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CONTROL OF ODOROUS AND VOLATILE ORGANIC COMPOUND EMISSIONS FROM COMPOSTING FACILITIES

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INTRODUCTION

Odor control at composting facilities has become one of the major issues affecting the efficacy of large and small operations alike. The practice of constructing facilities without odor control equipment in rural, unpopulated areas has led to problems at many facilities as subdivisions and industrial/commercial enterprise zones encroach upon a once remote composting site. Many times, this encroachment is accompanied with increased waste loading at the facility, thereby generating more odors which must be managed. The wide array of odorous compounds generated at composting operations usually results in very pervasive odors. Compost odors have been noted to concentrate in the lower atmosphere during inversion weather conditions, thereby resulting in odor detection miles away from some larger composting operations (Brown *et al.* 1989).

In addition to odors, the 1990 Clean Air Act Amendments have targeted Volatile Organic Compounds (VOC's) for control and treatment due to there reactivity as precursors to ozone. These compounds are sometimes referred to as reactive organic compounds (ROC's) or non-methane hydrocarbons (NMHC's). The generation of these compounds in non-attainment areas for the pollutant ozone (generally the more urban areas of our country) will become more strictly controlled as regulations continue to be developed. Ultimately, these regulations will impact sewage treatment plants (STP's) and accompanying solids processing units as well as solid waste processing facilities (SWPF's). Although not clearly defined as yet, it is likely that composting operations may come under the purview of these regulations. Therefore, control of VOC's at composting facilities, particularly larger biosolids and solid waste composting operations, may become necessary.

This paper presents information regarding current state of the art in odor and VOC control at composting facilities. A description of odors and VOC's will be presented, components of control, and treatment technologies in use today. Control of particulate emissions and bioaerosols, while important, will not be addressed here. Others have provided information on these topics (Epstein 1994; Clark *et al.* 1983). Likewise, a detailed description of odor and VOC regulations are available elsewhere (Card 1994; Lopez *et al.* 1994).

DESCRIPTION OF EMISSIONS

Odor detection and its measurement is a complex problem. This is because odor perception has several dimensions and the most sensitive instrument for measuring and quantifying odors is the human nose. The most common method of quantifying odors is by sensory measurement with the use of a group of trained panelists. Through the controlled introduction of odorous air to panelists, its detectability, intensity, character, and hedonic tone may be established. *Detectability*, the most commonly measured and reported odor characteristic is usually reported as a dilution-to-threshold (D/T) ratio or ED_{50}. D/T indicates how many volumes of clean, fresh air are required to be mixed with a volume of odorous air to reach the odor recognition threshold. *Odor intensity* relates to the perceived strength of an odor which is a function of concentration. Odor intensity is important in establishing the pervasiveness or carrying power of an odor. *Character* is a descriptor of what an odor smells like, and *hedonic tone* is the perceived acceptability or pleasantness of an odor. Because these characteristics may be somewhat subjective, odor panels of eight or more individuals are often used to establish statistical significance in an odor analysis situation. When odor problems occur at composting facilities, odor panel analysis work can be done to determine the D/T value and intensity values associated with odors. Dilution to threshold values in exhaust gas from composting facilities have been reported between 70 and 1,700 D/T, depending upon the facility type/process used, and exhaust gas collection methodology (Williams 1994; Ostojic *et al.* 1994). Usually a D/T value of several hundred is not uncommon for

biosolids or municipal solid waste composting facilities. Data for yard waste composting operations is not as readily available due to the lack of analytical work performed at these operations.

Many different groups of compounds are present in compost exhaust gases at varying concentrations. The mixture of these compounds can result in odors which have greater intensity or a higher D/T value than the summation of the individual compound characteristics. The most significant groups of odorous compounds identified at composting facilities include reduced sulfur compounds, ammonia and amine compounds, fatty acids, terpenes, acetone, phenol, and toluene (Bohn 1977; Hentz *et al.* 1992; Miller 1992; Van Durme *et al.* 1992). The most common sulfur based compounds contributing to odors at composting facilities include hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide, carbon disulfide, and methanethiol (Derikz *et al.* 1990; Miller 1992). A number of references document the presence of these odorous compounds in exhaust gases from composting facilities. Table 1 shows compounds either specifically identified or implicated in composting odors. Only a handful of the compounds shown in Table 1 are listed as hazardous air pollutants (HAP's) in the Clean Air Act Amendments (CAAA). However, virtually all of the compounds shown (with the exception of hydrogen sulfide and ammonia) are volatile organics or hydrocarbons which are designated criteria pollutants. The quantity of these compounds emitted from composting facilities varies depending upon feedstock materials, process type and material quantities processed. The need for controlling odors and VOC emissions from composting facilities is discussed in the following section.

NEED FOR ODOR AND VOC EMISSIONS CONTROL

The primary reason for emissions control at composting facilities in the past has been to control odors. This reason will continue to remain in the forefront of the minds of planners, designers, and operators. Neighbors close to composting facilities simply do not want to be impacted by malodors from the facility. Such nuisance conditions can create highly emotional debates over the continued operation of the facility. Most states have some form of regulation governing the release of odorous emissions. The majority employ a nuisance approach which relies on citizen complaints to initiate enforcement of the regulation. Once odor problems have increased to this level, it is a major up-hill battle for composting facility operators to develop acceptable solutions. A handful of states have emission or ambient standards for odors. Such rules provide more clear cut standards against which the facility must perform.

With the passage of the 1990 Clean Air Act Amendments (CAAA), standards for volatile compounds (VOC's) and hazardous air pollutants (HAP's) are being developed for numerous sources of these air pollutants. Solid waste treatment, storage, and disposal facilities (TSDF) as well as publicly owned treatment works (POTW) emissions are listed categories of major and area sources of HAP's. According to Title III of the CAAA regulation, major sources of hazardous air pollutants (air toxics) must install a maximum achievable control technology (MACT) device in accordance with EPA schedules. In order to be considered a major source, the facility must have the potential to emit over 10 tons per year of a single-listed compound or 25 tons per year of the aggregate of the listed compounds on the HAP list. MACT is defined as being equal to the average of the top 12% best performing sources in the same source category. Although composting facilities are not specifically listed in the source category list, they may be considered a point source under the POTW category (for biosolids) or the TSDF category (for municipal solid waste or yard waste). Because the regulations are in the early development stage, it is not known how they will ultimately impact composting operations. Currently, MACT standards for POTW's and TSDF's are due in November 1995 and MACT installation is required by May 1997 for Major Sources. While this schedule may change, it is incumbent upon composting facility owners and operators to determine if their operation would be considered a major source through emission inventory estimating of actual and potential pollutants.

Title I of the CAAA, criteria pollutants will, perhaps, play a bigger role in impacting composting facilities, depending upon the location of the composting facility. Unlike air toxics (HAP's), which have local impact, criteria pollutants (such as VOC's) have regional impact. In other words, if the composting facility is located in a designated non-attainment area, regulations will be more stringent. For example, a regional non-attainment designation of "Extreme" would require less than 10 tons per year of aggregate volatile organic compound emissions from a POTW to prevent its classification as a major source. Because it is still unclear how composting operations will fit into these categories, it is prudent to either measure or estimate HAP and VOC emissions to determine if your facility is near any of these category levels (Card 1994; Lopez *et al.* 1994)

TABLE 1: Compounds either specifically identified or implicated in composting odors. Physical data is taken from Weast (1971), odor descriptions and high and low threshold values from Ruth (1986), and the ADL threshold values are derived from Leonardos et al. (1969).

Name	Formula	m.w.	b.p.	sol/100g	odor	odor threshold ug/m3 low	odor threshold ug/m3 high	odor threshold ug/m3 ADL[a]	Refs[b]
Sulfur Compounds									
*Hydrogen sulfide	H_2S	34.1	-60.7	437 ml	rotten egg	0.7	14	6.7	A,B
Carbon oxysulfide	COS	60.1	-50.2	50 ml	pungent	c	c	-	A
*Carbon disulfide	CS_2	76.1	46.3	0.22g	disagree, sweet	24.3	23000	665	A,C
Dimethly sulfide	$(CH_3)_2S$	62.1	37.3	insol	rotten cabbage	2.5	50.8	2.5	A,C
Dimthyl disulfide	$(CH_3)_2S_2$	94.2	109.7	insol	sulfide	0.1	346	-	A,C,E
Dimethyl trisulfide	$(CH_3)_2S_3$	126.2	165*	insol	sulfide	6.2	6.2	-	A,C,E
Methanethiol	CH_3SH	48.1	6.2	v.slight	sulfide, pungent	0.04	82	4.2	A
Ethanethiol	CH_3CH_2SH	62.1	35	v.slight	sulfide, earthy	0.032	92	2.6	
Ammonia and nitrogen containing compounds									
Ammonia	NH_3	17.1	-33.4	90g	pungent, sharp	26.6	39600	33100	A,B
Aminomethane	$(CH_3)NH_2$	31.6	-6.3	very	fishy, pungent	25.2	12000	-	
Dimethylamine	$(CH_3)_2NH$	45.1	7.4	very	fishy, amine	84.6	84.6	88.1	
Trimethylamine	$(CH_3)_3N$	59.1	2.9	very	fishy, pungent	0.8	0.8	0.52	
3-methylindole (skatole)	$C_6H_5C(CH_3)CHNH$	131.2	265	soluble	feces, chocolate	$4.0*10^{-5}$	268	-	
Volatile fatty acids[d]									
Methanoic (formic)	HCOOH	46.0	100.5	inf	biting	45.0	37800	-	
Ethanoic (acetic)	CH_3COOH	60.1	118	inf	vinegar	2500	250000	2500	D,G
Propanoic (propionic)	CH_3CH_2COOH	74.1	141	inf	rancid, pungent	84.0	60000	-	D
Butanoic (butyric)	$CH_3(CH_2)_2COOH$	88.1	164	inf	rancid	1.0	9000	3.7	D,G
Pentanoic (valeric)	$CH_3(CH_2)_3COOH$	102.1	187	3.7g	unpleasant	2.6	2.6	-	D
3-methylbutanoic (isovaleric)	$CH_3CH_2CH(CH_3)COOH$	102.1	176	4g	rancid cheese	52.8	52.8	-	
Ketones									
Propanone (acetone)	CH_3COOH_3	58.1	56.2	inf	sweet, minty	47500	1610000	241000	A
*Butanone (MEK)	$CH_3COOH_2CH_3$	72.1	79.6	very	sweet, acetone	737	147000	30000	A
2-pentanone (MPK)	$CH_3COOH_2CH_2CH_3$	86.1	102	slight	sweet	28000	45000	-	A
Other compounds									
Benzothiozole	C_6H_4SCHN	135.2	231	inf	penetrating	442	2210	-	C
*Ethanol (acetaldehyde)	CH_3CHO	44.1	20.8	inf	green sweet	0.2	4140	385	
*Phenol	C_6H_5OH	94.1	181.8	soluble	medicinal	178	2240	184	E

[a] - values recalculated from volume/volume data assuming 20 degrees C and 1 atmosphere.

[b] - References: A - identified by Derikx et al., (1990) B - identified by Miller et al. (1991) C - identified by Fisher et al. (1986) D - identified by Chanysak et al. (1982) E - identified by Koe and Ng (1987) in decaying refuse not strictly composting.

[c] - no odor threshold values for carbon oxysulfide are to be found in the literature.

[d] - identified by class by Manios et al. (1989) in compost extracts and by Miller (1991) using Draeger tubes for organic acids in an open composting yard.

* - Listed as hazardous air pollutant in 1990 Clean Air Act amendments.

Reference: Adapted from Miller, 1992.

COMPONENTS OF CONTROL

There are four basic elements of odor control which must be adequately addressed at a composting facility to ensure effective control of odor and VOC emissions:

- Reduction through Process Control
- Containment and Transport
- Treatment
- Dispersal of Residual Odors

Good process control at composting facilities is essential to reduce the amount of odors generated. In a 1993 survey of biosolids composting facilities, all those facilities which responded indicated good process control as a priority to odor control (Goldstein *et al.* 1993). Control of the feedstock quality and quantity has a direct bearing on odor generation. While the quantity of material may not be a viable variable, the quality or stability of the feedstock is. Wilbur and Murray (1990) reported that the odor producing potential of various WWTP sludges during composting decreased in the following order: secondary > primary > nitrified or digested. Proper moisture and nutrient contents of the mixtures of sludges, biosolids, solid wastes, yard wastes, or other materials is a crucial first step. For example, an improper nutrient balance can lead to excessive ammonia production during composting. Adequate mixing of feedstocks to insure homogeneity, adequate porosity and the elimination of large clumps (> 3 inches) will help to reduce odor production. At the Montgomery County, Maryland biosolids composting facility, a 40% reduction in odorous compound generation during composting was noted after the mobile windrow mixing equipment was replaced with an automated continuous feed mixer (Murray *et al.* 1991). Proper aeration of the composting mass as well as temperature control also are necessary to minimize odor generation. Differences in composting technologies is significant in this regard. A simple turned windrow process will not provide adequate oxygen to maintain a fully aerobic process during the most active phase of composting. Turning of windrows provides oxygen for a short time period - usually minutes - followed by rapid depletion of oxygen. The resulting anaerobic condition will generate more reduced sulfur-type compounds, which are very pervasive, than a fully aerobic process. Turning an active windrow may release the odors rather than controlling them. Wilbur and Murray (1990) also showed that as compost pile temperatures were lowered with higher aeration rates, significantly more odors were released during composting. They attribute this to the supposition that as pile temperatures increased, degradation rates were slowed. While this may be true at higher temperatures (above 60°C), it is also likely that too great of an aeration rate actually will strip odors and VOC's out of the composting mass before they can be absorbed and degraded in subsequent zones of the pile.

Containment and transport of odors is imperative if odor treatment and dispersion are to be employed. After inventorying odor sources, odors from the active process can be collected and ducted to a treatment system. Containment with building or reactor walls is commonly applied in biosolids and MSW composting operations. Because most of the odorous compounds generated are water soluble, they tend to be transported with water droplets in steam plumes. Containing these moist airstreams must be accompanied by transporting to a treatment system in order for the odor control system to be effective. Many vessel and some static pile systems collect compost process offgases from the discharge of an aeration blower and then duct these gases to a treatment system. A relatively concentrated and small quantity gas stream is then available for treatment. Other systems draw air from above the composting mass for treatment. This approach reduces the concentration of gases requiring treatment but can significantly increase the gas quantity.

Treatment systems which have been used to collect emissions from composting facilities include:

- Multi-stage Wet Chemical Scrubbers
- Biofiltration
- Bioscrubbers
- Carbon Adsorption
- Chemical Counteractants
- Masking Agents

Multi-stage wet chemical scrubbers have been used at numerous biosolids composting facilities with mixed success (Brown *et al* 1989). Two basic types of scrubbers are used, mist scrubbers and packed tower scrubbers. Mist scrubbers rely on reactive chemicals to oxidize odors quickly in the vapor phase by misting the scrubbant countercurrent to the odorous gases being treated in a large chamber. Packed tower scrubbers rely on plastic media with a high surface to volume ratio over which scrubbant is cascaded while the exhaust gases pass through. Packed towers usually contain a reservoir of scrubbant at the bottom to which fresh chemicals are added prior to recirculating over the media. A relatively large overflow stream is generated which must be treated at a WWTP. Mist scrubbers typically operate in a once-through fashion with no scrubbant recirculation. However, a much smaller overflow stream is generated than for packed tower scrubbers. Both types of chemical scrubbers are usually operated in stages (2-4) to allow different chemistry to affect the removal of different groups of compounds. Typically, an acid is used in the first stage to remove ammonia prior to the second stage where bleach is used to oxidize reduced sulfur compounds. Variations exist in this basic system such as the addition of surfactants for enhanced organics (VOC's) removal, acid for pH adjustment, and peroxide addition for removal of any chemical residual odors. This type of odor treatment system is used at numerous enclosed reaction facilities. A significant benefit of using these systems is that residual odors can be discharged through a stack at elevated levels, thereby increasing dispersion/dilution of the odors prior to impacting off-site receptors.

Biofiltration has been gaining increased acceptance as a treatment technology for composting facilities as better designed operations are built and removal data is generated. Biofilters rely on adsorption of odors and VOC's on to a moist media followed by biological oxidation of these compounds. Typically, gases are forced through a three- to four-foot deep layer of media consisting of mixtures of compost, soil, wood chips, bark, sand, etc. where adsorption and degradation takes place. Biofilters require a significant land area due to the low loading rates which are required.

Bioscrubbing uses the same principle as biofiltration, only in a liquid-phase system rather than a gas/liquid/solid-phase system. Odorous air is bubbled through activated sludge or a biological "broth" type system where odors are absorbed and broken down biologically. Only a few composting facilities use this practice and it is generally predicated on the location of the facility in the vicinity of an activated sludge system.

Activated carbon has been utilized with poor performance. This is because dust and moisture in compost facility exhaust fill carbon adsorption sites, thereby reducing its effectiveness.

Chemical counteractants have shown some success in odor treatment but are not as widely used as other chemical scrubbing technologies. A highly reactive stream of counteractant is sprayed in a very fine mist into compost exhaust gases. Reactions occur instantaneously and alter odor intensity and concentration. They generally are not as effective as wet chemical scrubbers or biofilters.

Masking agents are nothing more than perfumes designed to cover up compost or other odors with a more pleasant odor. In other words, the hedonic tone and the character of the odor may be changed but the intensity and concentration is not diminished. They are not recognized as effective means of treatment.

Dispersion of any residual odors after treatment is a component of any composting facility which should not be ignored. Simply put, dilution can be the solution to odor pollution if enough distance is available between the composting operation and receptors. Unfortunately, encroachment around existing facilities has created troubles for numerous operations. Basic dispersion of residual odors through a building roof upblast fan rather than across ground level can drastically reduce odor problems if enough other odor control measures are in place. Stacks have the advantage of discharging high enough in the air to allow mixing odors with ambient air prior to the plume of gases reaching ground level where receptors might not notice them. Area sources (such as compost piles or biofilters) have discharges at ground level which does not allow for dispersion prior to off-site transport, especially during stable air conditions. Modelling of residual odors is recommended for most facilities being built or expanded to insure off-site odor problems do not occur. Several authors document the issues of dispersion from composting facilities in detail (Walker 1991; Haug 1990).

TREATMENT SYSTEM CASE STUDY RESULTS

Treatment systems are generally not used at composting facilities unless exhaust gases are contained (in a structure or through ducting) and directed to an odor treatment device. The majority of composting systems in the U.S., which employ some means of odor treatment system, utilize multi-stage chemical scrubbers or biofiltration. Other treatment technologies listed previously have been utilized at only a handful of facilities. In addition, operating data on their performance is not readily available. Because multi-stage chemical scrubbing and biofiltration are the most common systems used for compost facility emissions treatment (more than 20 of each in operation), information about these technologies is presented.

Multi-Stage Chemical Scrubbers

Due to the complexity of compost facility emissions, multi-stage chemical scrubbing systems are generally used instead of single-stage scrubbers. At least two, and up to four stages are used to achieve effective odor reduction. Complex chemical dosing is generally required based on changing characteristics of the air stream being treated. The first stage of treatment typically is designed to remove ammonia and associated amine compounds so that subsequent chemical oxidation stages are more effective at reducing organics. Ammonia removal is achieved by scrubbing the airstream with large amounts of water (if available) to cool the process gas and the addition of an acid to absorb ammonia and other acid soluble organic compounds. The second stage usually employs sodium hypochlorite (bleach) to oxidize reduced sulfur compounds such as dimethyl disulfide, dimethyl sulfide, and hydrogen sulfide. Some installations choose to add acid in this stage to reduce the pH of the scrubbant, thereby converting $NaOCl$ to $HOCl$, which has a higher oxidation reduction potential. (Hentz, *et al.* 1992). The addition of surfactants practiced by some facilities to enhance organics removal and hydrogen peroxide polishing is sometimes used in a final stage to oxidize any residual chemicals prior to discharge. Data on the effectiveness of these scrubbers to remove odors at full-scale composting operations is shown in Table 2. Several other facilities utilize chemical scrubbers for odor treatment but data on effectiveness was not available. The primary data available is in the form of odor removal D/T data. A brief description of each facility follows.

Table 2
ODOR REMOVAL DATA FROM SEVERAL WET SCRUBBER INSTALLATIONS AT COMPOSTING FACILITIES

FACILITY	DATE OF TEST	D/T INLET		D/T OUTLET		ODOR REMOVAL	
		Range	Average	Range	Average	Range	Average
Akron, OH [1]	3/93 and 8/93	53-338	180	12-85	47	55-85	74
Hamilton, OH [1]	9/91	158-289	223	84-158	127	0-47	31
HRSD, VA [2]	6/90	—	1700	—	200	—	88
Lancaster, PA [1]	9/88	130-380	—	60-140	—	55-67	—
Montgomery County, MD [1]	1/92	175-315	230	52-94	63	69-76	72
Montgomery County, MD [3]	?	—	—	—	—	80-90	—
Schenectady, NY [1]	7/90	480-860	660	110-200	150	70-83	77
Schenectady, NY [4]	9/90	—	558	—	21	—	96

D/T = Dilutions to Threshold or ED_{50}.

References:
1 - Ostojic, *et al.* 1994.
2 - Van Durme, *et al.* 1992.
3 - Hentz, *et al.* 1992.
4- Muirhead, *et al.* 1993.

Akron, Ohio operates a 70-dry ton per day Paygro biosolids composting system. Offgas from the headspace above the compost reactors is collected and treated through a two-stage packed tower system consisting of acid addition in the first stage and sodium hypochlorite in the second stage. Full-scale performance resulted in 55-85% odor removal efficiency.

Hamilton, Ohio operates a 17-dry ton per day Simon Waste Tunnel reactor to process biosolids. Offgases from this reactor can be routed to either a multi-stage mist scrubber or a biofilter. Full-scale tests included various combinations of acid, sodium hypochlorite, and sodium hydroxide. Because odor removal efficiencies never exceeded 50%, the scrubber system was shut down in 1991 and the biofilter (discussed later) was utilized.

Hampton Roads Sanitation District (HRSD) operates a 12-dry ton per day static pile biosolids composting facility in Newport News, Virginia. Although this facility has been in operation since 1980, it has no odor treatment system. Plans to expand the operation to 17-dry tons per day at a different location included pilot testing of odor treatment options (Van Durme, *et al.* 1992). The most promising pilot test resulted in 88% odor reduction through a two-stage packed tower consisting of sulfuric acid in the first stage, followed by a mixture of sodium hypochlorite and sodium hydroxide in the second stage.

Lancaster, Pennsylvania operates a 30-dry ton per day Taulman biosolids composting facility. This is a vertical top-down flow reactor. Offgas from the reactor was processed through a single-stage sodium hypochlorite mist scrubber. At the time when odor testing was performed in 1988, an odor removal efficiency of 55-67% was achieved. However, odor problems continued. Modifications in the wet scrubbing system to multi-stage with acid stage followed by a hypochlorite stage yielded significant improvement. However, subsequent odor testing was not performed to verify removal results. The State of Pennsylvania did its own stack test on the scrubber and determined that an 89% removal rate was being achieved on total reduced sulfur compounds.

Montgomery County, Maryland operates a 40-dry ton per day aerated static pile biosolids composting facility which is totally enclosed. Process offgases from the active compost piles are treated through a three-stage mist system which includes acid, surfactant and hypochlorite, followed by hydrogen peroxide. 1992 test data showed that a 72% odor reduction was achieved with this high-tech scrubbing system. However, Hentz, *et al* (1992) reported that between 80% and 90% of odors were removed from this process exhaust by the scrubbing system.

Schenectady, New York operates a 15-dry ton per day American Biotech air-lance biosolids composting facility. Process offgas is treated through a multi-stage packed tower scrubber that was modified several times. The present sulfuric acid (first stage) followed by sodium hypochlorite/sodium hydroxide two-stage system reportedly achieves 96% odor reduction (Muirhead 1993).

With the exception of the latest system in Schenectady, all wet scrubber systems reviewed had difficulty in consistently achieving stack discharge gas detectability below 50 D/T. One advantage of the wet scrubber systems is that discharge stacks are used to disperse any residual odors from the treatment process even further before being detected by a receptor. No published data was found on the overall VOC removal efficiency of these systems. However, presumably, if much of the organic compounds responsible for odors are removed, then VOC reduction is also occurring.

Biofilters

Biofilters are gaining increasing popularity as an odor control treatment technology for composting facilities due to their simple operation, low cost, and ability to treat multiple compounds simultaneously. Currently, over two dozen composting facilities in the U.S. rely on biofilters for their primary odor treatment device. Much work has been accomplished in the past three to five years to improve problem areas of biofilters, primarily air distribution and moisture control. Most of the poor performance case studies of the past are due to poor moisture control or overloading. Typical biofilters in use today at composting facilities are uncovered and consist of an air distribution piping network embedded in gravel beneath a three to four-foot deep biofilter media consisting of mixtures of wood chips, bark, compost, soil, etc. When loading rates are kept below 5 CFM/SF and nominal gas detention times greater than 45 seconds are maintained, very good odor removal efficiencies are obtained. Table 3 shows odor and VOC removal efficiencies for seven different biofilters.

Four of these installations (*Dartmouth, New Hampshire; Lewiston-Auburn, Maine; Plymouth, Massachusetts, and Yarmouth, Massachusetts*) utilize the agitated bed composting technology to process biosolids. A large headspace above the compost bins results in significant dilution of offgases prior to treatment.

Hamilton, Ohio was described earlier. Concentrated offgas from the horizontal tunnel system is cooled with a water spray system prior to treatment in the biofilter.

Sevier, Tennessee is a solid waste/biosolids co-composting plant which utilizes a drum compostor and an aerated static pile technology. Data reported here is for the most odorous gases being treated from the initial digester drum.

Table 3
ODOR AND VOC REMOVAL DATA FROM SEVERAL BIOFILTER INSTALLATIONS AT COMPOSTING FACILITIES

Facility	Date of Test	D/T Inlet		D/T Outlet		Odor Removal %		TRS Removal %	VOC Removal %
		Range	Average	Range	Average	Range	Average		
Dartmouth, MA [1]	5/93, 12/93	—	—	—	—	76-97	86	81	—
Hamilton, OH [2]	9/91-3/92	180-1200	635	5-25	19	—	97	99	99
Hoosac, MA [3]	9/93	—	—	—	—	—	95	99	52
Lewiston-Auburn, ME [4,5]	9/93	71-158	115	7-11	8	90-94	93	—	—
Plymouth, NH [6]	4/92	170-318	227	< 10-35	23	79-96	90	—	—
Sevier, TN [7]	11/93	—	1020	—	22	—	99	93	82
Yarmouth, MA [4]	4/93	143-262	214	4-26	12	88-98	95	>90	—

D/T = Dilutions to Threshold or ED_{50}
TRS = Total Reduced Sulfur
VOC = Total Volatile Organic Compounds

References:
1 - Amirhor, *et al.*,1994.
2 - Wheeler, 1992.
3 - E&A Environmental Consultants, Inc., 1993.
4 - Giggey, *et al.*, 1994.
5 - Ostojic, *et al.*, 1994.
6 - Kuter, *et al.*, 1993.
7 - E&A Environmental Consultants, Inc., 1994.

As this data shows, odor removal at all of these facilities was very good, ranging from 86 to 99%. Removal of TRS compounds showed nearly equal performance of 78 to 99%. VOC removal data was less available, but between 52 and 99% was reported at three facilities. One of the key phenomena of biofilter performance is the consistent results of D/T values in the exhaust being below 25 regardless of inlet D/T values. This is very important since residual odors are not diluted well from open biofilters due to its large ground level area source characteristics. Continued development of adsorptive media which resists air channelling over time will help improve biofilter performance. Data on biofilter designs and operating criteria is published elsewhere (Williams, 1994; Leson *et al.* 1991).

CONCLUSIONS

Odor and VOC emissions control at composting facilities needs to be managed on a more proactive basis than passive basis as has been done historically. Because odors generated at these facilities tend to be very pervasive, odor problems can occur miles from a facility. Nuisance odor conditions can create ill-will between operators and neighbors, and can trigger enforcement action from state regulatory agencies. With the enactment of the 1990 Clean Air Act Amendments, regulations regarding VOC control are being developed. Facility owners and operators should determine actual or calculated inventory emission data from their facilities in order to determine potential for impact by these regulations and/or the need for additional treatment systems.

Odor and VOC emissions need to be addressed in the design and operations of larger composting operations. Components which must be included in an effective odor management system include minimization of generation, collection and transport, treatment and dispersion/dilution of residual emissions. Based on case study reviews, multi-stage chemical scrubbers and biofilters are the two treatment technologies most commonly used and with the most promising results. Both have the capability to remove high percentages of odors and VOC's. Continued proactive research and development of these and other technologies will help ensure the successful continued growth of composting as a preferred waste management option.

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