J. ENVIRON. SCI. HEALTH, A33(8), 1719–1739 (1998)

TESTING OF PEATS FOR REMOVAL OF ODORS FROM LIQUID SWINE MANURE

Key Words: Peat, liquid swine manure, odor removal, hogs

Anthony M. Rizzuti [1], Arthur D. Cohen [1], Patrick G. Hunt[2] and Matias B.Vanotti [2]

[1]Department of Geological Sciences, University of South Carolina Columbia, SC 29208 ; [2]USDA-Agricultural Research Service, Coastal Plains Soil, Water, and Plant Research Center, 2611 West Lucas Street, Florence, SC 29501-1241

ABSTRACT

This paper reports on research designed to investigate the capacities of different kinds of peat to remove odor-causing compounds from liquid swine manure (LSM). Two experiments were conducted. In experiment #1, five different peat types (both wet and dry) representing a wide range of properties were tested. Eight percent slurries (of peat/LSM) were measured for odor changes at 6, 24, and 96 hours using odor panel and GC/FID analysis. Experiment #2 was designed to determine more precisely the kinds of odor-causing compounds thatwere changing during treatment. Two extremely different wet peat types were tested in 8 percent slurries after 24 hours of treatment. Odor changes were evaluated using both an odor panel and GC/MS, head-space, solid-phase, microextraction (HSM).

The GC/FID and odor panel results indicated that wet peats were much more effective in removing odor-causing compounds from LSM than were dry peats. Wet peats significantly reduced the LSM odor intensity after 6 hours of treatment, and completely eliminated odors after the 24 hour treatment. The results from the GC/MS HSM method (experiment #2) confirmed the results from experiment #1 and also, allowed us to more precisely identify the specific odor-causing compounds being reduced and to distinguish specific changes in these compounds between peat types. Of the 23 malodorous compounds identified in experiment #2, all showed significant reductions; however, one peat was better at reducing 10 of these, while the wet North Carolina peat was better at reducing 9 others. These results suggest that improvements in odor removal efficiency and costs can be achieved by selection of specific peat types for a specific LSM site.

INTRODUCTION

Odors produced from liquid swine manure have resulted in major air pollution problems and significant complaints from local inhabitants in areas near to intensive livestock production (Willrich and Miner, 1971; Jongebreur, 1977; Watson and Freind, 1987). A wide variety of medical complaints have also been attributed to these emissions (Satchell, 1996).

Various methods have been studied to reduce these air pollution problems. Fenlon and Mills (1980) reported that addition of lime to liquid swine manure could reduce certain odors. Stevens and Cornforth (1974), Chen et al., (1994), Copelli et al. (1986), and Williams and Evans (1981) found that aeration of stored liquid swine manure also tended to reduce odors. MacKenzie and Tomar (1987) reported that mixing triple superphosphate fertilizer with liquid swine manure reduced emissions of ammonia, a significant odor-causing compound. Bourque, et al.

(1987) identified and tested aerobic microorganisms that exist in liquid swine manure and found that some can degrade various malodorous substances. However, their studies as well as those of others (e.g. Ritter, 1981) have shown that microorganisms selected from a given swine waste will not necessarily work for another swine waste .

Several studies have indicated that peats and peat extracts are effective removers of odor from animal waste. For example, peat has been used as a litter in milking cow barns, where it was found to outperform rice straw and sawdust in adsorption of ammonia and odor removal (Petola, 1986). Peat has also been used effectively in biofilter applications for odor remediation in livestock buildings (e.g. Zeisig et al., 1977; Zeisig et al., 1982; Noren, 1986; Valentin, 1986; Williams and Miller, 1992). In these biofilters, ventilation air is blown through a bed of Sphagnum moss peat (or Sphagnum moss peat and heather) and the natural microorganisms within these beds degrade the odors. In a related study, Namkung and Rittmann (1987) showed that biodegradation of taste and odor-causing compounds in drinking water could be enhanced by addition of fulvic acid extracts from peat to biofilm reactors. Additionally, Mathur et al. (1990) reported significant reductions in odors of animal manures that were mixed with Sphagnum moss peats during composting, and Al-Kanani et al. (1992) showed that Sphagnum moss peat slurried in liquid swine manure could eliminate a great number of the odor-causing compounds under either aerated or nonaerated conditions. In the latter study, the peat amendment was found to work better than several chemical treatments including 1.5 M H_2SO_4, 1.7 M H_3PO_4, monocalcium phosphate monohydrate, elemental S, $CaCO_3$, and CaO.

However, in nearly all of these studies, only Sphagnum moss peat was tested. Although Sphagnum peat is available commercially in many parts of the country, it is not necessarily the indigenous peat type in regions where swine production is common. In North Carolina, for example, where swine production has increased dramatically in recent years, many kinds of peat are found. However, Sphagnum moss peat is not a particularly common one of these (Cohen, 1979; Ingram, 1987). Additionally, previous studies that have utilized a variety of different peat types have indicated that the type of peat used can strongly affect its sorption/desorption properties (e.g., gasoline-derived hydrocarbons [Cohen et al., 1991b; Cohen et al., 1995; Cohen et al., 1996; Rizzuti and Cohen, 1995; Rizzuti et al., 1996; Stack et al., 1993], metals [Rizzuti and Cohen, 1995; Rizzuti et al., 1996; Stack et al., 1994; Cohen et al., 1995a, Cohen and Stack, 1995], and nitrates [Cohen et al., 1996; Cohen and Stack, 1995]).

OBJECTIVES AND SCOPE

Although previous work by others has shown that peats can remove odors from liquid swine manure, nearly all of this work has been done with only one peat material, dry Sphagnum moss peat. However, since earlier research has shown that different peat types can have different capacities to extract contaminants from water, one would predict that different peat types will also be found to have different capacities for odor removal from liquid swine manure. It may be that a local peat may be more effective and/or more economical to use than Sphagnum moss peat. Additionally, no previous studies have evaluated the relative differences in effectiveness of a peat for odor removal if it is wet (as it occurs in nature) or artificially dried (as it tends to be sold for other purposes). Therefore, the objectives of our study were: 1) to investigate the capacities of different kinds of peats to remove odor-causing compounds from liquid swine manure; 2) to identify which odor-causing compounds were being reduced; and 3) to evaluate if drying the peat affects its performance.

MATERIALS AND METHODS

Peat Sample Selection

Peat samples were selected from the peat sample bank at the University of South Carolina's Geology Department. The peat bank consists of a large assortment of highly characterized natural peats from various parts of the United States (Cohen et al., 1991a). One advantage of using these highly characterized samples is that the results of odor tests can be correlated with the already known compositional properties of these peats to determine which parameters are most likely to be controlling odor removal and, more importantly, which parameters can be used to predict whether a particular untested peat would be a good candidate for this kind of use.

Liquid Swine Manure

Liquid swine manure (LSM) was collected at a commercial nursery-pig farm in North Carolina from the effluent being flushed into a holding lagoon from a hog barn. The LSM was stored in a refrigerator at 4° C prior to use. It had a pH of approximately 7.0 and its total solids measured 0.25 %. This undiluted LSM was used as the standard in all tests.

Experiment #1

The purpose of this experiment was to determine if different kinds of peat have different capacities to remove odors from LSM. Secondarily, it was to test if drying a peat has any effect on its odor-removing capacity. The first hypothesis was tested by using five different peat types representing a wide range of chemical and physical properties. These included two sapric peats (Snuggedy Swamp & North Carolina), two fibric peats (Okefenokee Nymphaea & Maine Sphagnum), and an intermediate, or hemic, peat (Minnesota Hemic) (Table 1). The terms "sapric", "fibric", and "hemic" as utilized in this paper follow the definitions in ASTM standard classification D4427-92 (ASTM, 1995), with sapric being most decomposed and fibric being least decomposed.

The second hypothesis was tested using these peats in both a wet condition (i.e. with inherent moisture contents as received from the bog) and a dry condition (i.e. oven-dried to zero moisture content). Relative effectiveness of odor removal was evaluated by two methods: 1) odor panel and 2) GC/FID analysis of head-space gases [modified from Chen et al., (1994)].

In this experiment, each peat sample was slurried with LSM for 6, 24, or 96 hours. This experiment was done in triplicate and included a standard consisting of LSM without peat addition (at all three times). For dry weight tests, eight percent slurries were prepared by combining 1.6 grams (dry weight) of peat with 20 grams of the LSM standard in 50ml polyethylene vials. For wet weight tests, wet weight equivalents of the dry weight samples were used. The vials were then sealed, and shaken vigorously by hand for approximately one minute, and left undisturbed for either 6, 24, or 96 hours. After these time periods, the samples were centrifuged for 15 minutes at 2000 rpm and tested for odor type and intensity by an odor panel of 4 people who sniffed the sample for approximately 3-5 seconds immediately after unscrewing the vial top. The panel was provided with a list of possible odor descriptions with which to characterize these smells. In order to avoid odor fatigue, the odor panel did not smell more than 9 samples per day. After testing for odor type and intensity, the sample's liquids were then removed and acidified to a pH of approximately 2.0 (using 3-5 drops of concentrated phosphoric acid). Ten milliliters of this acidified liquid were then removed from each sample and placed into 15ml borosilicate glass vials fitted with screw cap minivert valves and silicone

TABLE 1

Peat Samples Used for Odor Removal from Liquid Swine Manure

Sample Designation	ASTM Classification # D4427-92	Location	Dominant Botanical Components
Okefenokee Nymphaea peat	Fibric	Okefenokee Swamp, GA	Nymphaea, Sagittaria, and grass-sedge
Maine Sphagnum peat	Fibric	Maine	Sphagnum
Snuggedy Swamp peat	Sapric	Snuggedy Swamp, SC	Myrica, Persea, & Lyonia
North Carolina peat	Sapric	First Colony Farms, NC	Persea, woody dicot, grass and fern
Minnesota Hemic	Hemic	Minnesota	Spruce and woody dicot

septa. These vials were then placed into a 72°C water bath for approximately 45 minutes. After this time, 100 microliters of headspace was removed using a Hamilton model 1710N gas tight syringe and injected into a Hewlett Packard GC/FID (model 5890 Series II) with a Restek DB5 column. A split/splitless injector was used in the splitless mode. The oven program utilized was: 35°C for 1 min.; a ramp of 10°C/min. to 250°C, and a post run temperature of 250°C held for 5 minutes. Each analysis took 42.5 minutes to run. Results from the LSM standards were compared with those from the peat-treated LSM to determine the percent reductions of odor-causing compounds. Identification of compounds was achieved by analyzing known standards of odor-causing compounds found in

LSM. All triplicate samples were averaged. Average FID responses for all samples showed a relative standard deviation of less than 5%.

Experiment #2

The purpose of this experiment was to identify specific odor-causing compounds present in the LSM and to determine how much these compounds were reduced by different peats during treatment. For this experiment, odor panel and GC/MS "head-space, solid-phase, microextraction" (HSM) [modified from Zhang and Pawlizyn, (1993)] methods were utilized. The HSM method was chosen because it has been shown in other studies to be reasonably precise and inexpensive for analyzing gases in very low concentrations. The hypotheses to be tested were: 1) that HSM could be used to detect changes in specific odor-causing compounds during ours tests and 2) that the amounts of reduction in identified compounds would differ between peat types tested.

To test these hypotheses, two wet peats of extremely different composition were used (a mixed hardwood peat from North Carolina, and a typical Sphagnum moss peat from Maine). The North Carolina peat was chosen because it comes from the same area as did our LSM sample. It is well known that North Carolina has numerous hog farms that, in recent years, have increased dramatically in numbers, and it was therefore advantageous to test this type. The Sphagnum peat was chosen because it has been utilized most often by others in previous LSM odor reduction tests. As in experiment #1, all tests were conducted as slurry tests.

In this experiment wet Maine Sphagnum and wet North Carolina peats were slurried with LSM for 24 hours and compared with a standard consisting of LSM without peat addition. The preparation method for the GC/MS HSM analysis was as follows: (1) 3.73 grams (dry weight- using wet weight equivalent) of peat were combined with 53.3 grams of LSM in 150ml polyethylene vials. This represents the same proportions of peat to LSM (8%) used in experiment #1. The vials were sealed, and shaken vigorously by hand for approximately one minute. These vials were then left undisturbed for 24 hours. (2) After this time period, the samples were centrifuged for 15 minutes at 2000rpm and tested for odor type and intensity by an odor panel as described before. (3) The sample's liquids were then acidified with phosphoric acid to a pH of approximately 2.0 and a 26.7ml aliquot of the acidified liquid was placed into a 40ml EPA head-space vial (amber glass, with open screw cap and Teflon-faced silicone septa), and heated in a 72°C water bath for approximately 45 minutes. (4) Subsequently, a 85um polyacrylate HSM fiber needle was injected into the vial for 20 minutes to allow head-space gases to accumulate on the needle's fibers. (5) The needle was then placed into a Hewlett Packard Gas Chromatograph (model 5890), the run was started, and the fiber needle was left in the injection port for 1 minute, then removed. The GC was fitted with a Restek DB5 column and connected to a Hewlett Packard Mass Spectrometer (model 5970). A split/splitless injector was used in the splitless mode. The oven program utilized was: 35°C for 1 min.; a ramp of 10°C/min. to 250°C, and a post run temperature of 250°C held for 5 minutes. Each analysis took 24.5 minutes to run. Results from the LSM standards were compared with those from the peat-treated LSM to determine the percent reductions of odor-causing compounds. Compounds were identified by comparing the peaks mass spectra to the National Institute of Standards and Technology (NIST) library. All samples were analyzed only one time.

RESULTS AND DISCUSSION

Experiment #1 Results

Odor Panel Results

6 Hour Study - After 6 hours, all of the wet peat samples had a light manure odor

that was much less intense than the LSM standard. The dry peat samples were described as having a musty odor or a musty odor combined with a light manure odor (Table 2).

24 Hour Study- After 24 hours, all wet peat samples (including those in experiment #2) had no manure odor at all. Dry samples, on the other hand, had either a musty odor or a musty odor combined with a light manure odor (Table 2).

96 Hour Study- After 96 hours most of the wet peat samples still had no manure odor. However, one peat type (Oke.Nym.) had a very very light odor of manure. In contrast, the dry peat samples had either a strong musty odor combined with a strong manure odor or a stronger musty odor combined with a stronger manure odor (Table 2). Sometimes these odor combinations were quite overwhelming.

Thus, based on odor panel results, wet peats would seem to be more effective in controlling odors from LSM than dry peats. Wet peat treatment removed most of the swine waste odors within 6 hours and removed all odors after 24 hours. However, dry peat treatment tended to immediately replace the LSM odors with a musty odor that became a combined musty-swine waste odor after 24-96 hours. In some cases, this combined odor was more offensive than the original odors of the LSM. In comparing the relative effectiveness of the different peat types, the odor panel found no significant differences from one peat type to another. This was true for both wet and dry peats.

GC/FID Results

General Characteristics- The GC/FID chromatograms indicated that the area of interest, where a number of important LSM odor compounds resided, was within the

TABLE 2

Odor Panel Descriptions of Types and Intensities of Odors

Sample	6 hr. (wet)	24 hr. (wet)	96 hr. (wet)	6 hr. (dry)	24 hr. (dry)	96 hr. (dry)
LSM	Stmo	Stmo	Stmo	stmo	stmo	Stmo
Oke. Nym.	Lmo	no odor	Vlmo	mu/lmo	mu/lmo	stmu/stmo
Maine Sphag.	Lmo	no odor	No odor	musty odor	musty odor	stmu/stmo
Snuggedy	Lmo	no odor	No odor	mu/lmo	lmu/lmo	stmu/stmo
North Carolina	Lmo	no odor	No odor	lmu/lmo	lmu	stmu/stmo
Minnesota	Lmo	no odor	No odor	musty odor	musty odor	Vstmu/ Vstmo

LSM= liquid swine manure; vlmo= very light manure odor; lmo= light manure odor; stmo= strong manure odor; lmu= light musty odor; lmu/lmo= light musty odor & light manure odor; mu/lmo= musty odor & light manure odor; stmu/stmo= strong musty odor & strong manure odor; vstmu/vstmo= very strong musty odor & very strong manure odor.

first 2 minutes (1.3-1.8 minutes) of FID retention time (Figures 1 and 2). This area contained several odor-causing compounds (Acetic Acid, Propionic Acid, & Butanoic Acid) with similar retention times. Since these compounds were all located within a single wide peak, it was not possible to determine how much of each compound was removed by each peat type. However, increases and decreases in this peak area correlated well with most of the odor panel results. This was especially true for the wet peat samples. The dry sample results, on the other hand, did not correlate well with the odor panel results.

Wet peat treatment- The LSM treated with wet peat, which had been reported to have no odors by the odor panel, tended to have small to extremely small (almost non-existent) GC/FID peaks in the area of interest. Furthermore, very little change was observed in the peaks in this area from 6-96 hours. The peaks representing the

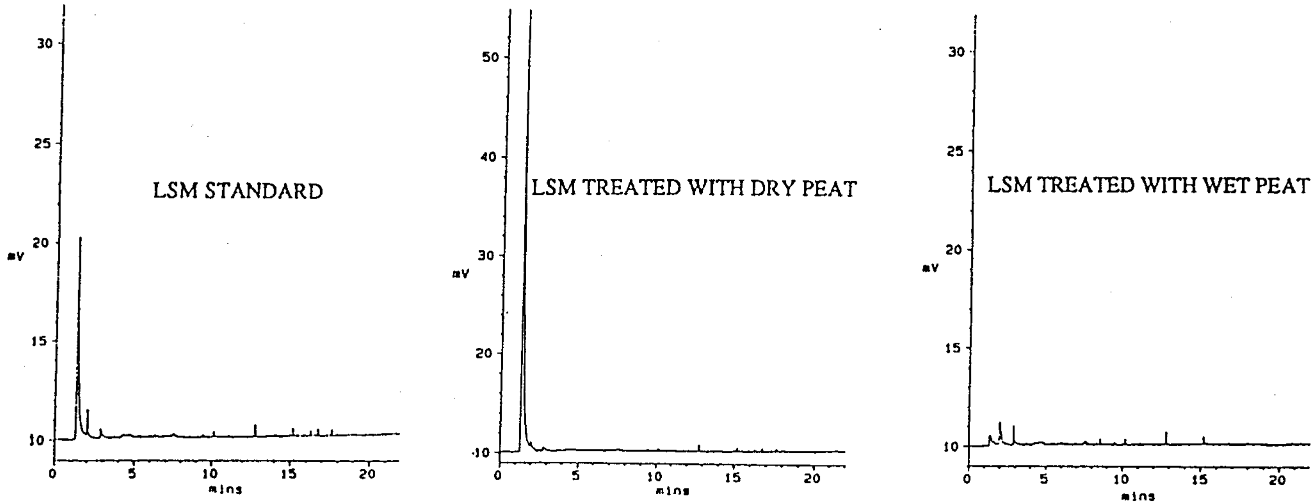

FIGURE 1
Examples of GC/FID chromatograms showing changes in odor-producing compounds found in LSM after 24 hour treatment with Snuggedy Swamp peat. Note: area of interest falls between 1.3 and 1.8 mins. (combined acetic, propionic, and butanoic acids).

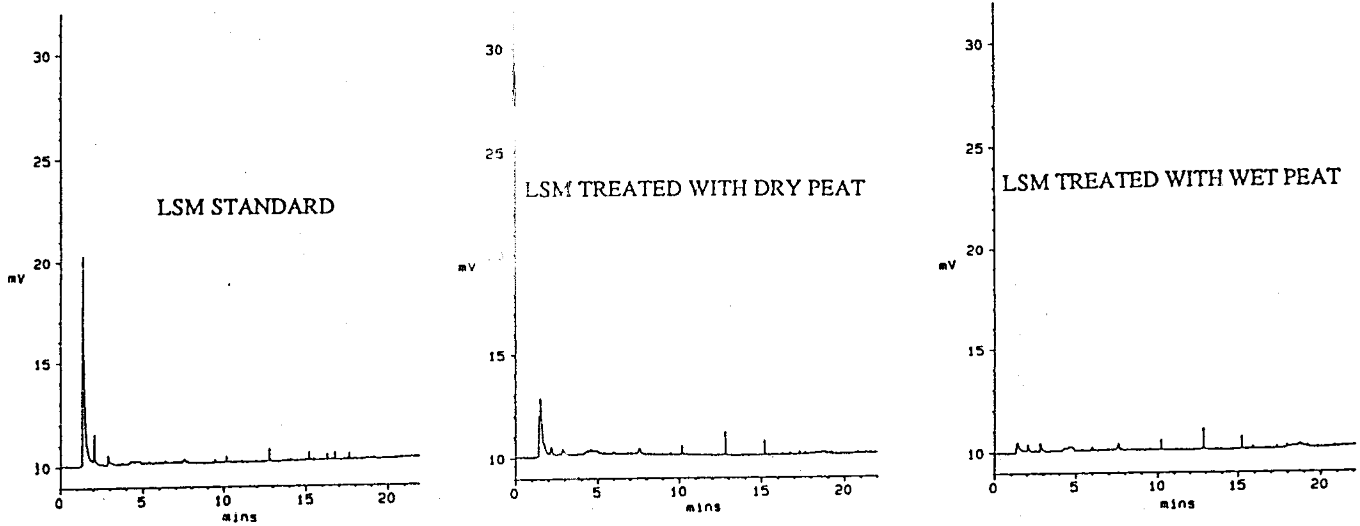

FIGURE 2
Examples of GC/FID chromatograms showing changes in odor-producing compounds found in LSM after 24 hour treatment with North Carolina peat. Note: area of interest falls between 1.3 and 1.8 mins. (combined acetic, propionic, and butanoic acids).

three odor-causing compounds were significantly reduced by all wet peat samples (Figure 3). No correlation's were found between degree of decomposition (fibric, hemic, or sapric) and odor removal.

A comparison of GC/FID results between different kinds of wet peat revealed only a few differences (Figure 3). Some wet peat types (North Carolina peat & Maine Sphagnum peat) reduced the odors slightly quicker than the others. However, all wet peats removed 95-98% of these compounds after a 24 hour time period. After 96 hours, the amounts of reduction of odorous compounds leveled off or very slightly increased or decreased. Overall, all of the wet peats worked extremely well at removing the three odor-causing compounds and their results correlated very well with the odor panel results.

Dry peat treatment- The LSM treated with dry peat, which was described by the odor panel as having a manure odor or a musty-manure combination odor (Table 2), generally had much larger peaks in the area of interest on the FID chromatograms. Some samples (especially after 96 hours) actually had peaks that were larger than the peaks for the LSM standard. However, large, unpredictable differences between samples were observed (Figure 3). After 6 hours, three dry peat samples (Maine Sphagnum peat, North Carolina peat, & Minnesota Hemic peat) removed some of the malodorous compounds, while two of the other dry peats (Okefenokee Nymphaea peat & Snuggedy Swamp peat) actually increased the amount of these compounds. From 24-96 hours, some decreases and some large increases (over 300% for Snuggedy Swamp peat) occurred in this peak area. After 96 hours, one dry peat type (Minnesota Hemic peat) had no reduction in these compounds, while two dry peat samples (Okefenokee Nymphaea peat & Maine Sphagnum peat) had huge increases in these compounds, and the other two dry peat samples (Snuggedy Swamp peat & North Carolina peat) had slight to moderate

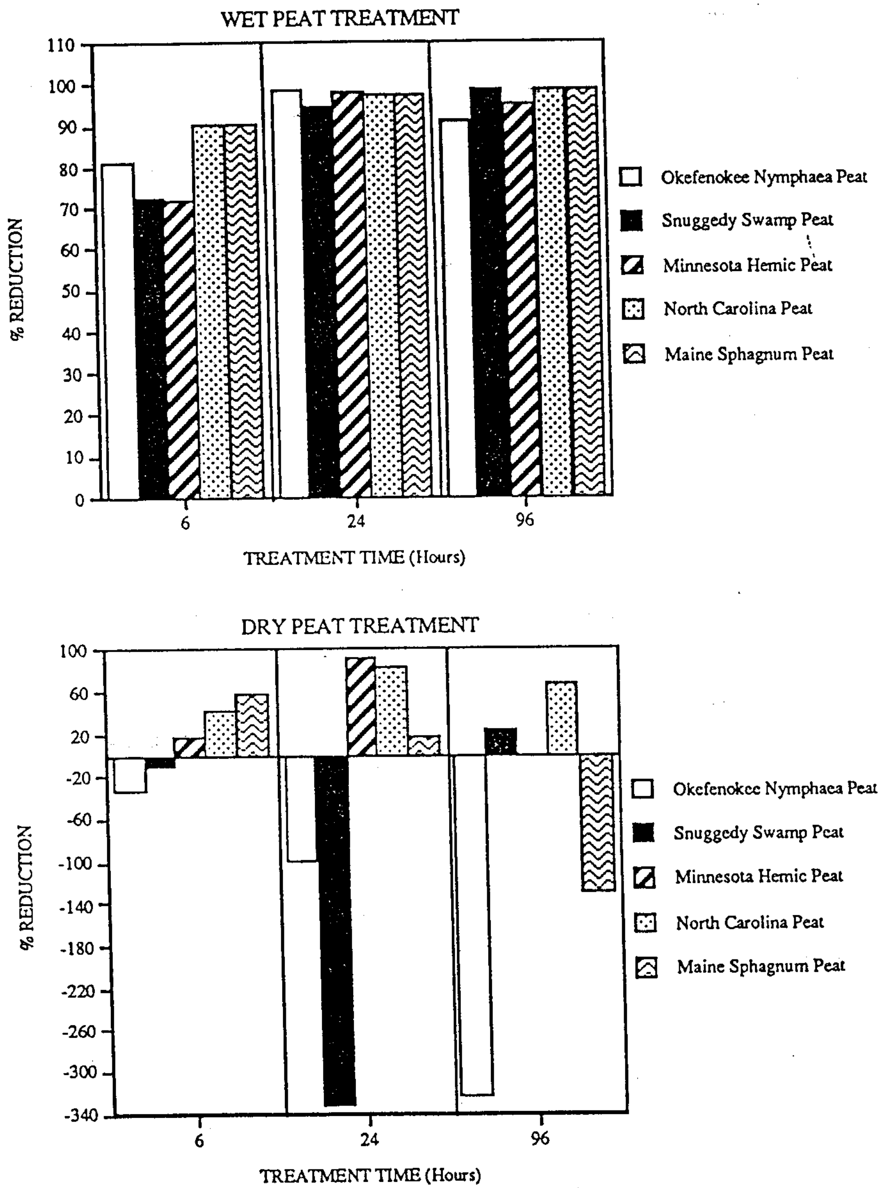

FIGURE 3
Changes in LSM odor-producing compounds (combined acetic, propionic, & butanoic acids) after wet or dry peat treatment using GC/FID analysis [% reduction vs. treatment time (hours)].

reductions in these compounds. Only one dry peat type, North Carolina Peat, had no increase in these compounds at any time period tested. Thus, the North Carolina dry sample worked better at reducing the malodorous compounds than any other dry type tested. It produced a 42% reduction in these compounds after 6 hours, an 83% reduction after 24 hours, and then decreased slightly to a 68% reduction after 96 hours. Even though this dried peat worked very well, the natural, wet North Carolina Peat worked much better at removing these compounds (over 98% reduction after 96 hours, Figure 3).

In general, as with the wet peat treatment, no significant correlation's were found between degree of decomposition and odor removal. However, after the 96 hour test the two sapric peats (North Carolina and Snuggedy Swamp) showed slight to moderate reductions in odors, while the two fibric peats (Okefenokee Nymphaea and Maine Sphagnum) showed large increases in odors, and the hemic peat showed no odor reduction.

Overall, because the results for the dry peats were unpredictable and did not correlate well with the odor panel results, it is concluded that the removal of the inherent moisture (i.e. the moisture found in peat in its natural state) from a peat by drying adversely effects its capacity to remove odors from LSM. Drying the peat may either change the peat's chemistry and/or its microbiological content, or both. Another possibility could be that reaction sites are reduced by drying, simply as a result of shriveling and consequent reduction in surface area. Further tests are needed in order to determine which factors are controlling these results.

Experiment #2 Results

The results from the GC/MS HSM method confirmed the results from the odor panel and GC/FID analysis and provided more precise information on specific changes in odor-causing compounds (Table 3). Also, many more malodorous

TABLE 3

GC/MS "Headspace Solid-Phase Microextraction" Showing Reduction of Odorous Compounds that are Found in LSM (24 Hours, Using Wet Peat)

Retention Time	Compound	Percent Reduction	
		Maine Sphagnum Peat	North Carolina Peat
3.787	Acetic Acid	48.12	60.07
4.182	Propionic Acid	100.00	100.00
5.304	Butanoic Acid	68.69	45.20
5.796	Pentanoic Acid	100.00	100.00
6.950	Benzaldehyde	100.00	92.31
7.383	Phenol	94.04	50.56
8.089	2-ethyl Hexanol	96.75	95.70
8.378	3-methyl, Butanoic Acid	100.00	83.33
8.916	2-methyl Phenol	100.00	97.84
10.391	4-ethyl Phenol	90.01	81.88
10.643	Octanoic Acid	99.41	74.61
11.518	Hexanoic Acid	70.93	91.49
12.402	Indole	95.02	76.33
13.380	Decanoic Acid	93.00	98.45
13.741	1H-Indole, 3-methyl	93.41	99.30
13.901	Dodecanoic Acid	77.92	83.36
15.311	2,4-bis(1,1-dimethylethyl)Phenol	57.56	93.58
16.404	Propionic Acid,2-meth.1(1-dimeth	70.24	52.30
16.532	Tetradecanal	75.02	90.79
17.749	Hexadecanal	70.01	87.84
18.489	9-Octadecanal	69.13	93.67
20.453	Hexadecanoic Acid	86.01	42.43
21.674	Sulfur Molecule (S8)	78.66	55.77

compounds were identifiable using this method than were identifiable using the GC/FID method.

Several significant differences were revealed between the two peat types. Of the 23 malodorous compounds identified, the Maine Sphagnum peat was much better at reducing 10 of these [butanoic acid, benzaldehyde, phenol, 3-methyl butanoic acid, 4-ethyl phenol, octanoic acid, indole, (propanoic acid,2-methyl-,1-dimethylethyl), hexadecanoic acid, sulfur molecule (S8)], while the North Carolina peat was much better at reducing 9 of these [acetic acid, hexanoic acid, decanoic acid, (1H-Indole, 3-methyl), dodecanoic acid, 2,4-bis (1,1-dimethylethyl) phenol, tetradecanal, hexadecanal, 9-octadecanal]. Four malodorous compounds (propionic acid, pentanoic acid, 2-ethyl hexanol, and 2-methyl phenol) were reduced about the same amount by both of the peat types. Since LSM can vary in composition from one region to another, this kind of information may be very useful in designing the most efficient treatment process for a specific site.

SUMMARY AND CONCLUSIONS

The results of this study reveal several important findings regarding the use of different peat types to remove odor-causing compounds from LSM. GC/FID (Experiment #1) and odor panel results (for both experiments) indicate that wet peats are much more effective in removing odor-causing compounds from LSM than are dry peats. Except for one type, the dried peats did not effectively remove these compounds and, in some cases, increased them and/or made the odor problem even worse. In addition, no significant correlation was found between degree of decomposition and odor removal for either wet or dry peat treatment.

GC/FID results also revealed some differences in amounts and rates of change in odors with time. Some wet peat types reduced the odor-causing compounds quicker than others. However, all wet peats removed 95-98% of these compounds after a 24 hour time period. After 96 hours, the amounts of reduction of odorous compounds leveled off or very slightly increased or decreased. On the other hand, the results for the dry peats revealed large, unpredictable differences between the different peat types. After 6 hours, three dry peat samples removed some of the malodorous compounds, while two of the other dry peats actually increased the amount of these compounds. From 24-96 hours, some decreases and some large increases (in one case by over 300%) occurred in this peak area. After 96 hours, one dry peat type had no reduction in these compounds, while two dry peat samples had huge increases in these compounds and the other two dry peat samples had slight to moderate reductions in these compounds. Only one dry peat type, North Carolina Peat, had no increase in these compounds at any time period tested. Thus, the North Carolina dry sample worked better at reducing the malodorous compounds than any other dry type tested.

The GC/MS HSM method used in experiment #2 was found to be much more precise than the GC/FID method used in experiment #1. It not only revealed that both wet peats were very effective at removing odor-causing compounds from LSM, but also, allowed us to more precisely identify the specific odor-causing compounds being reduced and to distinguish specific changes in these compounds between peat types. Of the 23 malodorous compounds identified in experiment #2, all 23 showed significant reductions; however, the wet Maine Sphagnum peat was much better at reducing 10 of these, while the wet North Carolina peat was much better at reducing 9 others. In order to confirm and expand the usefulness of these findings, further testing of several additional peat types using the GC/MS HSM method is currently being undertaken.

ACKNOWLEDGMENTS

This research was partially funded by a contract from the USDA-Agricultural Research Service, Coastal Plains Soil, Water, and Plant Research Center in

Florence, SC (CRIS 6657-13000-005-06 S) and partially by the Department of Geological Sciences, University of South Carolina.

REFERENCES

Al-Kanani, T., Akochi, E., MacKenzie, A.F., Alli, I, and Barrington, S., J. Environ. Qual., 21, 704-708, (1992).

ASTM (D4427-92), *ASTM Std.* , 4.08, 628, (1995).

Bourque, D., Bisaillon, J-G., Beaudet, R., Sylvestre, M., Ishaque, M., and Morin, A., Appl. Environ. Microbiol., Jan., 137-141, (1987).

Chen, A., Liao, P.H., and Lo, K.V., Bioresource Technology, 49, 83-87, (1994).

Cohen, A.D. "Peat Appraisal Report: Dare County Bombing Range, NC" U.S. Army Corps of Engineers Contract #DACA 21-78-C-0104, (1979), 159 pp.

Cohen, A.D. and Stack, E.M., Encyclopedia of Energy Technology and the Environment, 3, 2205-2218, (1995).

Cohen, A.D., Rollins, M. S., Durig, J.R., and Raymond, R., Jr., J. Coal Qual., 10(4), 145-151, (1991a).

Cohen, A.D., Rollins, M.S., Zunic, W.M., and Durig, J.R., Water Res., 25(9), 1047-1060, (1991b).

Cohen, A.D., Stack, E.M., Eltayeb, S., and Liu, J., Am. Chem. Soc. J., 7, 907-910, (1995a).

Cohen, A.D., Stack, E.M., Rizzuti, A.M., Eltayeb, S., Liu, J., and Durig, J.R., Geol. Soc. Am. Abstr. Programs, 27(6), 139, (1995b).

Cohen, A.D., Borden, R.C., Stack, E.M., Liu, J., and Durig, J.R. "Evaluation of Peat-based and Nutrient Media for Remediation of Hydrocarbon Contaminated Groundwater in Permeable Barrier Applications" EPA/600/X-96/001, (1996), 53 pp.

Copelli, M.S., de Angelis, S., and Bonazzi, G. "Aeration of pig slurry to control odours and to reduce nitrogen levels" Elsevier Appl. Sc., London, (1986), pp. 252-257.

Fenlon, D.R. and Mills, P.J., Agr. Wastes, 2, 13-22, (1980).

Ingram , R.L., N. Car. Geol. Surv. Bull., 88, 1-84, (1987).

Jongebreur, A.A., Agri. Environ., 3, 259-265, (1977).

MacKenzie, A. F. and Tomar, J.S., Can. J. Soil Sci., 67, 687-692, (1987).

Mathur, S.P., Panti, N.K., and Levesque, M.P., Biol. Wastes, 30, 323-333, (1990).

Namkung, E. and Rittmann, B.E., J. AWWA, July, 107-112, (1987).

Noren, O. "Design and use of biofilters for livestock buildings" Elsevier Appl. Sc., London, (1986), pp. 234-237.

Peltola, I. "Use of peat as litter for milking cows" Elsevier Appl. Sc., London, (1986), pp. 181-187.

Ritter, W.F., Can. Agric. Eng., 23, 1-4, (1981).

Rizzuti, A.M. and Cohen, A.D., Geol. Soc. Am. Abstr. Programs, 27(6), 88, (1995).

Rizzuti, A.M., Cohen, A.D., and Stack, E.M., J. Environ. Sci. Health Part A, A31(8), 1917-1949, (1996).

Satchell, M., U.S. News World Rep., Jan 22, 55-59, (1996).

Stack, E.M., Eltayeb, S., Liu, J., Cohen, A.D., and Durig, J.R., Am. Chem. Soc. J., 6, 1001-1005, (1994).

Stack, E.M., Liu, J., Ives, J., Cohen, A.D., Durig, J.R., Am. Chem. Soc. J., 5, 392-395, (1993).

Stevens, R.J. and Cornforth, I.S., J. Sci. Food Agric., 25, 1249-1261, (1974).

Valentin, F.H.H., J. Filtr. Sep., July/Aug., 224-226, (1986).

Waston, R.D. and Friend, J.A.R. Br. Soc. Anim. Prod., 11, 41-51, (1987).

Williams, A.G. and Evans, M.R., Agr. Wastes, 3, 311-322, (1981).

Williams, T.O. and Miller, F.C., BCYCD, Oct., 72-77, (1992).

Willrich, T.L. and Miner, J.R. Litigation experiences of five livestock and poultry producers. Livestock Waste Management and Pollution Abatement Proceedings, ASAE, 271, 99-101, (1971).

Zeisig, H.D. und Kreitmeier, J. "Erdfilteranlagen- Ban- und Betriebsanleitung - Erganzungsblatter: Stand Dezember" Bayerisches Staatsministerium fur Landesentwicklung und Umweltfragen, Weihenstephan, (1982).

Zeisig, H.D., Kreitmeier, J., and Franzpeck, J. "Untersuchungen uber Erdfilter zur Verringerung der Geruchsbelastigung aus Tierhaltungen" Schriftenreihe der Landtechnik, Weihenstephan, Freising-Weihenstephan, (1977).

Zhang, Z., and Pawliszyn, J., Anal. Chem., 65, 1843-1852, (1993).

Received: November 7, 1997