BIOLOGICAL ODOR CONTROL STRATEGIES AT WASTEWATER TREATMENT PLANTS

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ABSTRACT

Biological treatment of odor at wastewater treatment plants is an established technology. Recent developments also aim at the use of biofilters and biotrickling filters for the treatment of complex air streams containing multiple pollutants. Examples are the treatment of odorous air containing toxic Volatile Organic Compounds and odorous air from biosolids composting, which contains a mixture of sulfur compounds and ammonia. The present paper demonstrates the applicability of biofilters and biotrickling filters for treatment of such air streams.

INTRODUCTION

Waste air treatment at wastewater treatment facilities has for long been focussed on the prevention of odor with hydrogen sulfide being the principal target for treatment. Like many other facilities, the Hyperion Treatment Plant of the City Los Angeles, California, currently employs packed tower chemical scrubbers for waste air cleaning. These type of reactors effectively remove hydrogen sulfide at a short residence time. However, new developments in air emission regulations as well in solids handling processing require a re-evaluation of available techniques for air pollution control. For the Hyperion Treatment Plant, two developments are of particular importance:

1. New regulations limiting the emission of toxic Volatile Organic Compounds (VOCs) in the Los Angeles Basin are likely to take effect within a few years. This is a concern because air emissions from many wastewater treatment operations contain a wide variety of VOCs, including aromatics such as benzene and toluene, and chlorinated compounds such as methylene chloride and chloroform.
2. County ordinances have banned the land application of Class B biosolids. As a consequence, the City of Los Angeles is in the process to convert its plants to the production of Class A biosolids by thermophilic anaerobic digestion (Iranpour *et al.*, 2003). This has caused an increase of odorous emissions, which may

tentatively be attributed to the production of hydrogen sulfide and organic sulfur compounds, volatile fatty acids, ammonia and other nitrogen compounds.

Biological waste air treatment using biofilters and biotrickling filters has developed to a reliable and cost-effective technology for treatment of POTW air streams (Converse *et al.,* 2001 and 2002; Cox *et al.*, 2001 and 2002; Iranpour *et al.*, 2002a and b). The principle of treatment is biodegradation of pollutants by microorganisms to innocent end-products. Because microbial populations in biofilters and biotrickling filters generally are very divers, these type of reactors can simultaneously remove complex mixtures of pollutants, which would otherwise require a series of alternative technologies (for instance wet scrubbers followed by activated carbon absorption).

In the present contribution, we demonstrate by pilot-scale experiments how biofilters and biotrickling filters can be used for treatment of complex odorous air streams containing toxic VOCs. In addition, a literature survey was conducted to evaluate biofilters and biotrickling filters for the treatment of odors generated during biosolids composting and digestion processes.

MATERIALS AND METHODS

Hyperion Treatment Plant: HTP is the main wastewater treatment facility in Los Angeles, covering a service area of 600 square miles, inhabited by approximately 3.8 million people. The flow to HTP averages around 360 mgd, all of which receives primary and secondary treatment, the secondary being a high-purity oxygen activated sludge system. Experiments with the pilot biofilter were performed at the headworks building of HTP, where currently 170,000 m^3/h of ventilation air is being treated in chemical scrubbers. The air contains hydrogen sulfide as the main odorous pollutant as well as a wide variety of VOCs and other pollutants (Table 1).

Biofilter setup: The pilot biofilter (diameter 0.61 m; height 1.8 m) contained two sections for spatially separated removal of H_2S and VOCs (Figure 1). The first section (bottom) was 0.25 m deep and designated for removal of H_2S, whereas the second section (top) for VOC removal was 0.75 m deep. Both sections contained a mixture of compost, perlite and crushed oyster shells as the packing material. The two sections were separated by a plenum and each section had an independent, timer-controlled system for supply of secondary effluent water through permeable soaker hoses on top of each section. Secondary effluent was supplied once a day for a period of about 10 min to provide moisture and nutrients at an approximate rate of 2 L/min to each of the H_2S and VOC removal sections. Excess water was drained from the biofilter through an outlet port located at the bottom of the first section. The available pressure in the headworks ventilation air discharge line was sufficient to provide a slip-stream of initially 42.5 m^3/h to the bottom of the biofilter (up-flow configuration), corresponding to an overall EBRT in the biofilter of 25 sec. Over ten months of operation of the biofilter, however, increasing pressure drops over the biofilter caused a reduction of the gas flow rate and a gradual increase of the EBRT to 52 sec.

Biotrickling filter setup: The biotrickling filter was operated parallel to the biofilter. It was constructed of 304 stainless steel with a diameter of 1.5 m and a height of 3.4 m (Figure 2) containing seven layers of a PVC COOLdek^{tm} Munters 12060 structured packing. The packed bed height was 2.1 m, resulting in a bed volume of 3.8 m^3. Air from the headworks was introduced into the bottom of the reactor (gas upflow) at an average flow rate of 600 m^3/h, which corresponds to an empty bed gas residence time of 24 s. A 0.75 HP pump was used for continuous trickling of recycle liquid over the packed bed at a rate of 1.4 m^3/h (superficial liquid velocity of 0.8 m/h). The liquid was collected at the base of the reactor, containing approximately 0.6 m^3 of recycle liquid. Secondary effluent water from the plant was supplied at 6 – 12 L/h as a source of nutrients and to purge the produced sulfate. Control of pH in the recycle liquid was done with a Cole-Parmer stand-alone pH controller, which actuated the metering of 0.75-1.3 M NaOH to the bottom of the reactor when the pH in the recycle liquid dropped to a value less than 7.0.

Analytical methods: H_2S concentrations were on a daily basis determined using a Jerome 631-X hydrogen sulfide analyzer (Arizona Instruments, Tempe, AZ). VOC removal was determined on a semi-weekly basis by sampling the inlet and outlet air in 10 L Tedlar bags for about 4 minutes. Samples were analyzed usually within 24 h according to EPA method TO-14 using a GC equipped with photoionization and electrolyte conductivity detectors. Concentrations of organic reduced sulfur compounds were determined by Performance Analytical Inc. (Simi Valley, CA) after 253 days of operation. Analyses were done in triplicate using a GC with a chemiluminescence detector. On the same day, samples were taken for odor analysis by Odor Science & Engineering (Bloomfield, CT).

RESULTS

A HTP pilot studies for combined H_2S and VOC removal

H_2S removal: With H_2S concentrations typically ranging between 10 and 50 ppm over the day, both the biofilter and biotrickling filter consistently removed H_2S at greater than 97% efficiency over the test period of 10 months (Figures 3 and 4). Outlet concentrations were almost always below 1 ppm, which currently is the limit required by the South Coast Air Quality Management District. In the biofilter, H_2S was completely removed in the first section designated for H_2S removal and, hence, no penetration of H_2S to the second section for VOC removal occurred. This is an important design factor because oxidation of H_2S results in production of sulfuric acid, which can possibly inhibit VOC biodegradation by low pH. These considerations do not play a role for the biotrickling filter because of the continuous recirculation of a liquid phase with a pH controlled by caustic soda metering. The concentration profiles over the height of the biotrickling filter, shown in Figure 5, demonstrate that H_2S was removed in the first one-third section of the reactor. Hence, the gas residence time in the biotrickling filter can be significantly reduced without affecting the H_2S removal efficiency. It can also be seen that the pH did not have an effect on H_2S removal.

VOC removal: Table 2 demonstrates that VOC removal in the biotrickling filter was dependent on the pH. Without pH control and a pH in the recycle liquid declining to a value of approximately 1.5 – 2, none of the VOCs present in the headworks ventilation air were removed. However, 35 to 45% removal was observed for easily biodegradable VOCs such as toluene and benzene when a neutral pH was maintained in the biotrickling filter. This demonstrates the importance of pH control when the objective is to remove VOCs from waste air containing H_2S and other sulfur compounds. However, factors other than the pH seem to be important as well, because biodegradable VOCs such as xylenes and dichloromethane were not removed at either pH.

The biofilter displayed a higher efficiency in VOC removal. A representative example (day 253 after startup) is shown in Table 3. Removal was observed for the non-chlorinated aromatics benzene, toluene and xylenes. From the chlorinated compounds, only dichlorobenzenes were degraded at a significant level. Other chlorinated VOCs were not removed over the entire testing period of 10 months.

Removal of organic sulfur compounds and odor: These analyses were performed 253 days after the startup of the pilot units. The results in Table 4 demonstrate that some organic sulfur compounds were removed, in particular by the biofilter, but others not. Analyses of inlet and outlet streams revealed that the odor reduction was greater than 97% in both pilot units. H_2S removal and odor reduction appear to be strictly correlated. This indicates that H_2S is the major odorous pollutant in headworks ventilation air, and that its removal is a key factor in reducing odor.

B Biological techniques for odor from sludge composting and digestion

Biosolids land application is regulated by the Part 503 Biosolids Rule with respect to concentrations of pollutants and pathogens and the biological stability (U.S. EPA, 1993). However, public acceptance of land application is also governed by odor resulting from biosolids production and processing. The composition of odor generated during sludge digestion (Morton et al., 2002) and composting (Table 6) is similar to that of odors from typical wastewater treatment processes (e.g., Table 1), but in addition it contains relatively high concentrations of ammonia.

Several pilot and full-scale biofilters have been installed at biosolids composting facilities, as summarized in Tables 5 and 6. Experiences with biotrickling filters are very limited, as well as the application of biofilters at sludge digestion. The data in Table 6 demonstrate that biofilters can achieve significant reduction of odor from biosolids composting, despite the fact that the design of the biofilters, the type of packing materials, and the operational conditions may vary (Table 5). Ammonia is simultaneously removed with H_2S and organic sulfur compounds, however, there are indications that high ammonia concentrations may cause inhibition of biofilter performance over the long term (Giggey *et al*., 1994). This can possibly be attributed to accumulation of nitrate as the end-product of ammonia biodegradation.

CONCLUSIONS

Biological treatment is an economically attractive and environmentally friendly technology for waste air treatment at wastewater treatment plants. The present results demonstrate the feasibility of biotrickling filters and biofilters in treating complex air streams containing multiple pollutants. In the case of odorous air containing toxic VOCs, biotrickling filters and in particular biofilters can simultaneously reduce the odor and the emission of toxic VOCs. Likewise, biofilters can be used at biosolids handling processes that generate odors containing a mixture of hydrogen sulfide, ammonia, and organic sulfur compounds.

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Table 1. Average composition of headworks ventilation air.

Pollutant[a]	Concentration	Pollutant[a]	Concentration
H_2S	10-50 ppm	Benzene	0.5-2.5 ppb
		Toluene	10-153 ppb
Carbonyl sulfide	19-52 ppb	Xylenes	12-125 ppb
Methyl mercaptan	149-165 ppb	Dichlorobenzenes	1-210-ppb
Dimethyl sulfide	8-12 ppb	Methylene chloride	4-120 ppb
Carbon disulfide	6-8 ppb	Trichloroethylene	1-15 ppb
Tert-butyl mercaptan	2-3 ppb	Chloroform	16-102 ppb
		Tetrachloroethylene	15-225 ppb

Table 2. VOC removal efficiency (RE) in biotrickling filter with and without pH control.

VOC	No pH control, pH 1.5 – 2		pH control, pH ~7	
	Inlet conc. (ppb)	RE (%)	Inlet conc. (ppb)	RE (%)
Benzene	1-22	0	8-13	34.7
Toluene	10-153	-4.0	38-73	46.7
Xylenes	13-120	-3.3	19-124	-1.7
Dichlorobenzenes	1-9	-19.2	11-17	-7.0
Methylene chloride	4-43	-0.7	11-63	-3.0
Trichloroethylene	1	-4.2	4-15	-4.6
Chloroform	16-76	-2.2	58-102	-3.9
Tetrachloroethylene	15-89	-0.9	33-151	3.7

Table 3. VOC removal efficiency (RE) in biofilter (day 253 after startup, average of three determinations).

VOC	Inlet concentration (ppb)	RE (%)
Benzene	0.5-1	0-50
Toluene	20-60	42-86
Xylenes	40-150	40-75
Dichlorobenzenes	3.5-8	43-60
Methylenechloride	40-90	ND[a]
Trichloro ethylene	ND	ND
Chloroform	50-80	0-17
Tetrachloro ethylene	50-150	0-9

[a] ND = not determined.

Table 4. Removal efficiencies (RE) of organic sulfur compounds and odor removal in biofilter and biotrickling filter (day 253, average of three determinations).

Pollutant	Inlet concentration (ppb)	RE (%)	
		Biofilter	Biotrickling filter
Carbonyl sulfide	18.8-51.9	30-33	0
Methyl mercaptan	149-165	91-94	64-72
Dimethyl sulfide	8.1-11.5	0-21	0
Carbon disulfide	7.2-8.2	32-36	0
Tert-butyl mercaptan	<2	>31	>31
Odor (dilution to threshold ratio)	38,900-46,400	99-99.4	97-98.8

Table 5. Examples of biofilters for air treatment at biosolids composting facilities.

Source	Location	Target pollutants	Reactor dimension Area x height (m^2xm)	Packing	Pretreatment
Amirhor *et al.* (1994)	Darmouth, MA	S, N, odor	548x0.9	Bark mulch, wood chips, leaf compost	NS
Amirhor *et al.* (1997)	Somerset, MA	VOC, S, N, odor	1.2x1.2	Pine/spruce/fur or leaf/bark/woodchip	Ammonia scrubbing
Giggey *et al*. (1994*)*	Lewiston-Auburn, MN	Odor	2800x0.9	Compost, bark mulch, wood chips	Humidification
Lau *et al.* (1996)	Fraser Valley, Canada	N	504x1	Compost, wood waste, loam soil	
Rands *et al.* (1981)	Moerewa, New Zealand	S	42x1	Compost	

Table 6. Performance of biofilters at biosolids composting facilities.

Source	Gas residence time (s)	Removal of odorous S and N compounds		
		Pollutant	Conc. (mg/m^3)	RE (%)
Amirhor *et al.* (1994)	55-95	Dimethyl sulfide	0.08	55
		Dimethyl disulfide	1.1	83
		Methyl mercaptan	0.034	>90
		NH_3	34-106	98-99
		Odor	500-970 D/T	>80
Amirhor *et al.* (1997)	90	Dimethyl sulfide	0.38	25-36
		Dimethyl disulfide	0.56	19-28
		Methyl mercaptan	0.10	20-49
		NH_3		59-79
		Odor	394 D/T	64
Giggey *et al.* (1994)	72	Odor	115-338 D/T	90
Lau *et al.* (1996)	36-55	NH_3	28-50	95
Rands *et al.* (1981)	~170	H_2S	13-1150	>99

Figure 1. Pilot-scale biofilter at HTP.

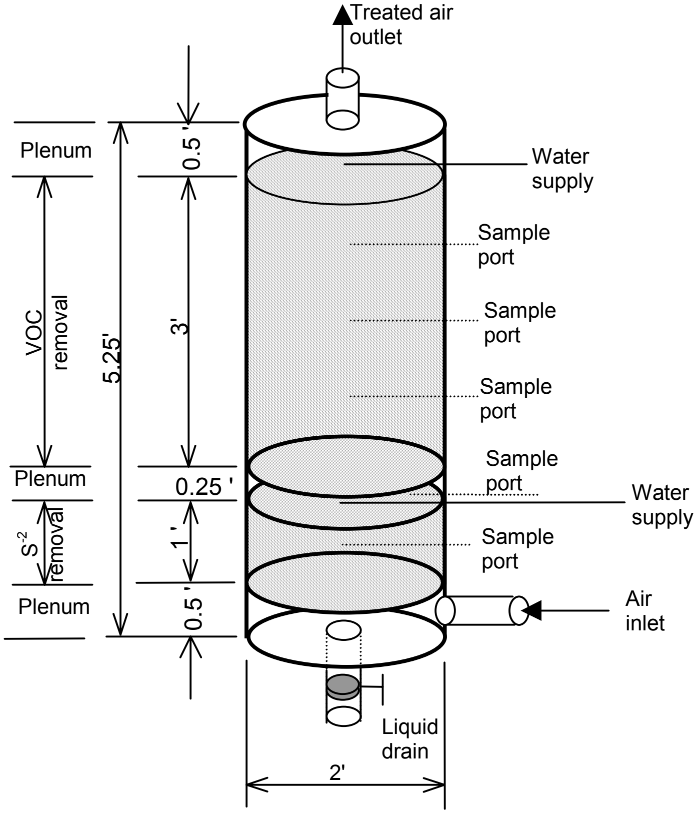

Figure 2. Pilot-scale biotrickling filter at HTP.

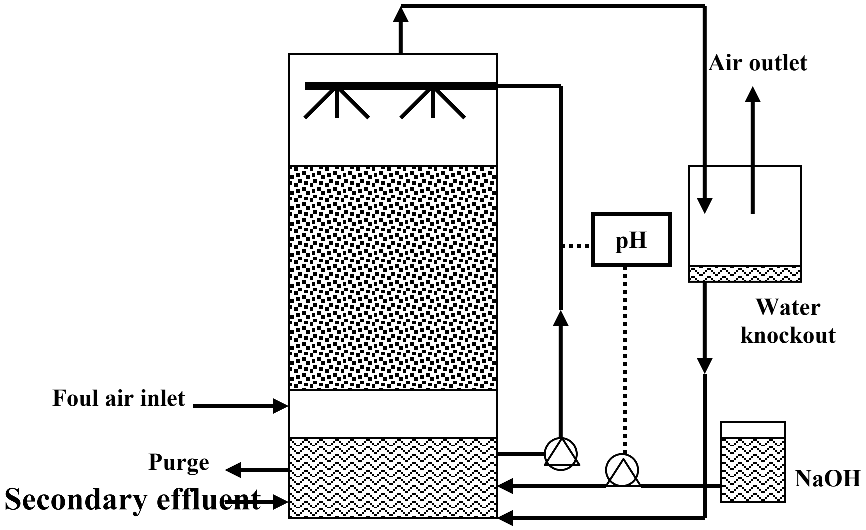

Figure 3. H_2S removal in biofilter.

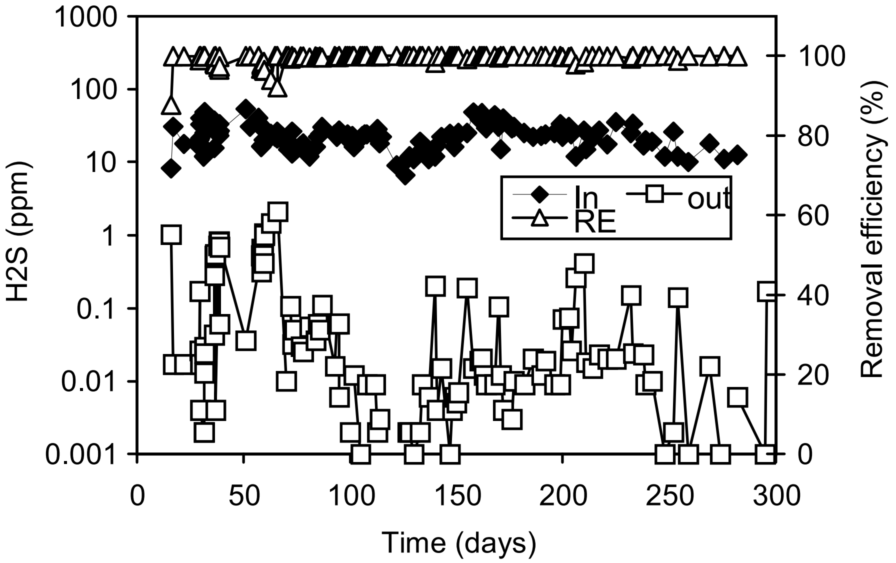

Figure 4. H_2S removal in biotrickling filter.

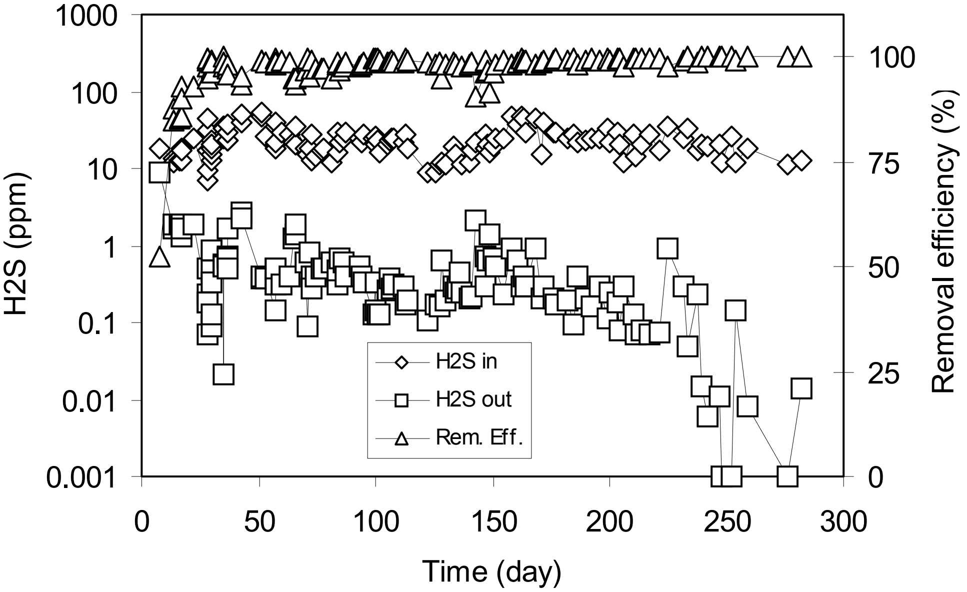

Figure 5. H_2S concentration profiles over height of biotrickling filter.