Measurement of Biosolids Compost Odor Emissions from a Windrows, Static Pile, and Biofilter

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ABSTRACT: A pilot study was conducted to compare odor emissions from a windrow process and an aerated static pile and to determine the odor reduction efficiency of a pilot two-phase biofilter for odor control of biosolids composting. Chemical compounds identified as responsible for odors from biosolids composting include ammonia, dimethyl disulfide, carbon disulfide, formic acid, acetic acid, and sulfur dioxide (or carbonyl sulfide). Aeration was found to reduce the concentration of ammonia, formic acid, and acetic acid by 72, 57, and 11%, respectively, compared to a nearby windrow, while dimethyl sulfide, carbon disulfide, and sulfur dioxide (or carbonyl sulfide) concentrations were below detection limits. Using dilution-to-threshold olfactometry, aeration followed by biofiltration was found to reduce the odor from biosolids composting by 98%. Biofiltration also altered the character of odor emissions from biosolids composting, producing a less offensive odor with an earthy character. Biofiltration was found to reduce the concentration of ammonia, dimethyl disulfide, carbon disulfide, formic acid, acetic acid, and sulfur dioxide (or carbonyl sulfide) by 99, 90, 32, 100, 34, and 100%, respectively. The concentrations of those odorants were estimated to be 3700, 110 000, 26, 37, 5, and 1.2 times reported human detection limits before the two-phase biofilter, respectively, and 42, 9600, 18, 0, 3, and 0 times human detection limits after the biofilter, respectively. *Water Environ. Res.,* **76,** 000 (2004).

KEYWORDS: ammonia, biofilter, compost, dimethyl disulfide, modeling, nitrogen, sulfur, volatile fatty acids.

Introduction

The purpose of this study was to (1) compare emissions from a windrow process to those from an aerated static pile process, (2) determine odor removal efficiency of a two-phase pilot biofilter, and (3) determine whether biofiltration can effectively control the odor from biosolids composting in hot summer conditions in Corona, California. Aeration and biofiltration have drastically reduced odor emissions from many composting facilities throughout the United States (Amirhor et al., 1997; Boyette, 1998; Devinny et al., 1999; Finn and Spencer, 1997; Goldstein, 1996; Toffee, 1997).

Aerated static pile composting is less odorous than windrow composting, as high oxygen levels in compost during the composting process reduce the formation of odorous compounds (Mosier et al., 1977). As of 1998, there were 321 biosolids composting projects in the United States; of these facilities, 121 are operated using aerated static piles (Goldstein and Gray, 1999).

Further reduction in odors from composting can be achieved by pulling air through compost and treating the exhaust gases with biofiltration. The use of negative aeration and biofiltration had been documented to reduce odor emissions from compost facilities by 98% or better (Devinny et al., 1999).

Biofiltration is an effective odor treatment technology that can be used to obtain high levels of odor reduction (Amirhor et al, 1997; Boyette, 1998; Devinny et al., 1999; Goldstein, 1996; Toffee, 1997). Furthermore, biofiltration is recognized by an increasing number of state and air quality regulatory agencies as the best available control technology for treating odor (Finn and Spencer, 1997). In biofiltration, a humid, contaminated airstream is passed through a porous material (e.g., wood chips, bark, and compost) supporting a complex microbial community. Microorganisms in the biofilter consume and metabolize odorous chemicals via enzymatic activity and oxidation. Under optimal conditions, nearly complete transformation of odorous compounds to carbon dioxide, water, and excess biomass is possible.

Materials and Methods

The windrow, aerated static pile, primary biofilter, and secondary biofilter are diagrammed in Figure 1, with a photo in Figure 2.

Windrows. Windrows were trapezoidal and included a combination of biosolids, green waste, stable bedding, and recycled compost (Table 1). The windrow tested in this project was approximately 15 m long, 6 m wide at the base, and 2 m high. The windrow was turned 3 times a week and odor sampling occurred on day 10 after construction of the windrow. A straddle-type windrow turner was used to aerate the windrow.

Aerated Static Pile. An aerated static pile was constructed using a combination of biosolids, green waste, stable bedding, and recycled compost (Table 1). The aerated static pile was 23 m long, 23 m wide, and 2 m tall (Figure 1), and the total volume of the aerated static pile was 915 m^3. The aerated static pile was not turned during this experiment.

Primary Biofilter. The primary biofilter was composed of bark and wood chips mixed with mature green waste compost that did not fit through a 6-mm screen. The primary biofilter was 27 m long, 6 m wide, and 1.5 m high (Figure 1). The primary biofilter was covered with opaque polyethylene sheeting enclosure to trap headspace gases for collection and distribution to the secondary biofilter. The total volume of the primary biofilter was 337 m^3.

Secondary Biofilter. The secondary biofilter was composed of bark and wood chips from various species of trees mixed with compost. The secondary biofilter was 26 m long, 6 m wide, and 1.5 m high (Figure 1). The total volume of the secondary biofilter was 240 m^3.

Aeration System. Thirteen high-pressure, belt-driven Grainger (Riverside, California) blowers (model 4C330, 5 hp 3 phase) specified to pump 611 L/sec at a pressure of 20 cm of water were used. Eight blowers were used for negative aeration of the compost pile. Four-inch (in diameter) polyvinyl chloride (PVC) pipes with

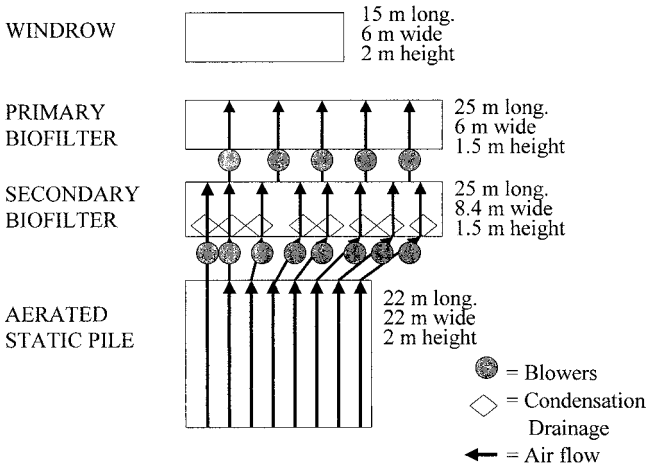

Figure 1—Aerated static pile and primary and secondary biofilter layout.

0.6-cm holes for the first 11.3 m (in length) and 1.3-cm holes for the last 11.3 m were used for aeration. Five blowers were used to pump air from the primary biofilter to the secondary biofilter. Aeration data are shown in Table 2.

Data Collection

Temperature and moisture data were collected at nine points in the aerated static pile, at three representative points in the primary biofilter each day, and at three representative points in the secondary biofilter each day. Temperature, relative humidity, and airflow data were collected at nine different points from days 1 to 13 after construction of the aerated static pile. Compost and biofilter temperatures were recorded using a Reotemp® (San Diego, California) temperature probe. Relative humidity was recorded using a digital thermohygrometer. Airflow rates were determined using a hot wire anemometer.

After construction of the aerated static pile on day 10, four samples for dilution-to-threshold values were collected immediately after the aerated static pile and four dilution-to-threshold values were collected from the exhaust gas of the secondary biofilter. Odor samples were collected using 5-L Tedlar bags (SKC, Fullerton, California), low-flow sampling pumps (SKC), and an 18.5-L vacuum box and vinyl tubing. Tedlar bags filled with odor samples were shipped overnight to Odor Science and Engineering, Inc. (Bloomfield, Connecticut). *Dilution to threshold* is defined as the dilution with odor-free air at which 50% of an odor panel detected the odor. Dilution to threshold was determined by means of forced choice dynamic dilution olfactometry. The eight-member panel was screened for olfactory sensitivity and their ability to match odor intensities. The olfactometer and the odor presentation procedure met the recommendations of the American Society for Testing and Materials (ASTM) Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series of Limits (ASTM E679-91) (ASTM, 1991).

Odorous Gas Collection and Sampling

Odorous gas samples were collected from an isolated surface area using an emission isolation flux chamber. Gases evaluated in this study are presented in Table 3. The flux chambers were stainless steel cylinders coated with Teflon. They were open on one end, 0.45 m in diameter, and 0.3 m high. A dry sweep gas (ultra-high pure zero air) was introduced to the flux chamber at a fixed, controlled rate (5 L/min) as a carrier where it mixed with the contaminants from the surface. The flux chamber contains a fixed volume and is designed to isolate the surface from the factors that can alter emissions such as wind or properties of the waste itself. The flux chamber was buried to a depth of 2.5 cm to create a seal between the chamber and the surface. The flux chamber and sweep air system is designed so that the contents are well mixed and no stratification exists. A probe was placed inside the flux chamber to extract a gas sample for subsequent analysis. The probe was designed to collect a sample composite at various altitudes (0.10, 0.17, and 0.25 m in height) within the flux chamber. Sampling was conducted at a rate less than or equal to the sweep air rate. The remainder of the flux chamber contents was allowed to vent through a 5-cm opening located on the top of the chamber.

During monitoring, one flux chamber was placed on the windrow and one was placed on the static pile. One-hour integrated samples were composited from two separate locations. To measure gases from the biofilter, three flux chambers were equally spaced on the surface of the secondary biofilter.

To determine the efficiency of the biofilter, untreated air from the windrow compost pile was sampled and analyzed. The aerated static pile extraction exhaust was sampled using two 1.25-cm inline PVC ball valves at the third and seventh downstream lines immediately before the entrance to the primary biofilter pile canopy. One-hour integrated samples were taken at two locations.

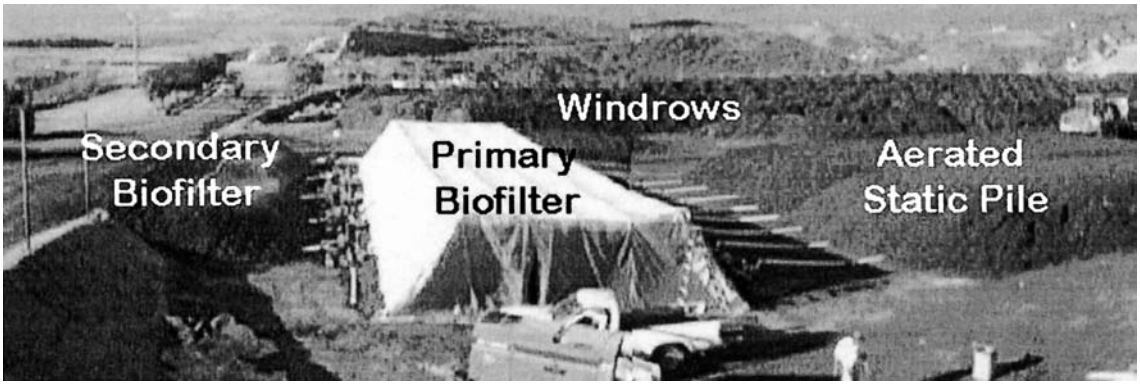

Figure 2—Photo of windrows, aerated static pile, and primary and secondary biofilters.

Table 1—Composition of the aerated static pile and windrow.

Material	Aerated Static Pile Cubic Meters	Aerated Static Pile Wet Tons	Windrow Cubic Meters	Windrow Wet Tons	Aerated Static Pile and Windrow Percent Moisture
Biosolids	261	283	44	48	80
Green Waste	197	51	33	9	30
Stable Bedding	261	77	44	13	38
Recycled Compost	196	109	33	19	
Total	915	522	156	88	50

Ammonia Sampling and Analysis. The sampling train for ammonia consisted of two midget impingers, each filled with 15 mL of 0.1-M sulfuric acid, an empty bubbler, and a buffer filled with tared silica gel. The silica gel impinger was connected to the vacuum side of a leak-free sample pump and a calibrated rotameter. The impingers and bubblers were contained in an ice bath to condense ammonia, water vapor, and other condensable matter present in the sample stream. Two impingers were placed in series to ensure no breakthrough. The samples were collected for two hours at a sampling rate of 1 L/min. An additional sample was collected from the exhaust side of the blower feeding the untreated gas to the primary biofilter to determine the ammonia concentration before treatment at the biofilter. Samples were analyzed for ammonia using ion chromatography (Dionex 2020, Sunnyvale, California) according to U.S. Environmental Protection Agency (U.S. EPA) Method 206 (U.S. EPA, 1982). Atmospheric Analysis (Ventura, California) performed the chemical analysis.

Carboxylic Acid Sampling and Analysis. Carboxylic acids including formic, acetic, propionic and butyric acids in air samples were quantified using Occupational Safety and Health Administration Method 28 (OSHA, 1981). The sampling train consisted of two midget impingers, each filled with 15 mL of a carbonate-bicarbonate solution, an empty bubbler, and a bubbler filled with tared silica gel. Two impingers were placed in series to ensure no breakthrough. The silica gel impinger was connected to the vacuum side of a leak-free sample pump and a calibrated rotameter. The impingers and bubblers were contained in an ice bath to condense the acids, water vapor, and other condensable matter present in the sample stream. The samples were collected for two hours at a sampling rate of 1 L/min. The samples were analyzed for formic, acetic, propionic, and butyric acid by high-pressure liquid chromatography with an ultraviolet (UV) detector (HPLC-UV). Moisture gain was determined volumetrically in the impingers and gravimetrically in the silica gel for quality control. Acid concentrations in the flux chamber were determined using the carboxylic acid content collected in the impingers along with the sampling rate and net elapsed sampling time. Samples were analyzed for carboxylic acids using ion-exclusion chromatography coupled with a UV detector (HPLC-UV). The UV detector was set at 210 micrometers to record the corresponding UV absorption. The chemical analyses were performed by Atmospheric Analysis (Ventura, California).

Sulfur Sampling and Analysis. Gas samples were collected before and after the biofilter in Tedlar bags. Integrated gas samples were collected during each sampling run from the flux chamber sample line using the vacuum side of a leak-free sample pump and calibrated rotameter. The samples were collected in 10-L Tedlar bags at a rate of approximately 50 mL/min for two hours. The Tedlar bags were enclosed in lead-free chambers for protection against contamination and photoreactivity. Because of the reactivity of the sulfur compounds, chemical analyses were performed within 24 hours. Total sulfides were analyzed using a Hewlett Packard 5890 gas chromatograph, flame photometric detector, and a DB-1 column. Sulfides scanned using gas chromatography/flame ionization detector following U.S. EPA Method 16 (U.S. EPA, 2000). Compounds scanned are identified in Table 3. The chemical analyses were performed by Atmospheric Analysis (Ventura, California).

Table 2—Airflow, volume, and contact time.

	Aerated Static Pile	Primary Biofilter	Secondary Biofilter
Mean Airflow (m^3/minutes)	82	82	60
Volume (m^3)	915	337	241
Contact time (minutes)	11.1	4.1	4.0

Results and Discussion

Atmospheric air maintained an 11.1-minute contact time in the aerated static pile before entering the primary biofilter (Table 2). This contact time did not reduce the air temperature of the compost below the temperature required to qualify as a process to further reduce pathogens (PFRP) as defined by U.S. EPA. The odorous air from the compost had a contact time of approximately four minutes for both the primary and secondary biofilters (Table 2), while a one- to two-minute contact time is typically sufficient for odor removal. The total estimated airflows from the aerated static pile to the primary biofilter and from the primary biofilter to the secondary biofilter are presented in Table 2.

Dilution-to-Threshold Data. The combined effect of airflow conditioning and biofiltration reduced the odor from the aerated static pile by 98% (Table 4). Using a *t*-test to compare dilution-to-threshold values of odorous gasses before and after the biofilters, odor reduction resulting from biofiltration was highly significant ($p < 0.01$, $n = 8$). The biofilter was also found to change the character of the odor. While the odor from the aerated static pile was similar to the odor of rotten fish or meat, the odor from the biofilter was reported to be earthier.

Odorant Analyses. Of the compounds analyzed, only ammonia, formic acid, acetic acid, dimethyl disulfide, carbon disulfide, and sulfur dioxide (or carbonyl sulfide) were identified (Table 4). All other compounds were below instrument detection limits. The odor samples collected before the biofilter were analyzed qualitatively by the odor panelists and descriptors of the odor were as follows: rotten fish, rotten meat, spoiled food, compost, urine, putrid, decayed meat, bad fish, latrine, and sour. The odor samples after the biofilter were analyzed qualitatively analyzed by the odor panelist and descriptors of the odor were as follows: burnt, penicillin, burnt coffee, bacon fat/burnt, manure, sour, rotten, compost, wastewater, earthy, garbage, dirty socks, mildew, and fishy.

Ammonia comprises more than 99% of the nitrogen emissions from biosolids, and a small fraction of amines are also volatized (Rosenfeld and Henry, 2000). Ammonia has a pungent medicinal odor and a human detection limit of 26 $\mu g/m^3$ (Ruth, 1986). The ammonia concentration coming off the windrow was approximately

Table 3—Compounds evaluated during the study.

Analyte	Formula	Odor[1]	Human Detection Limit[1] ug/m^3	Human Detection Limit[1] (ppb)	Analytical Detection Limit	Point °C	Molecular Weight
Volatile Fatty Acids							
Formic Acid	HCOOH	Biting	45	24	32 ppb	101	46
Acetic Acid	CH_3COOH	Vinegar	2500	1019	24 ppb	118	60
Propionic Acid	$C_3H_6O_2$	Rancid, pungent	84	28	20 ppb	141	74
Butyric Acid	$C_4H_8O_2$	Rancid	1.0	0.3	17 ppb	164	88
Nitrogen Compounds							
Ammonia	NH_3	Pungent	26.6	38	1 ug/m^3	−33.4	17
Sulfur Compounds							
Ethyl mercaptan	C_2H_6S	Rotton cabbage	0.032	0.01	50 ppb	35	62
Hydrogen sulfide	H_2S	Rotten eggs	0.7	0.5	50 ppb	−60.7	34.1
Carbon disulfide	CS_2	Disagreeable, sweet	24.0	7.7	50 ppb	46.3	76.1
Dimethyl sulfide	CH_3-S-CH_3	Rotten cabbage	2.5	1.0	50 ppb	37.3	62.1
Dimethyl disulfide	$(CH_3)_2S_2$	Rotten cabbage	0.1	0.026	50 ppb	109.7	94.2
Dimethyl trisulfide	$(CH_3)_2S_3$	Rotten cabbage	6.2	1.2	50 ppb	165	126
Methyl mercaptan	$(CH_3)SH$	Rotten cabbage	0.04	0.02	50 ppb	6.2	48.1
Allyl mercaptan	CH_2=CH-CH_2-SH	Garlic, coffee	0.2	0.1	50 ppb	NA	74.2
Propl mercaptan	CH_3-CH_2-CH_2-SH	Unpleasant	0.2	0.1	50 ppb	NA	76.2
Amyl mercaptan	CH_3-$(CH_2)_3$-CH_2-SH	Putrid	0.1	0.02	50 ppb	NA	104
Benzyl merecaptan	$C_6H_5CH_2$-SH	Unpleasant	1.6	0.3	50 ppb	NA	124
Sulfur dioxide	SO_2	Irritating	1175	449	50 ppb	NA	64.1
Carbon oxysulfide	COS	Pungent	NA	NA	50 ppb	−50.2	60.1

[1] (Ruth, 1986).

9000 times the lowest reported human detection limit, while the ammonia concentration coming off the negative aerated static pile was approximately 2500 times this value. While negative aeration did dramatically reduce ammonia emissions, a significant amount of ammonia still volatilized from the static pile. Because the blowers in this pilot study were undersized, the contact time of the compost and negative air was approximately 11 minutes. Greater flowrates could dramatically reduce the ammonia emissions.

The ammonia concentrations before and after the biofilter were 3700 and 42 times the human detection limit, respectively. Biofilters can reduce the concentration of ammonia in an airstream via the polarity of the ammonia molecule and high solubility in water, acid trapping by protonation (converting ammonia [NH_3] to ammonium [NH_4^+]), and oxidation of ammonia to nonvolatile NO_2^- or NO_3^-. It is likely that all these mechanisms occurred in the biofilter to reduce the ammonia concentration.

Dimethyl disulfide was not detected coming off windrows or the aerated static pile, and the purge gas used in flux chambers likely diluted the samples to a concentration below the detection limit. The dimethyl disulfide concentrations before and after the biofilter were 110 000 and 6700 times the human detection limit, respectively. It is likely that most of the dimethyl disulfide was oxidized to sulfate (SO_4^{2-}) or elemental sulfur. The sulfate could have reduced the pH of the biofilter and assisted in trapping the ammonia. Biosolids typically contain between 0.7 and 2.1% total elemental sulfur (Sommers et al., 1977), and some fraction of this is in the form of compounds with high vapor pressures that produce odor. Banwart and Bremner (1976) found that dimethyl disulfide accounted for 55 to 98% of total sulfur evolved from biosolids application to soil in aerobic conditions. Dimethyl disulfide, which is produced by numerous bacteria found in wastewater (Tornita et al., 1987) and fungi (Bojesson et al., 1993; Sunesson et al., 1995), possesses a rotten cabbage odor with a low human detection limit of 0.1 μg/m^3 (Ruth, 1986).

Carbon disulfide was not detected coming off the windrows or aerated static pile. The carbon disulfide concentrations before and after the biofilter were 26 and 18 times the human detection limit, respectively. Although carbon disulfide is another abundant odorant emission from biosolids (Banwart and Bremner, 1976), its contribution to the compost odor is far less significant than that of dimethyl disulfide. Carbon disulfide also possesses a rotten cabbage smell, with human detection limits of 24.3 μg/m^3 (Ruth, 1986). The reasons for the poor control of carbon disulfide are unclear.

It was impossible to reliably distinguish between the carbonyl sulfide and sulfur dioxide peaks on the gas chromatograph, so these two compounds were reported as a total concentration. Sulfur dioxide (or carbonyl sulfide) was not detected coming off the windrow or aerated static pile. The sulfur dioxide (or carbonyl sulfide) concentrations before and after the biofilter were 1.2 and 0 times the human detection limit, respectively. Apparently, the aerobic biofilter environment oxidized sulfur, forming sulfur dioxide (or carbonyl sulfide). Because sulfur dioxide and carbonyl sulfide peaks were combined, and because little data exists on the human detection limit of carbonyl sulfide, the human detection limit of sulfur dioxide (1175 ug/m^3) was used to estimate odor intensity for both compounds.

The formic acid concentrations from the windrow and aerated static pile were 81 and 35 times the human detection limit, respectively. The formic acid concentrations before and after the biofilter were 37 and 0 times the human detection limit, respectively. The acetic acid concentrations from the windrow and the aerated static pile were 5 and 4 times the human detection limit, respectively. The acetic acid concentration before and after the biofilter was 4 and 3 times the human detection limit, respectively. Propionic and

Table 4—Odorant concentrations in air samples collected above the windrow and aerated pile before and after biofilters.

Odorant	Sample Location	Detection Limit PPB (v)	Odorant Concentration (ppb)	Odorant Concentration (ug/m^3)	Dilution to Threshold Value	Human Detection Limit[2] (ug/m^3)	Odorant Concentration Divided by Human Detection Limit	Aeratic Pile Odor Reduction Compared to Windrow	Biofilter Odor Reduction
Dilution to Threshold	Before biofilter	NA	NA	NA	1291	1	1291		
	After Biofilter	NA	NA	NA	25.5	1	25.1		98%
Ammonia	Above Windrow	8	345137	239483	NA	26.6	9003	72%	
	Above Aerated Pile	8	95827	66492	NA	26.6	2500		
	Before Biofilter	8	141872	98442	NA	26.6	3701		99%
	After Biofilter	8	2389	1658	NA	26.6	42		
Dimethyl Disulfide	Above Windrow	50	<50	<192	NA	0.1	0	ND	
	Above Aerated Pile	50	<50	<192	NA	0.1	0		
	Before Biofilter	50	2882	11081	NA	0.1	110 810		91%
	After Biofilter	50	250	961	NA	0.1	9607		
Carbon Disulfide	Above Windrow	50	<50	<155	NA	24	0.0	ND	
	Above Aerated Pile	50	<50	<155	NA	24	0.0		
	Before Biofilter	50	628	1951	NA	24	26.2		32%
	After Biofilter	50	420	1305	NA	24	17.7		
Formic Acid	Above Windrow	32	1944	3650	NA	45	81	57%	
	Above Aerated Pile	32	843	1583	NA	45	35		
	Before Biofilter	32	892	1675	NA	45	37		100%
	After Biofilter	32	<32	<60	NA	45	0		
Acetic Acid	Above Windrow	24	4933	12100	NA	2500	5	11%	
	Above Aerated Pile	24	4389	10767	NA	2500	4		
	Before Biofilter	24	4056	9950	NA	2500	4		34%
	After Biofilter	24	2691	6600	NA	2500	3		
Sulfur Dioxide or Carbonyl Sulfide[3]	Above Windrow	50	<50	<131	NA	1175	0	ND	
	Above Aerated Pile	50	<50	<131	NA	1175	0		
	Before Biofilter	50	551	1441	NA	1175	1.2		100%
	After Biofilter	50	<50	<131	NA	1175	0		

[1] = Dilution-to-threshold values.
[2] = Lowest reported detection limit from Ruth (1986).
[3] = The peaks for sulfur dioxide and carbonyl sulfide overlapped, and the total peak area was used.
ND = nondetectable in air sample above the windrow or static pile.

butyric acids were not detected in any of the samples. While the biofilter controlled the formic acid emissions well, the biofilter did not effectively reduce the acetic acid concentration. Volatile fatty acids can be formed by anaerobic decomposition of cellulose, starch, hemicellulose, and pectins (Mosier et al., 1977). The lowest reported human detection limits for formic and acetic acids are 45 and 2500 μg/m^3, respectively.

Temperature Data. The data demonstrate that compost temperatures were in excess of the PFRP requirement of temperatures in excess of 55 °C for 3 days. The mean temperature of the aerated static pile for the first 3 days was 64 °C, so the pile achieved the temperatures required for Class A material (Figure 3). Biofilters function best in mesophyllic temperatures below 38 °C (Devinney et al., 1999), so the temperature of the secondary biofilter was probably more appropriate for more effective odor control.

Relative Humidity and Moisture Data. The mean water contents of the aerated static pile, primary biofilter, and secondary biofilter were 45 ± 3%, 54 ± 1%, and 53 ± 1%, respectively. The optimum percent moisture for composting and biofiltration is between 40 and 60% water (Devinny et al., 1999). The aerated static pile, primary biofilter, and secondary biofilter were all close to or within the optimum range during the study.

The mean relative humidity of the gas going from the aerated static pile to the primary biofilter was 100% during the 13-day study, while the mean percent relative humidity of the gas going from the primary biofilter to the secondary biofilter was 96 ± 6%. The primary biofilter slightly reduced the amount of water vapor in the airstream before it entered the secondary biofilter. Apparently, some water vapor condensed on the side walls of the polyethylene enclosure over the biofilter media. Reducing the air temperature favors more efficient

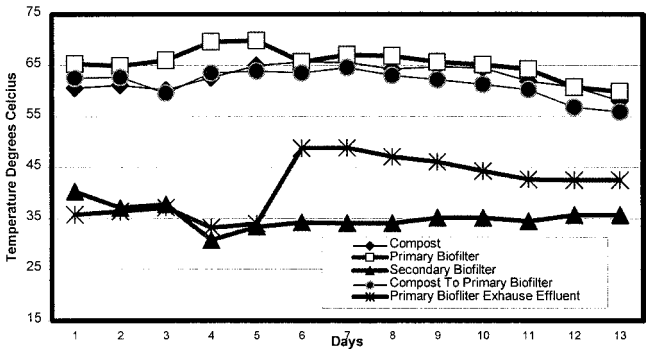

Figure 3—Aerated static pile, primary biofilter, biofilter, and airflow temperature vs. time (days).

biofiltration because the temperature of the exhaust gas from the aerated static pile was above the mesophylic range. The secondary biofilter had appropriate temperatures for mesophylic biofiltration. Furthermore, ammonia, formic acid, and acetic acid are soluble in water and can be filtered using a scrubber in addition to the biofilter.

Conclusions

The pilot study described here demonstrated the utility of biofiltration for controlling odor emissions from composting, especially combined with negative aeration. The aerated static pile produced fewer odors than a windrow, and substantial further odor reduction was achieved by biofiltration. Chemical odorants in this test included ammonia, dimethyl disulfide, carbon disulfide, formic acid, acetic acid, and sulfur dioxide (or carbonyl sulfide). Aeration reduced the concentrations of ammonia, formic acid, and acetic acid by 72, 57, and 11% compared to a nearby windrow, while dimethyl sulfide, carbon disulfide, and sulfur dioxide (or carbonyl sulfide) concentrations fell below detection limits. Dilution-to-threshold olfactometry indicated that aeration followed by biofiltration reduced the odor from biosolids composting by 98%. Biofiltration also altered the character of the odor emissions from biosolids composting so that qualitative odor descriptors provided by panelists evaluating gaseous emissions indicated that biofilter effluent was less offensive. Biofiltration reduced concentrations of ammonia, dimethyl disulfide, carbon disulfide, formic acid, acetic acid, and sulfur dioxide (or carbonyl sulfide) by 99, 90, 32, 100, 34, and 100%, respectively. The concentrations of the odorants were estimated to be 3701, 110 810, 26, 37, 5, and 1.2 times the lowest reported human detection limit before the two-phase biofilter, respectively, and 42, 9607, 18, 0, 3, and 0 times the human detection limit after the biofilter, respectively.

Acknowledgments

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Submitted for publication May 9, 2001; revised manuscript submitted July 30, 2003; accepted for publication August 13, 2003.

The deadline to submit Discussions of this paper is July 15, 2004.

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