A the area of bed (m^2), D the depth of bed (m), and Q is the odorous air flow rate (m^3/s).

EBRT requirements depend on the ability of biofilter media to complete the biodegradation process and are also a function of the allowable vertical velocity in the bed which impacts both treatment characteristics and pressure loss in the media. Another way of expressing the superficial velocity is as a volumetric loading rate, LR, represented by the equation:

$$\mathrm{LR} = \frac{Q}{A}$$

where LR is the loading rate ($\mathrm{m}^3/(\mathrm{h\,m}^2)$), Q the odorous air flow rate (m^3/s), A is the area of bed (m^2).

EBRT for odorous compounds typically found in wastewater collection and treatment systems varies with the system loading, the type of system and the media selection. For in-ground open vessel biofilters, EBRTs of 30–120 s are fairly common, with a nominal EBRT of 60 s. Higher EBRTs are required for soil-based media systems. For closed vessels with propriety organic-based media, EBRTs of 30–60 s are fairly common. The data presented in this paper suggest that EBRTs below 45 s may be cutting into required safety factors to maintain reliable odor treatment. These, rule of thumb EBRTs are typical for normal wastewater treatment odor applications. More challenging industrial applications may require EBRTs longer than 10–30 min to attain 90% air emissions removals for slowly biodegradable compounds [11]. These include certain species within the classes of compounds such as: phenols, acrylates, styrene, terpenes, aromatic hydrocarbons, cyclic aliphatic hydrocarbons, and halogenated hydrocarbons.

The appropriate LRs vary with type of media. For soil media, LRs of 15–50 $\mathrm{m}^3/(\mathrm{h\,m}^2)$ are common, while 35–90 $\mathrm{m}^3/(\mathrm{h\,m}^2)$ are common for organic media used in open vessel systems. Larger LRs of 150–400 $\mathrm{m}^3/(\mathrm{h\,m}^2)$ are common for proprietary media used in closed vessel systems. EBRTs and loading rates reported in this paper are based on field observation and experience but can vary significantly with each application. Designers are urged to consider the nature of each application, including evaluation of the complexity of the odorous air stream and temperature.

Recent data presented in this paper show that biotower systems are being designed for EBRTs substantially lower than that of biofilter systems. Biotower performance data are presented in this paper for systems with EBRTs from 1.7 to 37 s.

3.2. Temperature

Operation of a biofilter or biotower depends on gas and media temperatures. Microorganisms operate efficiently at temperatures ranging from about 15 to 30 °C. The higher the temperature, the higher the metabolic rate and the biodegradation rate up to a temperature of about 40 °C. At temperatures below 15 °C, the biological systems begin to slow down significantly, reducing treatment efficiency. At temperatures above 40 °C, the type of microbial system shifts from mesophilic to thermophilic bacteria, also potentially reducing odor removal performance. Conversely, solubility and adsorption rates decrease with increasing temperature. Biofilters and biotowers receive most of the heat required to maintain bed temperature from the odorous air and the rest from the metabolic activity of the microorganisms. Controlling odorous air temperature is important, and is discussed in Section 3.3.

3.2.1. pH considerations

Biofilter pH should be maintained at or near neutral to facilitate maximum microbial activity required for maximum odor and air emissions controls. Hydrogen sulfide-degrading compounds can survive at pH levels as low as 2, while biological degradation of other compounds commonly requires a near neutral pH. Therefore, for air emissions removal, monitoring must be conducted to ensure the pH stays in the range of about 6–7.5.

3.3. Moisture (temperature) control

Moisture control is one of the most important aspects of maintenance for biofiltration media, if not the most important, particularly for natural media. Media that is too dry will not support a diverse and robust microbial community. Media that is too wet can become too dense, resulting in compaction reduced porosity and high back-pressures. Perhaps most important of all is to provide a ‘stable’, moist environment. A general range of 40–70% moisture content is considered typical for organically based media based upon literature review, with a target of 40–60% typically reported [12].

If not humidified to near 100% relative humidity, airflow through the biofilter can rapidly strip moisture from the media. Drying can occur rapidly at even modest airflow rates. The net effect will be adverse impacts on the microorganisms and reduced odor removal. Conversely, warm humid air streams passing through media in a cool environment can condense large volumes of water that must be considered when setting irrigation rates.

Preconditioning (pre-humidifying) the inlet air stream is recommended to maintain the required moisture in the biofilter media bed. Alternatives for pre-humidifying the air include spray nozzles in the biofilter inlet air duct, spray chambers ahead of the biofilter, or water-only packed tower scrubbers in front of the biofilter. Pre-humidification alone will not be sufficient at high loading rates of exothermic biodegradation reactions or with open top biofilters exposed to arid sunny climates [6]. In these instances, top-mounted irrigation or soaker hoses may be needed as well.

Humidification control in biotowers serves two purposes: moisture management and nutrient supply. Humidification is typically provided either by once-through make-up water supplied by timed spray nozzles, or by make-up water added to a sump with the sump contents being recycled (pumped) over the media and blowdown wasted to drain. In either case, the once-through or recycled water moistens the media and provides the trace nutrients. The water supply provides the trace nutrients required by the microbes, since the biotower media itself is typically completely inert.

3.4. Airflow distribution

Even airflow distribution is important in biofilters and biotowers to ensure that uniform odorous gas and air emissions loadings within the media bed. Biofilter air flow distribution systems for in-ground open vessel systems usually consist of a network of perforated plastic piping laid below the bed and surrounded by crushed stone. Biofilter systems that use concrete tanks usually have a slotted or grating type system for air distribution. In those systems, the concrete floor and walls form a plenum for even air distribution. The plenum also serves to collect leachate from the bed.

Air distribution in biotower systems is very similar to chemical packed tower scrubbers, with the media supported on grating. Airflow can be upward through the media, but in some cases vendors promote downward flow.

3.5. Leachate control and drainage

Excess moisture drains out the bottom of the biofilter. The excess moisture can be from the humidification system; from precipitation, if the biofilter is an open vessel configuration; or even condensation from warm saturated air traveling through cool biofilter media. The liquid or leachate can be acidic because the formation of sulfuric acid and other acidic compounds as a byproduct of the biodegradation process. Leachate, which is acidic, must be contained, collected and disposed of. In-ground open systems are usually equipped with liners to prevent the leachate from leaking into the ground. Liners typically are manufactured of high density polyethylene. Alternatively, biofilters are constructed in concrete, FRP, HDPE or stainless steel vessels that collect the leachate. Drainage piping must be adequately sized to handle the maximum expected drainage load, including worst case rainfall. The media likewise must drain freely to allow release of excess moisture. The leachate is typically discharged back into the flow to the collection system or plant headworks, where it is a relatively minor contribution to the overall plant flow and load and its acidic characteristic is quickly diluted.

It is worth noting that permit limitations may have to be considered for biotechnology applications that discharge to collection systems. For instance, in Los Angeles designers had to consider pH limitations established for discharges into collection systems [13]. In that instance, typically low pHs characteristic of biotower blowdown and biofilter leachate could not be discharged untreated into collection systems.

3.6. Media selection

The selection of media for biofilter applications has evolved over time and continues to evolve. Materials such as soil, peat, bark, wood chips, compost, and heather, and inert additives such as perlite, lava rock, and plastics all have been used as media for biofilters. The most common media in successful biofilters are soil, bark, wood chips, and compost. Often media is a combination of these components. Synthetic materials such as plastic, polyurethane, or polyethylene packing are seeing field application in newer biotower systems. Performance data are presented herein for biotowers using lava rock, plastic foam, and polyethylene foam media.

A good biofilter medium should:

- support a large diverse microbial population;
- provide pH buffering capabilities;
- have the ability to retain microbes;
- be physically stable;
- have a low pressure drop;
- produce clear drainage water (leachate);
- drain freely, releasing excess moisture;
- have high bearing-strength.

The media selection involves a number of elective decisions, including media ingredients, particle sizing, cross-sectional depth, surface loading rate per square meter, porosity, desired service life, and local availability (cost). Properties of media selected are dependent on the air stream characteristics, including contaminants of concern and loading rates.

3.6.1. Soil biofilter media

Some soil biofilters reportedly have been operating nonstop for more than 20 years in Europe and also in Washington state [5]. According to soil-based biofilter proponents, soils are physically and chemically more stable than compost. Stability reduces compaction and shrinkage and allows soil biofilters (typically with sandy soil) to have a long life expectancy (10–20+ years). This is a key advantage over typical compost style filters, which have to be replaced every 2–5 years. Soils also provide good buffering of pH without further amendment. The primary disadvantage of in-ground (open vessel) soil biofilters is that they have low allowable gas loading rates and as such can be very land intensive. Great care is also required to avoid soil components that will cement particles together when exposed to low pH leachate.

3.6.2. *Organic-based compost style biofilter media*

Compost biofilters were first used in Germany in 1967 and have gained wide acceptance in Europe, Japan, New Zealand, and, more recently, in North America [14]. Compost consists of various organic materials and has a greater concentration and diversity of microorganisms than soil, which makes it advantageous as a medium in biofilter applications. Compost particles have large surface areas, and bulk compost has high air permeability, high water permeability, and good buffering capacity. These characteristics can be enhanced by blending compost with bark or wood chips as a bulking agent. Because of these characteristics, a smaller filter area may be required for a compost- or organic-based biofilter, as compared to a soil biofilter in a similar application. Potential disadvantages of compost biofilters include odor releases from immature and un-aerated compost, short-circuiting problems in compacted beds, and a generally shorter media life compared to soil bed or inert media systems. Higher organic-based content is often required for better air emissions removals.

3.6.3. *Synthetic materials*

Synthetic material such as plastic packing material, ceramics, and activated carbon pellets have been used as media in biofilter applications. Such media must typically be inoculated initially with soil, compost, or sewage sludge to assist development of the microbial cultures. In fact, synthetic material typically is only a fraction of the media mix for biofilter systems. Synthetic media materials are low in nutrients compared to native soil and compost style systems. It may be necessary to supplement the media with chemical elements and nutrients for effective biofiltration to occur. A significant advantage of synthetic materials is that they can be manufactured to more uniform particle sizes and generally will have a more even pore size distribution compared to soil or compost media. Synthetic materials (including typical soil media) are hydrophilic when dry and easily rewetted, so that inadvertent drying is not catastrophic as it might be in some compost media systems.

3.6.4. *Biotower media*

Biotower media typically are manufactured from synthetic materials that have high surface area per unit volume (>200 m^2/m^3), high void volumes, low air flow resistance, good chemical resistance, and good structural properties to maintain the integrity of the media. Typical media include lava rock or polyurethane foam systems. Some manufacturers are also experimenting with high surface area polyethylene media similar to packed tower scrubber systems and mixtures of porous clay balls with polyethylene packed tower media.

4. Performance data

Performance data have been collected from a total of 34 operating biotechnology-based odor control systems including six soil-based biofilters, 11 organic-based biofilters and 17 inorganic/inert media biotowers. Several of these sites also looked at air emissions reductions, as well. But, none of the test sites specifically were designed for air emissions removal only. All biotechnology-based odor control systems tested were treating foul air collected from wastewater treatment plant process units. Sources of odorous and air emissions loads included wastewater collection system lift station wet wells, plant headworks facilities, primary clarifiers, trickling filters, sludge dewatering facilities and sludge storage tanks.

The performance data collected include total odor, air emissions, and compound-specific removal efficiencies. Sampling consisted of a combination of whole air bag sampling for odor and total reduced sulfur (TRS) compound analyses and on-site measurement of H_2S, with samples taken from the 200 mm stack of a sampling hood (1.2 m × 0.6 m × 0.4 m). Whole air samples were collected in preconditioned Tedlar bags (10 L for odor samples and 1 L for TRS samples) using a vacuum chamber. Bag samples were shipped overnight to a testing laboratory and analyzed within 24 h of collection. Laboratory analysis for odor used the odor panel method and followed ASTM E-679-91 “Determination of odor and taste threshold by a forced-choice ascending concentration series method of limits.” Reduced sulfur compound speciation and quantification was completed using laboratory procedures adhering to EPA Method 15/16 and using gas chromatography/flame photometric detection. On-site field measurements of H_2S were performed using an Arizona Instrument Jerome 631-X H_2S Analyzer. Air emissions/VOC analysis also was completed for one soil biofilter and three biotower systems following modified EPA Method 14/15.

4.1. *Biofilter performance data summary*

Figs. 1–3 contain performance data compiled for soil-based, and organic-based biofilters. Removal data are provided for total odor, H_2S, and for three TRS organic compounds routinely detected: mercaptans, carbonyl sulfide, and dimethyl sulfide. For most biofilter sampling events, H_2S was the dominant compound present ranging from approximately 0.5 ppmv to as high as 1350 ppmv. Concentrations of TRS compounds generally were lower, ranging from 0.04 to 5.2 ppmv. In addition to providing the average removal efficiency, each figure also presents the range of observed efficiencies; i.e., minimum and maximum measured removal efficiency.

Soil-based media systems were full-scale field applications ranging in size from 34 to 1369 cm^3/min, with resulting EBRTs ranging from 30 to 177 s. The performance data in Fig. 1 indicate that the systems are capable of achieving consistently high odor and H_2S removal efficiencies with average removal efficiencies of 95% for odor removal and 99%, for H_2S removal. In addition, the narrow range of measured efficiencies indicates a consistent ability to at-

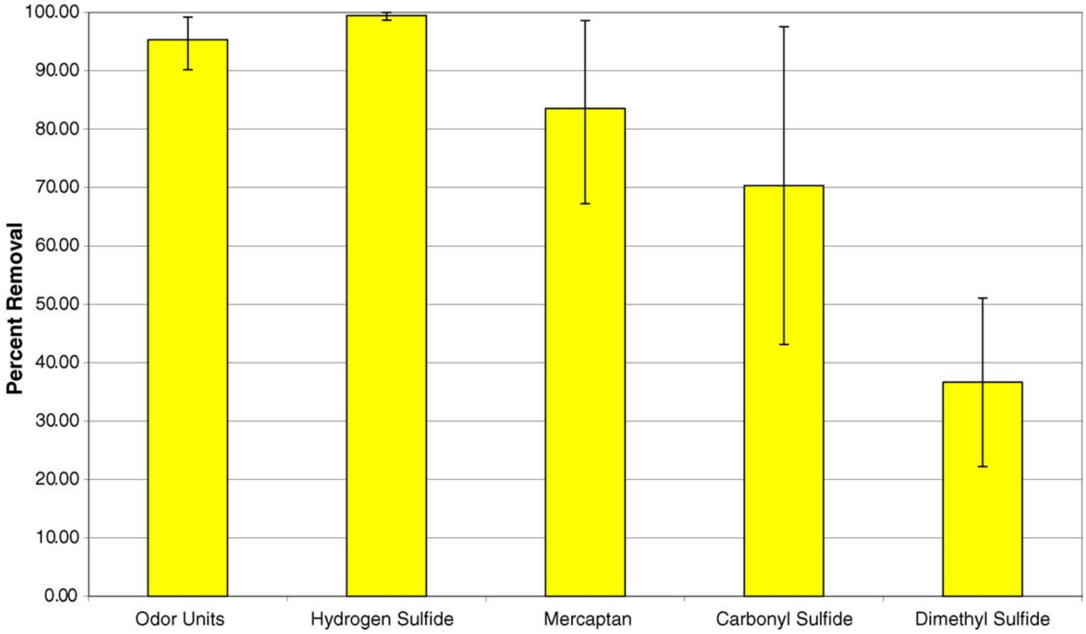

Fig. 1. Performance data for soil media biofilter systems.

tain high performance. Removal of TRS organic compounds is not as high, with average values ranging from roughly 37% for dimethyl sulfide to 84% for mercaptans. One possible explanation for the lower removal efficiencies may be due to the low inlet concentrations of TRS compounds. Another is that these compounds are inherently more difficult to treat. Fig. 2 summarizes the odor and H_2S removal performance for all organic-based media biofilter systems tested. Organic-based media systems included a full range from relatively small vendor package systems to larger open concrete vessel systems ranging from 5 to 411 cm^3/min resulting in EBRTs from 30 to 162 s. Organic-based media biofilters also achieved high H_2S removal averaging 98%. This included four systems operating at or below 30 s of empty bed contact time. Odor removal rates were much more varied and lower on average compared to soil biofilters, averaging 72%.

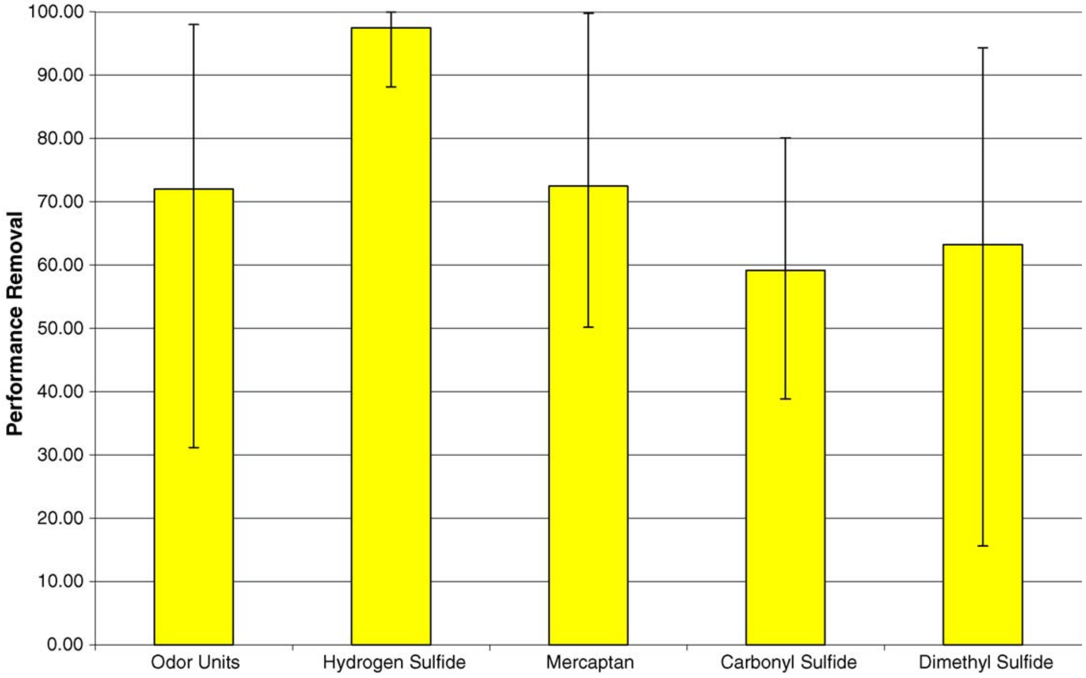

Fig. 2. Performance data for organic media biofilter systems.

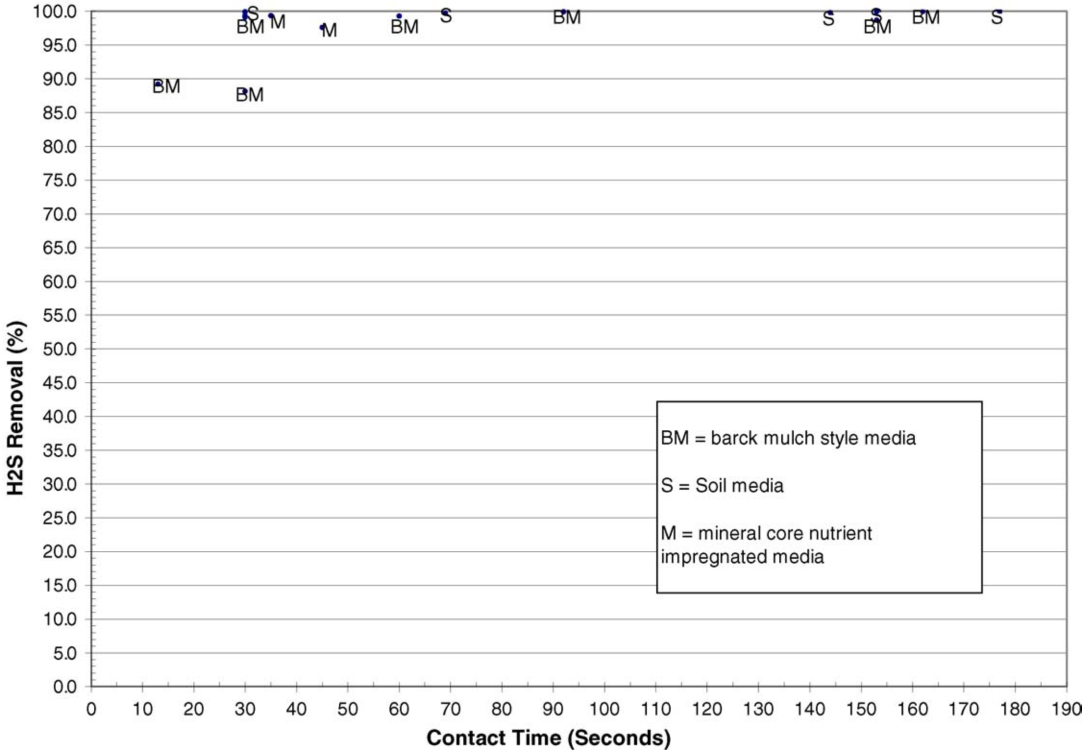

Fig. 3. H_2S removal vs. empty bed contact time for all biofilters tested.

The organic-based media had higher average removal for dimethyl sulfide.

Review of the data indicated that organic media biofilter system performance appeared to be reduced for systems at or below 30 s contact time. If all systems below this contact time are removed from the database, the average removal efficiencies go up to 95% for odor and 99% for H_2S.

Fig. 3 provides a plot of biofilter H_2S removal versus EBRT for all soil and organic media biofilters tested. The various data points for each type of media are

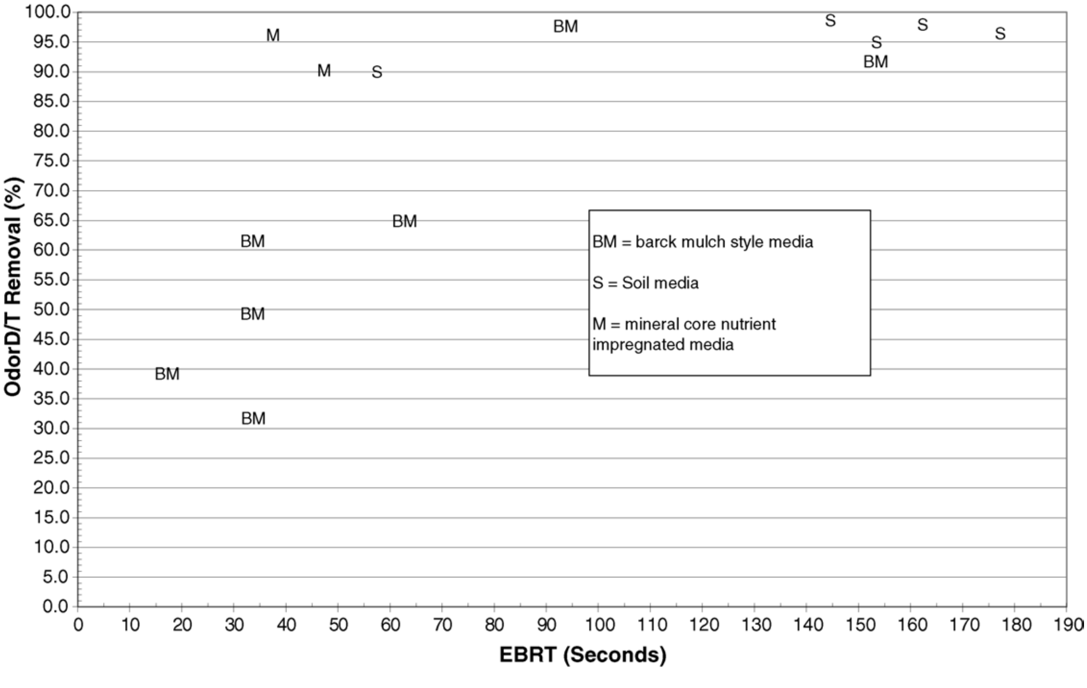

Fig. 4. Odor removal vs. empty bed contact time for all biofilter systems tested.

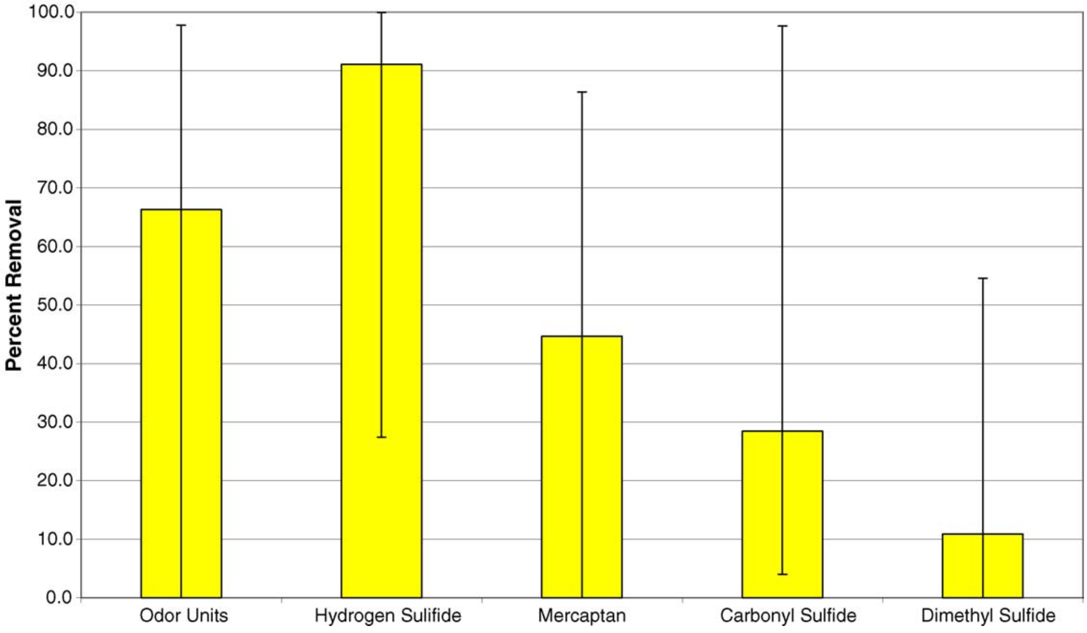

Fig. 5. Performance data for inorganic/inert media biotower systems.

also provided in a legend key that allows the reader to identify whether a particular biofilter was using soil, bark mulch, or an organic impregnated mineral core media.

The data presented in Fig. 3 indicate that for contact times of 30 s and over, relatively high H_2S removal rates were obtained for all biofilters tested. In the single instance where contact time was dropped to 13 s, H_2S removal was observed at a lower value of 89%. In that instance, the inlet H_2S was only 1.4 ppm. Therefore, it is not clear if the relatively low removal rate is due to the short contact time, the low inlet value, or both.

Fig. 4 is a similar plot for all biofilter data but in terms of odor removal by determination of odor detection thresholds by odor panel analysis (*D*/*T* reduction) versus empty bed contact time. With one exception, the odor removal data for biofilters indicate that for EBRTs greater than 45 s, 90% odor removal was achieved in terms of *D*/*T* reduction. For the one exception, a bark mulch media biofilter was operating at 60 s. The odor panel analysis and field observation indicated that the relatively offensive inlet character of the odorous air was changed in the biofilter such that biofilter exhaust air, though still relatively high in *D*/*T*, had changed character. The exhaust smelled of the bark mulch itself rather than the offensive rotten egg, sewer smell described by the odor panel for the inlet air.

4.2. Biotower performance summary

Data for biotower systems containing inorganic or inert media (Fig. 5) exhibit H_2S performance removal efficiencies similar to the soil and organic-based media systems but were lower in overall odor removal. The average H_2S removal rate was 96%, while the average odor removal rate was the lowest at 60%. TRS data collected from the biotower systems revealed a large variation in ability to remove TRS compounds, with reductions in percent removals for mercaptan and DMS compared to biofilters.

Data were available for biotower systems operating over a wide range of contact times, from 1.8 to 37 s. Inlet H_2S ranged from 0.1 to 1350 ppm for the various systems tested. Fig. 6 presents H_2S removal data to enhance understanding of the impacts of EBRT on biotower performance. Fig. 7 shows a similar plot for all biotower data, summarizing odor removal in terms of *D*/*T* reduction. The systems tested ranged from moderately small to fairly large with airflow rates ranging from 7 to 500 cm^3/min, resulting in EBRTs from 1.8 to 37 s. It can be seen from the data, that H_2S and odor removal efficiencies increase with increased contact time. For H_2S at a contact time of only 10 s, a removal rate of 90% was achieved. Based on the observed data, it appears that to reliably reach 98–99% H_2S removal efficiencies, a contact time of roughly 15 s is required. Instances have been observed with contact times as low as 6 s exceeding 98% H_2S removal. These instances were large pilot scale systems rather than long term full-scale wastewater treatment plant applications that had been on-line for years. Overall odor removal ranged from 37 to 94%. In general terms, increasing contact time increased odor removal rates. Based upon the available data, it appears that significantly longer contact times may be needed to reach 90% overall odor unit removal.

Data also were obtained during side-by-side testing of three biotower systems, of different design, treating odorous air from a headworks pump station. Average inlet hydrogen sulfide levels were relatively low at 2.3 ppm. The air stream also contained subpart per million levels of methyl

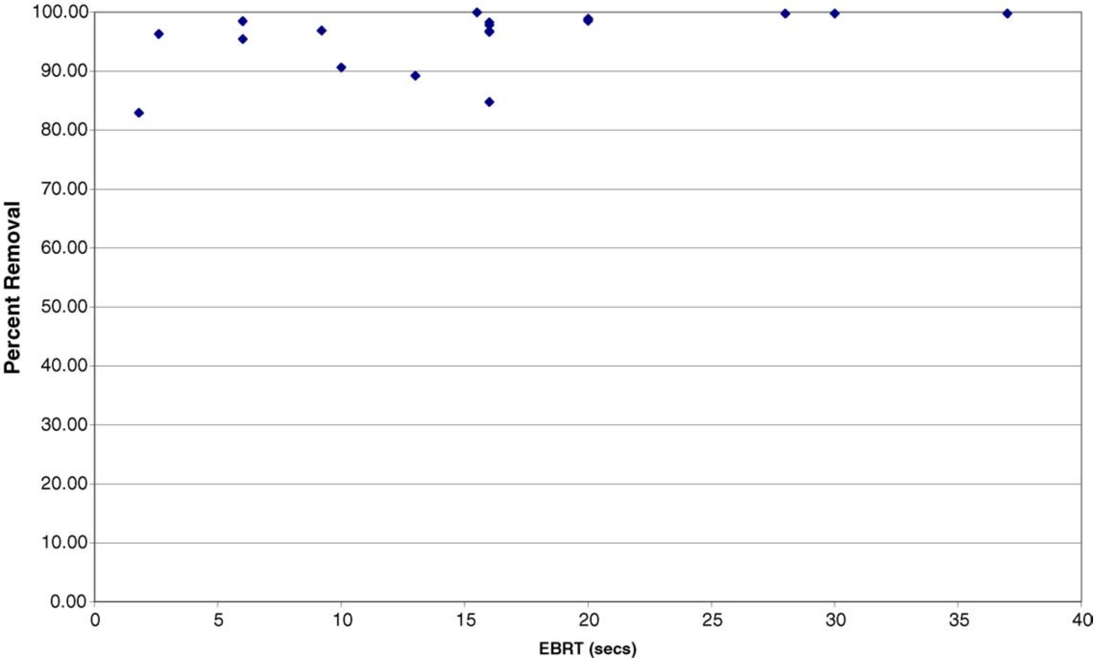

Fig. 6. H_2S removal vs. empty bed contact time for biotower systems.

mercaptan, dimethyl sulfide, dimethyl disulfide, and carbonyl sulfide. Figs. 8 and 9 provide side-by-side data summaries highlighting the average H_2S and odor removals experienced, as well as showing the percent standard deviation in performance for each system during a 6-week trial. Even with low inlet H_2S levels, all three biotowers performed reasonably well with 16 s contact time, and the performance was reasonably stable for H_2S removal as indicated by the small standard deviation in the percent removal data.

Odor removal (*D*/*T* reduction) for the three biotowers, shown in Fig. 9, indicates that all three units provided low odor reduction compared to biofilters, and that the variation in the data is higher in terms of standard deviation than for H_2S

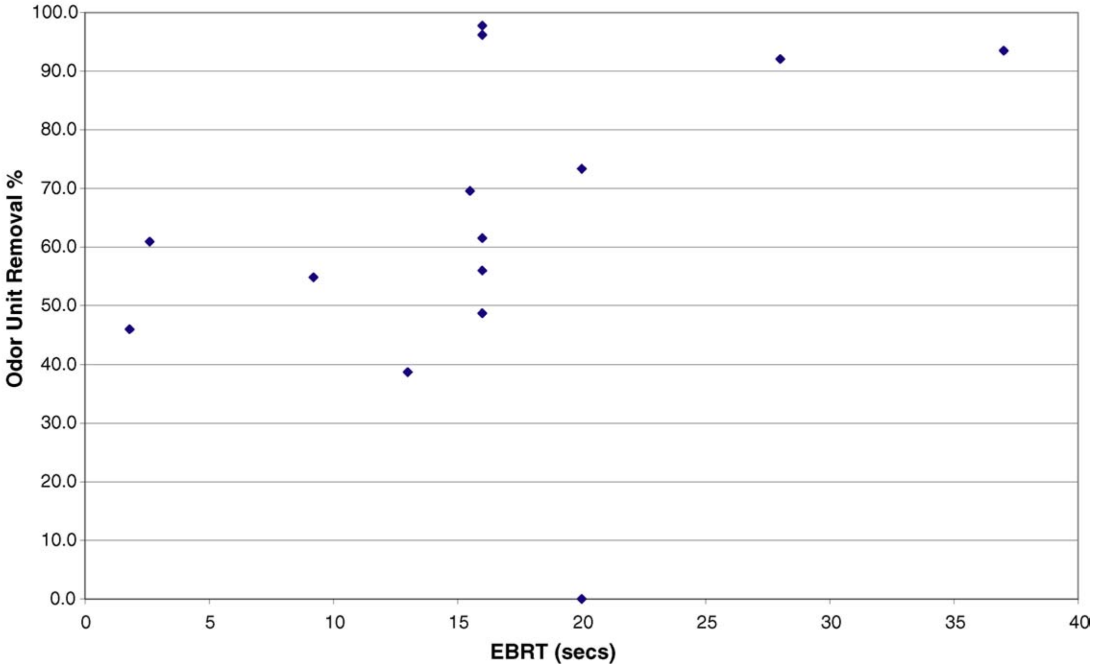

Fig. 7. Odor unit removal effiency vs. inorganic/inert media biotower contact time.

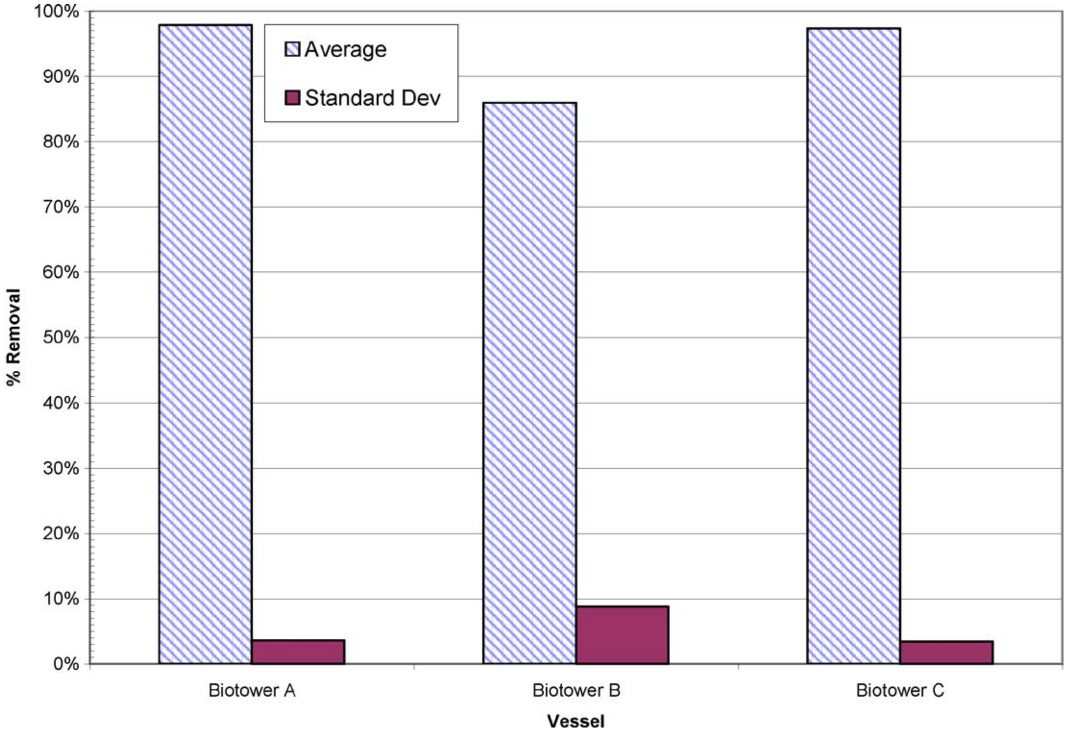

Fig. 8. Hydrogen sulfide removal for three biotower systems operating at 16 s EBRT.

removal. This may indicate that odor removal for a biotower is more variable than H_2S removal. It might also be a function of variability inherent in odor panel evaluations.

Fig. 10 summarizes the overall odor removal for all types of systems presented in this paper.

Comparison of the overall data suggests that soil biofilters are significantly better at providing overall odor reduction. However, as noted herein, if organic media biofilters with contact times at or below 30 s are removed from the data evaluation, then the average odor reduction for organic

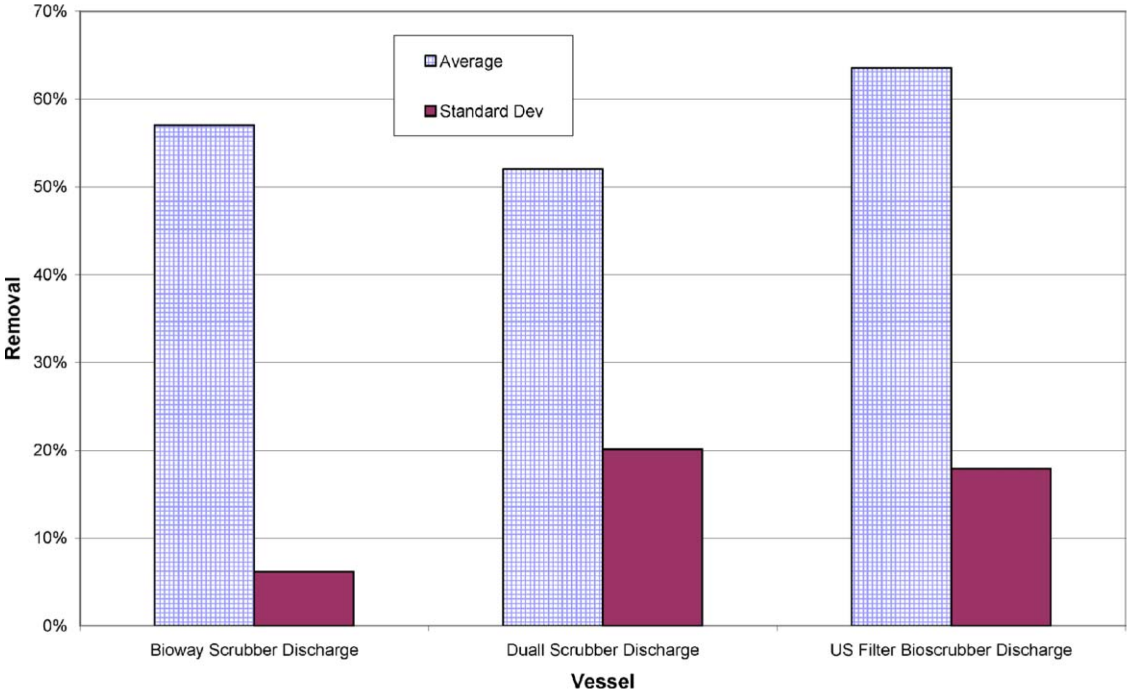

Fig. 9. Odor D/T removal for three biotower systems operated at 16 s EBRT.

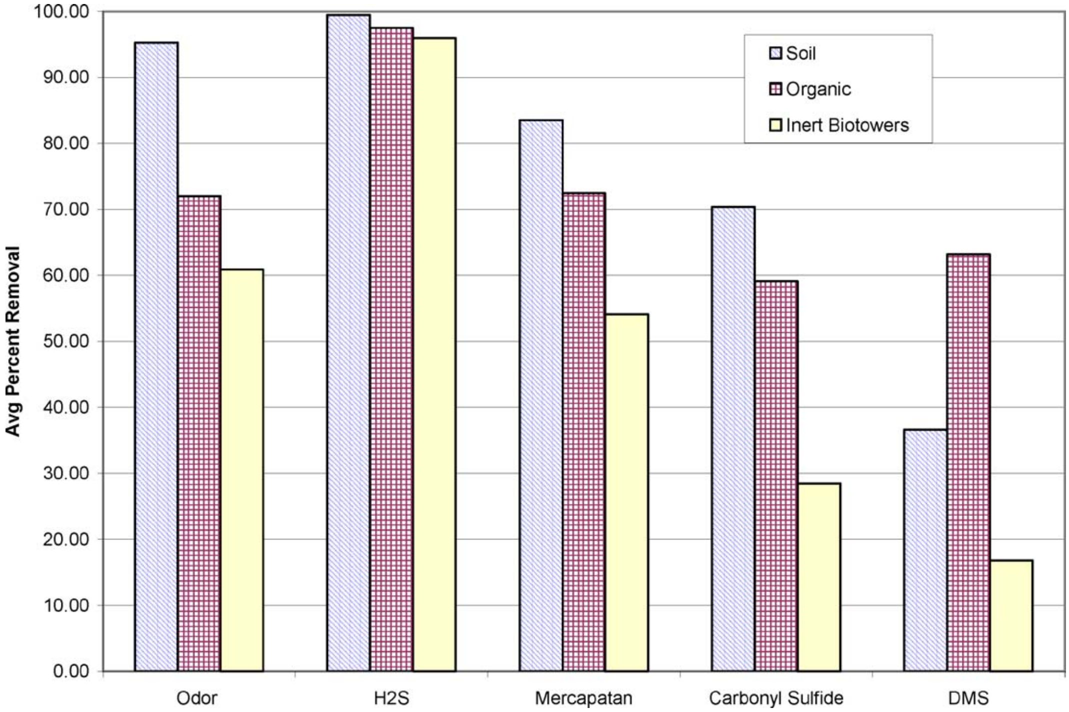

Fig. 10. Comparison of various biotechnologies odor removal performance.

media biofilters increases from 70 to 95%. For the biofilters evaluated as part of this study, this included 10 biofilters with contact times of 35 s or higher.

4.3. VOC removal

Limited data were available for VOC removal in biofilters and biotowers. VOC evaluation was done for only one of the 17 biofilters. As previously mentioned, literature review reports VOC removals ranging from 52 to 99% for organic media biofilters. In this study, a lightly loaded soil biofilter was actually tested, and overall VOC reduction in this case was only 16%.

VOC reduction on biotower systems was measured for three systems operated at 16 s EBRT and for one at 12 s EBRT. Fig. 11 summarizes the overall VOC reduction for all three systems at 16 s EBRT. The three units averaged 39% overall VOC reduction.

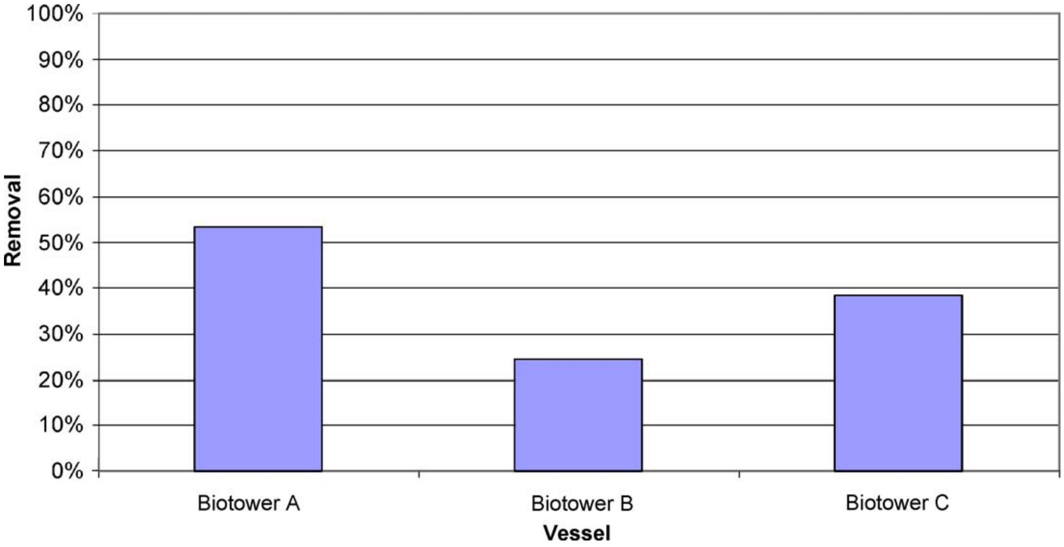

Fig. 11. VOC removal for three biotowers operated at 16 s EBRT.

5. Summary and conclusions

The following conclusions are drawn from the data presented in this paper:

- Biofilters, if designed and operated properly, are a reliable and often preferred approach to odor control at collection system and wastewater treatment plant applications.
- Biotowers are showing a rapid growth in full-scale system experience and appear to provide very high removal rates for H_2S at empty bed contact times well below those typically required for biofilters.
- Biotowers do not appear to provide overall odor reduction as high as biofilters. Typical biofilter systems observed provide odor removal in terms of *D*/*T* reduction in the 90–95% range, whereas biotowers only provided reductions averaging 60%. Much higher odor removal efficiencies have been observed in some instances, but only when the inlet air was dominated by high H_2S and other odorous compounds were not present at significant levels.
- Performance data collected from 34 operating biotechnology systems indicate that all media types – soil, organic, inorganic, and inert – are capable of achieving high H_2S removal rates with all systems tested achieving >84%. This included an inert media biotower system with a contact time of 1.8 s. Average removal efficiencies were between 96 and 99% for all biotechnology systems tested.
- Odor and TRS removal efficiencies were greatest for organic-based systems with EBRTs over 45 s, followed closely in performance by soil biofilter systems, and finally the inorganic/inert media biotower systems. For organic media biofilter systems with contact times at or below 30 s, overall odor removal was notably lower.
- Air emissions/VOC removal efficiencies in biotower systems were observed in the range of 24–53%, with an overall average of 39% reduction in VOCs. Generally, VOC removal data were not available for biofilters evaluated in this study with the exception of one lightly loaded soil biofilter. In that application, over all VOC reduction was 16%. Literature review suggests that organic media biofilters achieve VOC reduction in the range of 52–99%.

As evidenced by data presented herein, biotechnology-based odor control technology is capable of mitigating odors from collection system and wastewater treatment processes. It is recommended that the composition of the air stream to be treated (i.e., compounds present and anticipated inlet concentrations) be determined during design, as this may help in determining media type and contact time required to achieve removal rates necessary to prevent negative offsite impacts.

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