

Odor and Volatile Organic Compound Treatment by Biotrickling Filters: Pilot-Scale Studies at Hyperion Treatment Plant

H. H. J. Cox, M. A. Deshusses, B. M. Converse, E. D. Schroeder, R. Iranpour

ABSTRACT: A pilot-scale biotrickling filter was installed at the Hyperion Treatment Plant in Los Angeles, California, to study hydrogen sulfide (odor) and volatile organic compound (VOC) removal from headworks waste air. The performance of the reactor was continuously monitored during a 10-month period. At an average empty bed gas residence time of 24 seconds, 10 to 50 ppm of hydrogen sulfide was consistently removed at greater than 98% efficiency, corresponding to an average volumetric elimination capacity of 5.2 g/m³·h. Concentration profiles over the height of the reactor indicated nearly complete removal in the first section of the reactor, suggesting that elimination capacities up to 30 g/m³·h could be obtained. The odor reduction (as dilution to threshold) was 98%, which correlated with the efficiency of removal of hydrogen sulfide as the primary pollutant. Volatile organic compounds were present at concentrations up to 225 ppb. Moderate but significant removal of toluene and benzene was observed when the biotrickling filter was operated with pH control to neutralize sulfuric acid production from hydrogen sulfide oxidation. Xylenes and chlorinated VOCs were not removed regardless of experimental conditions in the reactor. The results led to the conclusion that VOC removal is the limiting process in biotrickling filters for the simultaneous removal of hydrogen sulfide and VOCs at publicly owned treatment works. *Water Environ. Res.*, **74**, 557 (2002).

KEYWORDS: biotrickling filter, biological waste air treatment, publicly owned treatment works, hydrogen sulfide, odor, volatile organic compounds.

Introduction

The University of California at Riverside, the University of California at Davis, and the City of Los Angeles (California) Bureau of Sanitation Hyperion Treatment Plant have been testing pilot-scale biotrickling filters and biofilters as alternatives to chemical scrubbers for odor treatment and removal of volatile organic compounds (VOCs) from odorous waste gases (Converse et al., 2001, accepted for publication; Cox et al., 2001). Waste gas from the headworks at the Hyperion Treatment Plant (1.7×10^5 m³/h) contains 10 to 50 ppm of hydrogen sulfide (H₂S) as the principal odor-causing agent as well as a broad variety of chlorinated and nonchlorinated VOCs at concentrations ranging from 0 to 225 ppb. The current use of chemical scrubbers has proven to be satisfactory with respect to odor and hydrogen sulfide treatment. However, chemical scrubbers fail to remove VOCs. In some cases, chemical scrubbers may even generate VOCs, which are subsequently emitted to the atmosphere (Wallis, 1996). Other drawbacks include a high consumption rate of chemicals (hypochlorite, peroxide, and caustic soda) and relatively high operating costs. Biological waste gas treatment is expected to provide an environmentally friendly

and cost-effective technique for waste gas cleaning at publicly owned treatment works (POTWs).

Waste air treatment in biotrickling filters and biofilters is based on diffusion of air pollutants to a biofilm immobilized on a porous packed bed, and subsequent biodegradation by microorganisms. The primary differences between these bioreactors are the type of packing (inorganic in biotrickling filters, organic in biofilters) and the recirculation of the liquid phase in biotrickling filters (Cox and Deshusses, 1998; Deshusses, 1997). Various pilot studies with biotrickling filters and biofilters have demonstrated that biological removal of hydrogen sulfide and odor from waste gases is efficient and cost effective (Iranpour et al., 2001; Iranpour et al., 2002). Additional reduction of VOC emissions is desirable, especially in the southern California air basin where new source review regulations for toxics have been effective since 1990. The upcoming regulations include the establishment of maximum achievable control technology standards as mandated under the Federal Clean Air Act Amendments of 1990.

Because biotrickling filters and biofilters host complex, mixed microbial populations (Cox and Deshusses, 1998; Deshusses, 1997; Devanny et al., 1999) capable of simultaneously treating a variety of pollutants, these reactors have the potential to effectively co-treat hydrogen sulfide and VOCs. This would reduce the overall emission to the atmosphere without posttreatment to remove VOCs as is needed for chemical scrubbers. Initial laboratory studies performed by the University of California at Riverside have demonstrated efficient co-treatment in biotrickling filters of H₂S and VOCs such as toluene and methyl *tert*-butyl ether (MTBE) (Cox and Deshusses, 2000; Deshusses et al., 2001). Results obtained with larger-scale reactors at POTWs, however, have been less successful so far, primarily because of lower-than-expected VOC removal efficiency (Iranpour et al., 2001). The reason for this discrepancy is unclear, perhaps because studies at POTWs primarily focused on hydrogen sulfide and odor removal only.

The objective of the present project was to determine the potential of biotrickling filters in removing both hydrogen sulfide and VOCs from waste gases from the headworks and other facilities at POTWs. In this paper, the performance of a pilot-scale biotrickling filter operated for a 10-month period is presented.

Methodology

Equipment. The biotrickling filter was constructed of 304 stainless steel with a diameter of 1.5 m and a height of 3.4 m (Figure 1), containing seven layers of a polyvinyl chloride (PVC) structured packing (COOLdek 12060, Munters, Fort Myers, Florida)

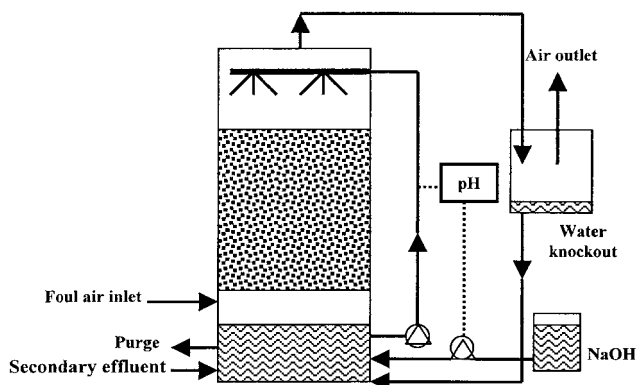


Figure 1-Schematic of the University of California at Riverside biotrickling filter.

with a specific surface area of $230 \text{ m}^2/\text{m}^3$ and a porosity of 90 to 95%. The packed bed height was 2.1 m, resulting in a bed volume of 3.8 m^3 . Air from the headworks was introduced to the bottom of the reactor (gas upflow) at an average flowrate of $600 \text{ m}^3/\text{h}$, corresponding to an empty bed gas residence time of 24 seconds. The available differential pressure from the headworks building was approximately 8.2 kPa and, thus, no blowers were required to operate the biotrickling filter at the specified gas flowrate. A 0.56-kW pump was used for continuous trickling of recycle liquid over the packed bed at a rate of $1.4 \text{ m}^3/\text{h}$ (superficial liquid velocity of 0.8 m/h). The liquid was collected at the base of the reactor, which contained approximately 0.6 m^3 of recycle liquid. Secondary effluent water from the plant was supplied as a source of nutrients and to purge the produced sulfate. The feed rate was 6 to 12 L/h and a constant recycle liquid volume was maintained by an overflow outlet. Effluent feed and purge rates were comparable, indicating that evaporation losses were negligible. The pH of the recycle liquid was controlled with a stand-alone pH controller (Cole-Parmer, Vernon Hills, Illinois), which actuated the metering of 0.75 to 1.3 M sodium hydroxide (NaOH) to the bottom of the reactor when the pH in the recycle liquid dropped to a value less than 7.0.

Experimental Schedule. Operation of the biotrickling filter started in April 2000 with the addition of raw influent wastewater from the plant and recycle liquid from a hydrogen-sulfide-degrading biotrickling filter as microbial seeds. Day 0 in graphs corresponds to the day of inoculation, after which standard operation was started. Results presented herein are during 10 months of continuous operation. The pressure drop across the reactor always remained less than 1.6 kPa and was on average 0.6 kPa. Operational parameters such as the gas flowrate, liquid recycle rate, and the secondary effluent feed rate were regularly determined and adjusted as necessary. Biotrickling filter performance was assessed by frequent analysis of hydrogen sulfide and VOC removal as well as the removal of organic sulfur compounds and odor (both only after 254 days of operation).

During the first 46 days of the experiment, the biotrickling filter was operated without pH control. A neutral recycle liquid pH was maintained after day 46, although failure of the pH control unit would occasionally cause the pH to drop. Throughout the experiment, various attempts were made to stimulate the removal of VOCs. These included the addition of specific bacterial cultures as

well as VOC spiking experiments (details are presented in the Results section).

Analyses. On a semidaily basis, the hydrogen sulfide concentration was determined by direct measurement in the inlet and outlet air ducts using an analyzer (Jerome 631-X, Arizona Instruments, Tempe, Arizona) capable of measuring hydrogen sulfide in the range of 0.001 to 50 ppm. Two or three measurements were usually sufficient to obtain reproducible results. On several occasions, continuous measurements were carried out with an InterScan hydrogen sulfide monitor (model 1176, Chatsworth, California) connected to a datalogger (Nomad, Intech Instruments, Ltd., Christchurch, New Zealand). For VOCs, inlet and outlet air were sampled in 10-L Tedlar bags for 3 to 4 minutes and analyzed the same day according to U.S. Environmental Protection Agency method (U.S. EPA, 1988) TO-14 using a gas chromatograph with photoionization and electrolyte conductivity detection. The method detection limit was 0.5 to 2 ppb, depending on the VOC. Analyses were done on a weekly or monthly basis. Organic sulfur compounds were analyzed in triplicate on day 254 by Performance Analytical, Inc. (Simi Valley, California), in a gas chromatograph equipped with a sulfur chemiluminescence detector. On the same day, samples were collected in Tedlar bags for odor analysis. American Society for Testing and Materials methods E-679-91 (ASTM, 1991) and E-544-99 (ASTM, 1999) were used for quantification of the dilution/threshold ratio and the odor intensity (Odor Science & Engineering, Inc., Bloomfield, Connecticut; odor panel of eight members). Gas flowrates to the biotrickling filter were regularly measured in the inlet air duct using a digital anemometer (model HHHF300A, Omega, Stamford, Connecticut) inserted to a straight PVC pipe (i.d. = 14.5 cm, length = 2 m).

Results

Pollutant Composition of Headworks Air. Air from headworks contains a complex mixture of hydrogen sulfide, organic sulfur compounds, aromatic VOCs, and chlorinated VOCs. Table 1 presents a summary of the range of concentrations of individual compounds observed during 10 months of operation of the

Table 1-Composition of headworks air.

Pollutant ^a	Concentration (ppb)
Hydrogen sulfide	10 000–50 000
Carbonyl sulfide	19–52
Methyl mercaptan	149–165
Dimethyl sulfide	8–12
Carbon disulfide	6–8
<i>Tert</i> -butyl mercaptan	2–3
Benzene	0.5–2.5
Toluene	10–153
Xylenes	12–125
Dichlorobenzenes	1–210
Methylene chloride	4–120
Trichloroethylene	1–15
Chloroform	16–102
Tetrachloroethylene	15–225

^a Concentrations of hydrogen sulfide and VOCs were the average of a large number (minimum of 7 for some VOCs; for most VOCs and hydrogen sulfide more than 20) of samples taken during ten months. Concentrations of organic sulfur compounds were the average of three determinations made after 254 days.

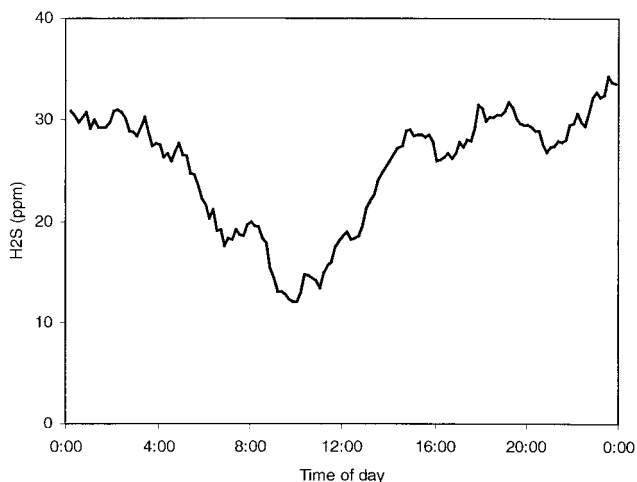


Figure 2—Continuous measurement of hydrogen sulfide inlet concentration on day 125.

biotrickling filter. Hydrogen sulfide was the primary pollutant present in concentrations ranging from 10 to 50 ppm. Organic sulfur compounds were also detected, but only at the parts-per-billion level. Toluene, xylenes, dichlorobenzenes, methylene chloride, chloroform, and tetrachloroethylene were the primary VOCs at concentrations up to 225 ppb. Volatile organic compounds analyzed for, but consistently present in, concentrations at or below the detection limit (0.5 or 2 ppb) were vinyl chloride; vinylidene chloride; carbon tetrachloride; 1,1-dichloroethane; 1,2-dichloroethane; benzylchloride; chlorobenzene; and methyl chloride.

The ranges reported in Table 1 indicate a wide fluctuation of the observed concentrations of the individual pollutants. For hydrogen sulfide, continuous measurements revealed that the concentration was lowest at the end of the morning, after which a rapid increase was observed during the afternoon (Figure 2). Identical trends were observed both on weekdays and during the weekend. Not surprisingly, hydrogen sulfide concentrations were found to be the highest during summer as a result of increased sulfate reduction in the collection system at elevated temperatures. Concentrations of

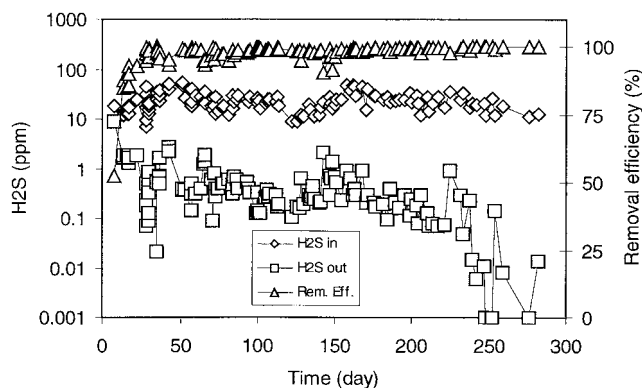


Figure 3—Hydrogen sulfide inlet and outlet concentrations and removal efficiency during 10 months of operation of the biotrickling filter (average empty bed gas residence time of 24 seconds).

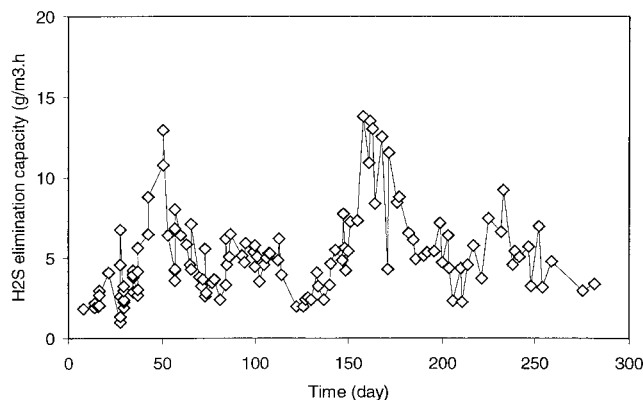


Figure 4—Hydrogen sulfide elimination capacity in biotrickling filter during 10 months of operation.

individual VOCs also varied greatly, but without apparent correlation to the hydrogen sulfide concentration or amongst each other.

Hydrogen Sulfide Removal. After start-up of the reactor, hydrogen sulfide biodegradation started immediately and the biotrickling filter reached steady performance after 1 month of operation. Because the reactor was initially operated without pH control, a rapid decrease of the recycle liquid pH to a value of 1.5 was observed. After 46 days of operation, a neutral pH was maintained in the recycle liquid by metered addition of caustic soda. As presented in Figure 3, the hydrogen sulfide removal efficiency was consistently greater than 98% during 10 months of operation regardless of the recycle liquid pH. The average hydrogen sulfide outlet concentration was 0.44 ppm and, with two exceptions, it was always less than 1 ppm, which is the current limit for hydrogen sulfide emissions allowed by the South Coast Air Quality Management District, Diamond Bar, California.

The hydrogen sulfide elimination capacity of the biotrickling filter (Figure 4), expressed as the amount of hydrogen sulfide removed per cubic meter of packed bed per hour, ranged from 1 to 13.8 g/m³·h, with an average capacity during 280 days of 5.2 g/m³·h. Higher hydrogen sulfide elimination capacities are reported in the literature (Kraakman et al., 1998). However, it should

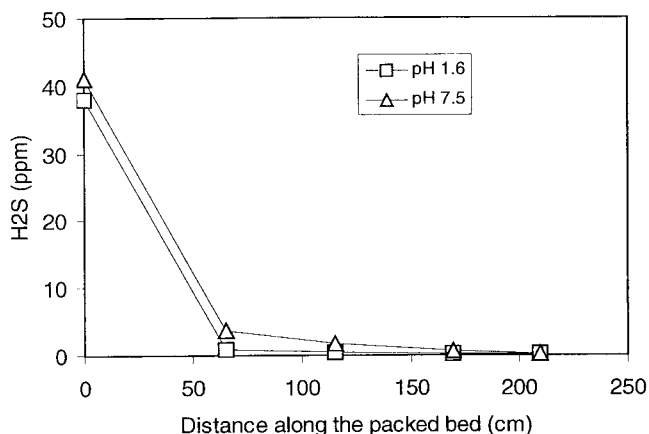


Figure 5—Hydrogen sulfide concentration profiles over height (inlet = 0 cm) of packed bed; profiles were determined during operation with and without pH control.

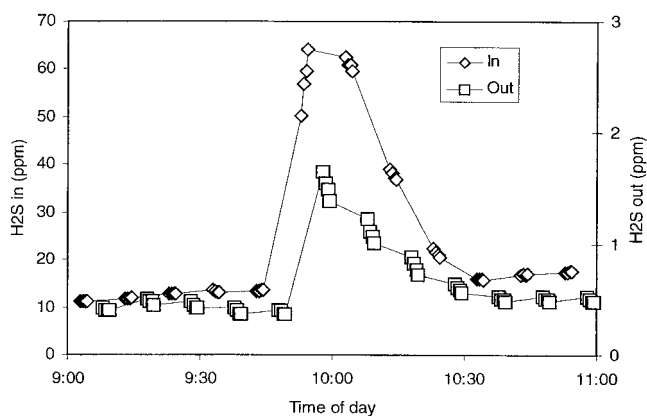


Figure 6—Biotrickling filter response to a hydrogen sulfide surge (day 126).

be noted that the biotrickling filter was not operated at its maximum elimination capacity. This is demonstrated in Figure 5, which shows hydrogen sulfide concentration profiles over the height of the reactor. These were determined both at low-pH operation of the biotrickling filter (before day 46) as well as during operation with pH control. An important but expected conclusion of the concentration profiles is that high hydrogen sulfide elimination can be obtained at high (30 to 50 ppm) hydrogen sulfide concentrations. The elimination capacity in the first section of the packed bed (0 to 0.65 m) was $30 \text{ g/m}^3\cdot\text{h}$, which demonstrates the applicability of biotrickling filters in removing hydrogen sulfide at a fast rate. On the other hand, removal of low hydrogen sulfide concentrations occurred at a much slower rate, as observed in the second (0.65 to 1.3 m), third (1.3 to 1.95 m), and fourth (1.95 to 2.6 m) sections of the packed bed. Whether this is due to mass-transfer limitation or to limitation of biological activity by low hydrogen sulfide concentrations cannot be concluded from the present results. Figure 5 also demonstrates that the pH did not have a significant effect on the concentration profiles; hence, hydrogen sulfide removal is feasible for a wide range of pH. Fluctuating hydrogen sulfide concentrations are the rule in field applications. This requires a fast response of the biotrickling filter to consistently keep emission levels below the allowed limit. On day 126, during a week of

continuous hydrogen sulfide measurements, a sharp increase of the inlet concentration occurred with a temporary maximum of 65 ppm at 10:00 a.m. (Figure 6). The origin of this surge could not be identified. Although a slight increase in the outlet concentration was observed, the biotrickling filter effectively removed the hydrogen sulfide peak. This demonstrates the fast response of the biotrickling filter to rapidly changing inlet concentrations. Such a response may be attributed to two factors. First, the biotrickling filter was operated below the maximum elimination capacity, as indicated by nearly complete removal of 40 ppm of hydrogen sulfide in the first two sections of the packed bed (Figure 5). Second, the large volume of recycle liquid in the bottom of the reactor may act as a sink for transient absorption of hydrogen sulfide during shock loadings.

Removal of Organic Sulfur Compounds. Removal of organic sulfur compounds was determined 254 days after the start-up of the biotrickling filter. Methyl mercaptan was removed at an average efficiency of 70%, which may indicate that hydrogen-sulfide-oxidizing microorganisms in the biotrickling filter were capable of also metabolizing this compound. A reduction of the *tert*-butyl mercaptan concentration was also observed, although an accurate estimation of the removal efficiency was not possible because *tert*-butyl mercaptan was present in concentrations close to the detection limit (2 ppb). Carbonyl sulfide, dimethyl sulfide, and carbon disulfide were not removed.

Removal of Volatile Organic Compounds. The average VOC removals with and without pH control in the biotrickling filter are presented in Table 2. In some cases, VOC concentrations were higher at the outlet than at the inlet (negative removal efficiency). This is believed to result from a combination of fluctuating VOC concentrations in the headworks air, a 5- to 10-minute delay in sampling between the inlet and outlet, and possibly absorption and desorption effects. Throughout the 280-day experiment, removal of VOCs was poor, regardless of experimental conditions. No removal of xylenes and chlorinated compounds was observed. Moderate but significant removal of toluene and benzene occurred, but only when a neutral pH in the biotrickling filter was maintained (Table 2). This was concluded because the removal efficiencies of these two compounds at neutral pH were the only values that were approximately 2 standard deviations greater than zero. As Table 2 shows, all of the other removal efficiencies were approximately

Table 2—Volatile organic compound removal efficiency in biotrickling filter with and without pH control.

VOC	No pH control ^a		pH control ^b	
	Inlet concentration (ppb)	Removal efficiency (%) ^c	Inlet concentration (ppb)	Removal efficiency (%) ^c
Benzene	1–22	0 (8.0)	8–13	34.7 (16.1)
Toluene	10–153	–4.0 (9.6)	38–73	46.7 (23.5)
Xylenes	13–120	–3.3 (14.5)	19–124	–1.7 (20.3)
Dichlorobenzenes	1–9	–19.2 (53.4)	11–17	–7.0 (33.5)
Methylene chloride	4–43	–0.7 (4.9)	11–63	–3.0 (8.9)
Trichloroethylene	1	–4.2 (5.9)	4–15	–4.6 (6.7)
Chloroform	16–76	–2.2 (4.1)	58–102	–3.9 (4.1)
Tetrachloroethylene	15–89	–0.9 (5.0)	33–151	3.7 (7.7)

^a Measurements over days 14 to 30, average of 12 determinations, operation without pH control, pH 1.5 to 2.

^b Measurements over days 57 to 133, average of 7 determinations, operation with pH control, neutral pH.

^c Standard deviation in parentheses.

Table 3—Removal of VOCs during spiking experiments (days 204 to 226, with pH control).

VOC ^a	Inlet concentration ^b (ppm)	Removal efficiency (%)
Benzene	0.18–0.36	6
Toluene	0.90–2.31	6
Xylenes	1.12–2.97	8
Dichloromethane	4.07–9.88	–8
Trichloroethylene	1.91–4.20	–6

^a Continuous feed of gasoline to the air stream as a source of toluene, benzene, and xylenes. Dichloromethane and trichloroethylene were fed as the neat liquids.

^b Average of 6 to 10 determinations.

equal to, or even much less than, their standard deviations and, therefore, are not significantly different from zero. This emphasizes that pH control is required for VOC removal, although other factors play a role as well because readily biodegradable compounds, such as xylenes and dichloromethane, were not removed at a neutral pH. One factor that was considered was the possibility of VOC-degrading microorganisms not being present in sufficiently high numbers to catalyze significant VOC removal. At first, approximately 6 L of laboratory cultures of pure species grown on toluene and dichloromethane were added to the biotrickling filter. This had no effect on the removal of either compound. Therefore, it might be concluded that the conditions prevailing in the biotrickling filter did not allow establishment and growth of a VOC-degrading population. In a subsequent experiment, the VOC loading was artificially increased to enhance the growth of VOC-degrading microorganisms. The concentrations of toluene, benzene and xylenes (added as gasoline), and dichloromethane and trichloroethylene were temporarily increased by continuous injection of neat VOC liquids to the inlet air stream for a period of several weeks. Although this procedure raised the concentration of the spiked VOCs from the parts-per-billion to the parts-per-million level and the pH was kept at a neutral value, no improvement of removal was observed (Table 3). At this point, it is unclear why the spiking experiment failed to enhance VOC removal.

Odor Removal. The average reduction of odor determined in the morning, afternoon, and evening of day 254 was 97 to 98.8%. The odor panel characterized the smell of the samples at various dilutions. The smell of both treated and untreated air was described as sewage, rotten eggs, rotten garbage, and mercaptan. The characteristic smell of hydrogen sulfide (rotten eggs) was mentioned for untreated samples only.

The observed odor reduction fully correlates with hydrogen sulfide removal. Although VOCs and especially organic sulfur compounds may have odor thresholds lower than that of hydrogen sulfide, concentrations of these compounds in the headworks air were apparently too low to significantly cause odor. Hence, poor removal of VOCs and organic sulfur compounds did not interfere with the odor-reducing performance of the biotrickling filter in this study.

Discussion

The present study shows that 10 to 50 ppm of hydrogen sulfide can effectively be removed at an empty bed gas residence time of 24 seconds in biotrickling filters. The hydrogen sulfide concentra-

tion profiles over the height of the reactor indicate that most of the compound is removed in the first section of the biotrickling filter. Thus, it can be estimated that the empty bed gas residence time can be reduced to 10 to 15 seconds while maintaining the same degree of removal. Because hydrogen sulfide was the primary odorous compound in the headworks air, nearly complete elimination of odor was observed as well. These findings confirm the applicability of biotrickling filters to hydrogen sulfide and odor removal at POTWs and other industries, as reviewed by Iranpour et al. (2001).

An additional, desirable feature of biotrickling filters is their elimination of VOCs. Although moderate removal of toluene, benzene, and dichlorobenzene was observed, the overall performance was less than expected. Similar observations have been reported by Chitwood et al. (1999), Deviny et al. (1998), Torres et al. (1996), and Webster et al. (2000). Effective VOC removal requires the presence of VOC-degrading microorganisms as well as conditions that facilitate growth and stimulate the activity of these microorganisms. In this respect, it should be noted that most hydrogen-sulfide-degrading microorganisms are autotrophic (i.e., they use carbon dioxide as the carbon source for growth, while oxidation of hydrogen sulfide provides energy for the cell). On the other hand, VOCs are used as a source of carbon and energy by heterotrophic microorganisms. Therefore, co-treatment of hydrogen sulfide and VOCs in one reactor requires the existence of a mixed consortium containing subpopulations with different requirements for growth and energy. Laboratory-scale experiments prior to this study have shown that VOCs such as toluene and MTBE can be removed at fast rates in biotrickling filters treating hydrogen sulfide (Cox and Deshusses, 2000; Deshusses et al., 2001). No cross inhibition was observed between hydrogen sulfide removal and the removal of toluene or MTBE in the laboratory-scale experiments as long as a neutral pH in the biotrickling filters was maintained. Therefore, it can be concluded that biotrickling filters can host mixed populations that simultaneously remove hydrogen sulfide and VOCs.

Poor VOC removal observed in the present study must then be attributed to conditions in the biotrickling filter not being favorable for heterotrophic microorganisms, especially because the addition of pure cultures that specialized in removing toluene and dichloromethane did not have any effect. One such condition is the pH. Whereas most hydrogen sulfide oxidizing species prefer an acidic environment (Islander et al., 1991), most VOC-metabolizing species prefer a neutral pH (Table 2). Even so, control of pH at a neutral value failed to facilitate the removal of the majority of the VOCs of the headworks air. Laboratory experiments have demonstrated VOC removal in biotrickling filters at rates of 10 g/m³·h to more than 100 g/m³·h for most of the VOCs found in the headworks air (e.g., Baltzis and Mpanias, 1998; Cox and Deshusses, 1999; Diks and Ottengraf, 1991; Fortin and Deshusses, 1999; Lu et al., 1999; Pol et al., 1998; Torkian et al., 2002). Such removal rates are orders of magnitude higher than those required for complete removal of VOCs at the concentrations in the headworks air at the gas residence time used in this study. One possible explanation for poor VOC removal could be that VOC concentrations at the parts-per-billion level were too low to sustain an actively growing heterotrophic population (Alexander, 1999). This was the motivation for conducting spiking experiments, although VOC removal remained low even after increasing concentrations by 2 to 3 orders of magnitude. Additionally, a toxic effect of the VOCs can be ruled out because spiked concentrations were still well below the concentrations often applied in biotrickling filter laboratory exper-

iments (e.g., Iranpour et al., 2001). Another explanation for poor VOC removal could be the accumulation of inhibitory concentrations of sulfate in the recycle liquid. An average sodium sulfate concentration of 10.5 g/L in the recycle liquid was estimated from conductivity. This concentration seems to be too low to cause inhibition because previous experiments with biotrickling filters simultaneously removing MTBE and hydrogen sulfide have indicated that MTBE removal was not affected by sodium sulfate in a concentration up to 60 g/L (Deshusses et al., 2001). Alternative explanations for poor VOC removal are currently being investigated. These include the nutrient composition of the secondary effluent feed and the possible accumulation of metabolites other than sulfate that could inhibit VOC biodegradation.

Conclusions

Overall, the present study demonstrates the feasibility of biotrickling filters in removing hydrogen sulfide and reducing odor at POTWs. Removal is fast and operation can be sustained over the long run without concern for excessive biomass buildup and increasing pressure drops, as are sometimes observed in biotrickling filters receiving high loads of VOCs (Alonso et al., 1997; Laurenzis et al., 1998; Smith et al., 1996). Economic evaluations have also indicated that biotrickling filters at POTWs are approximately 30% more cost effective at removing hydrogen sulfide than chemical scrubbers (Deshusses et al., 2001). However, poor VOC removal in POTW biotrickling filters remains a point of concern, as is the case with chemical scrubbers. This study and others discussed by Iranpour et al. (2001) show that VOC removal is the limiting factor in designing biotrickling filters for simultaneous hydrogen sulfide and VOC removal at POTWs.

Acknowledgments

Credits. This project was funded by the Water Environment Research Foundation, Alexandria, Virginia (project # 98-CTS-4). In-kind contribution was provided by the staff of the Applied Research Group of Wastewater Engineering Services Division (D. Vosooghi, P. Samar, D. Patel, V. Cheng, and R. Paracuelles); Hyperion Treatment Plant; and Environmental Monitoring Division of the Bureau of Sanitation, City of Los Angeles, California.

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Submitted for publication November 8, 2001; revised manuscript submitted July 1, 2002; accepted for publication July 2, 2002.

The deadline to submit Discussions of this paper is March 15, 2003.

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