Paper No.994087
An ASAE Meeting Presentation

EFFECTS OF ORGANIC COVER BIOFILTERS ON ODORS FROM LIQUID MANURE STORAGE

Zhi Zhang, Graduate Research Assistant
Tom L. Richard, Assistant Professor
Dwaine S. Bundy, Professor

Department of Agricultural and Biosystems Engineering
Iowa State University
Ames, Iowa 50011

Written for presentation at the
1999 ASAE Annual International Meeting
Sponsored by the ASAE

Toronto, Ontario Canada
July 18-21, 1999

Summary:

Experimental biofilters were built to test removal efficiency of odor and hydrogen sulfide from simulated manure storage lagoons. The low cost biofilters were made of dry straw, wet straw, and straw soaked with liquid manure. In the initial set of experiments, the average hydrogen sulfide reduction for straw soaked with manure (95%) was the higher than that of wet straw (91%). The odor removal efficiency with wet straw (55%) was higher than that of straw soaked with manure (45%), where odor removal efficiency was defined as the reduction of odor threshold numbers between the manure surface and the exhaust air stream. In a second set of experiments, the average removal efficiency of hydrogen sulfide with dry straw (92%) was greater than that of wet straw (81%), while odor treatment efficiency with dry straw (59%) was higher than that of straw soaked with water (37%).

Keywords: Odor, odor control, biofilter, hydrogen sulfide, manure

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA

Voice: 616.429.0300 FAX: 616.429.3852 E-Mail:<hq@asae.org>

Introduction

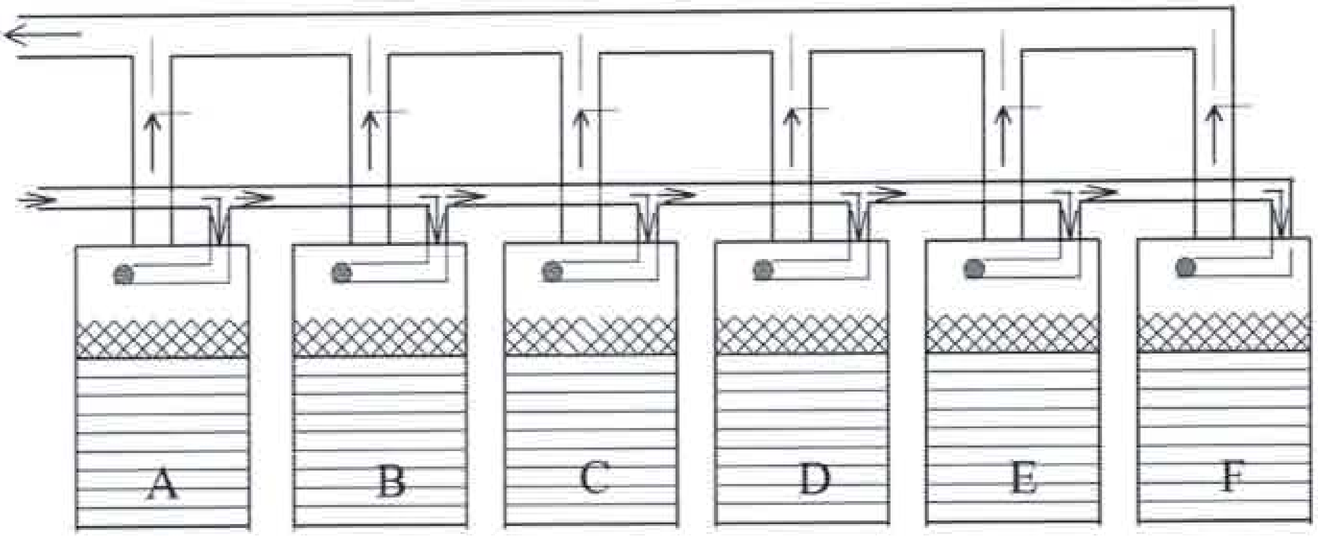
With the development of larger and more concentrated animal production sites, there has been increasing attention to offensive odorous substances. In the last few years, odors have become one of the most important issues for the livestock industry. Odor sources from livestock production systems include buildings, manure storages, and land application of manure. Most odor complaints and much odor research has focused on emissions from manure storage. For treatment of exhaust gases, physical and /or chemical methods (combustion, activated carbon adsorption, acid-alkali treatment, etc.) have been used and their efficiency is quite high (Thompson, 1990). But maintenance and operation costs of these methods are high (Ostojic et al., 1991) and thus biological methods have attracted attention as a more economical alternative.

The last several years have witnessed a rapid growth in the interest in biofiltration because of its relatively low cost and high removal efficiencies for a wide range of organic gases (Hartenstein and Allen, 1986). Biofiltration is an air pollution control technology that uses microorganisms to oxidize air contaminated with VOC and oxidizable inorganic gases (Bohn and Bohn, 1986; Filson et al., 1996). Biofilter treatment has been used sporadically in the US since the mid-1950s (Haug, 1993), with increasing adoption in recent years. The filter material must provide the chemical /physical properties needed by microbes, and for most application media must also provide nutrients and energy to the microbial ecosystem. Biofiltration of gases does not normally generate any hazardous residues or otherwise contribute to pollution (Janni,1996). Odorous compounds in the exhaust gas are first adsorbed on the surface of the substrate or absorbed in the water, which is typically present in the substrate. Subsequently, the compounds are biodegraded by a variety of microbiological processes. Microorganisms oxidize the adsorbed organic gas to carbon dioxide, water vapor, and other non-odorous compounds.

One recent application of biofiltration for livestock odor control is the use of organic floating covers on liquid manure storage. Organic covers are typically composed of chopped straw or cornstalks applied to a depth of about 20 cm. The covers float on the manure for several months, and are mixed and applicated with the manure during agitation or land application. In 1994 and 1995, approximately 30 hog earthen manure storage areas in Saskatchewan were covered with straw (Filson, 1996). The cost of placing the straw varied from 1 to 5 cents per square foot of area. Nicolai and Janni (1997) reported an average odor threshold reduction efficiency of about 78%, and a hydrogen sulfide concentration reduction about 86% with the biofilter medium of compost and kidney bean straw. Hartung (1997) found that average odor reduction efficiency was about 80% with the filter material of coconut fiber and peat fiber mixture.

Biofilter Construction

Figure 1 illustrates the plot-scale biofilter test apparatus used in this study of organic floating covers. Each biofilter treated odor emitted from a simulated manure storage lagoon. Six tanks, each with a height of 100 cm and diameter of 60 cm, were used in the experiment. The tanks were filled with liquid hog manure to a depth of 60 cm. An expanded metal mesh shelf suspended the biofilter bed approximately 2 cm above the manure surface. Chopped oat straw was placed at a depth of 20cm. A blower was connected with a 2-inch diameter main pipe to supply fresh air. A fresh air distributor was located 10 cm above the top of the biofilter and connected with 2"PVC pipe to an inlet manifold. Ten ¼ inch holes were drilled in the distributor in a line pointed toward the tank wall in order to distribute fresh air evenly across the surface of the biofilter and minimize short-circuiting. A 3 inch outlet hole on the cover of each tank connected to a 3″ PVC exhaust manifold. On each outlet pipe, a sampling port was installed to sample gases treated by biofitration. Each tank also had a sampling port located just above the manure surface. Three thermocouples were used to measure the temperature of manure, straw, and the air above the straw respectively.



① Inlet air
② Exhaust air outlet
③ Gas sampling port at manure surface
④ Exhaust gas-sampling ports

Figure 1. Biofilter Schematic.

Procedures

The results reported in this paper are from two trials with the biofilter test apparatus. The first trial lasted from April 1st to May 4th 1998. Straw was soaked with water or alternately soaked with manure about 5 minutes, added to tanks A,B,C and D,E,F respectively. A second set of trials was completed between June 4th to July 23rd. Dry straw was put on the mesh of tank C and D. Wet straw soaked with water about five minutes was added to tanks of E and F, while tanks A and B served as controls, containing manure but no organic covers.

Composite manure samples were collected from each tank immediately after loading. Samples were analyzed at the Iowa State University Analytical Services Laboratory using standard methods for TKN, Total P, Total K, % solids, % volatile solids, ammonia, COD, pH,and organic acid. Flowrate and velocity of exhaust gas were measured weekly through the gas sampling port on the outlet pipe using a hot -wire anemometer (TSI Incorporated, Model:8345, Shoreview, MN). Air velocity above the straw was similarly monitored weekly during the period of the experiment. Temperatures of manure, straw, and the air above straw were measured air samples were taken from the inlet and outlet of each tank and pumped into Tedlar (E. I. Dupont Inc. Wilmington Delaware) plastic bags. A fresh air sample was collected near the inlet blower at each sampling every time. All air samples were analyzed for hydrogen sulfide (H_2S) (Jerome Hydrogen Sulfide Analyzer, Arizona Instruments, Phoenix AZ) and odor threshold levels, which were determined by trained odor panel using a dilution olfactometer (Bundy et al, 1992).

Results

Manure Characteristics

The manure characteristics for the first and second trials are shown in the Table 1 and Table 2. Concentrations of all items except pH in the first trial are higher than those in the second trial, presumably related to the significantly higher TS and VS in the first trial's manure.

Temperature, Velocity, and Flowrate

The temperature of straw and air above straw was influenced by ambient weather conditions, so the fluctuation of straw and air temperatures was greater than that of liquid manure in the each trial (Table 3). The fluctuation of temperature of the second trial was greater than that of the first one as a result of seasonal changes between spring and summer. The average air velocity across the surface of straw was 0.08-0.09m/s in the first trial. During the second stage trial, the blower was relocated outside the building, increasing inlet pipe length and reducing the average air velocity to 0.06-0.07m/s. These velocities are well below the 3.6 m/s velocity at which Zahn (1997) measured maximum VOC concentrations from a full-scale manure lagoon. However, in our pilot-scale experimental system a slower velocity was necessary to achieve measurable differences in concentration across a short path length.

Table 1 Manure characteristics in the first trial.

Item		Wet straw			Manure soaked straw		
		A	B	C	D	E	F
TKN	mg/l as N	2860	2740	2730	2640	2650	2450
Total P	mg/l as P	586	538	572	559	602	527
Total K	mg/l as K	1480	1412	1393	1460	1511	1342
% solids	%	1.87	1.81	1.89	1.80	1.92	1.74
% Volatile solid	%	1.28	1.24	1.30	1.23	1.33	1.18
Ammonia	mg/l	2180	2140	2210	2190	2220	2200
COD	mg /l	37130	35880	36970	38210	32310	37440
pH		6.85	6.76	6.70	6.80	6.76	7.04
Acetic acid	mg/l	4286	4381	4126	4791	4121	4383
Propionic acid	mg/l	1801	1810	1716	1999	1731	1806
Iso butyric acid	mg/l	339	340	320	363	310	334
N butyric acid	mg/l	2464	2473	2362	2852	2366	2440
2-methyl butyric acid	mg/l	212	221	187	215	208	224
3-methyl butyric acid	mg/l	406	347	310	357	335	388
N valeric acid	mg/l	981	672	644	756	635	706

Table 2. Manure characteristics in the second trial.

Item		Controls		Dry straw		Wet straw	
		A	B	C	D	E	F
TKN	mg/l as N	1779	1945	2179	2111	1644	1747
Total P	mg/l as P	436.2	530.4	383.0	390.6	383.0	267.5
Total K	mg/l as K	1408	1304	1193	1110	1188	1196
% solids	%	1.40	1.56	1.45	1.27	1.29	1.13
% Volatile solid	%	0.84	0.96	0.90	0.77	0.78	0.65
Ammonia	mg/l	1452	1602	1962	2052	1480	1696
COD	mg/l	22990	27500	25630	22830	19110	15380
pH		7.80	7.75	8.12	7.68	7.67	8.14
Acetic acid	mg/l	3004	3500	1590	4074	2671	1589
Propionic acid	mg/l	819	1434	1431	1120	898	932
Iso butyric acid	mg/l	287	474	133	448	276	61
N butyric acid	mg/l	131	327	15	190	113	10
2-methyl butyric acid	mg/l	124	276	66	174	119	26
3-methyl butyric acid	mg/l	281	545	407	439	264	158
N valeric acid	mg/l	45	267	33	135	95	8

Table 3. Average temperature and velocity.

Item		Trial 1	Trial 2
Manure (°C)		15.9±1.6	22.1±5.3
Biofilter (Above mesh)	Water soaked (°C)	16.2±3.2	23.3±3.5
	Manure soaked (°C)	16.9±3.0	---------
	Dry straw (°C)	----------	23.0±6.1
	No straw control (°C)	----------	22.9±5.2
Head space (°C)		17.4±3.9	23.5±4.8
Velocity above biofilter (m/s)		0.08-0.09	0.06-0.07

Hydrogen Sulfide

Two factors, dilution and biodegradation, influenced H_2S reduction. After odor diffused through the biofilter it was diluted by the fresh air flowing across the surface of biofilter. Figure 2 shows the resulting average effect of biofilters composed of straw soaked with water and straw soaked with manure on hydrogen sulfide during the first trail. Samples from tanks with water soaked straw had average H_2S concentrations at the manure surface ranging from 321.2 to 851.8 ppb, while H_2S

concentrations in the outlet ranged from 37.7 to 73.2 ppb. The average reduction of H_2S was 91%. With the straw soaked with manure, H_2S concentration at the outlet ranged from 24.6 to 31.8 ppb. The average reduction was 95%. On average, the H_2S reduction efficiency of straw soaked with liquid manure was a little higher than that of straw soaked with water.

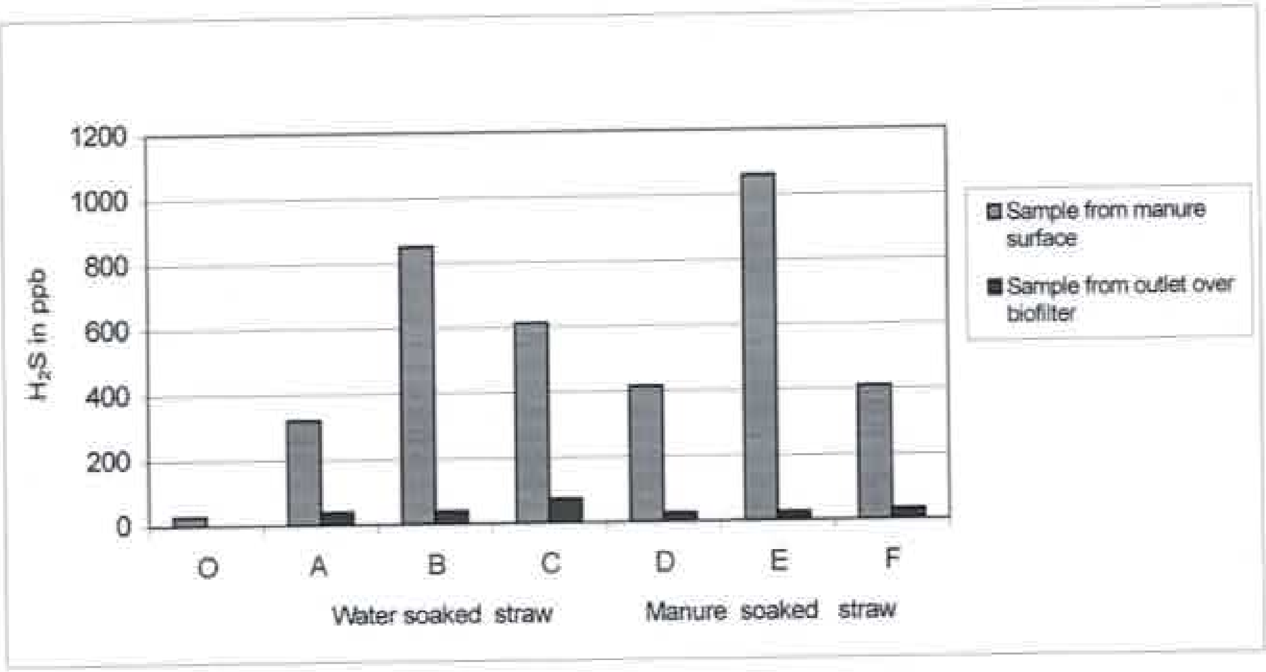


Figure 2. Plot of average effect of H_2S biofiltration with straw soaked with water and manure in the first trial.

Figure 3 shows the average effect on hydrogen sulfide concentration of the no straw, control dry straw and straw soaked with water in the second trial. With dry straw, the average concentration of hydrogen sulfide at the manure surface ranged from 1145.4 to 2037.1 ppb and at the outlet ranged from 110.2 to 114.6 ppb. The average H_2S reduction was 92%. With wet straw, the average H_2S reduction was 81%, with average concentrations at the manure surface ranging from 572.9 to 847.5 ppb and outlet concentrations ranging from 101.5 to 153.2 ppb. In the second trial, tanks A and B were used as control. On average, the average inlet concentrations of H_2S were from 407.04 ppb to 1079.17 ppb and that of the outlet was from 250.79 to 311.71 ppb. The average H_2S reduction was 50%.

Liquid manure, which adhered to straw, reduced the likelihood of nutrient limitations on biodegradation relative to dry or wet straw. Since the H_2S reduction efficiency of water soaked wet straw and dry straw was also quite good, nutrient requirements were apparently satisfied by straw or gaseous compounds (e.g. NH_3-N). The combination of physical and microbial factors operating in a biofilter makes interpretation of these results difficult. Generally speaking, bacteria active in a biofilter require an aqueous environment. Removal efficiencies should decrease greatly if filter becomes dry because of the reduced microbial activity. But in the second set of trials, the result did not follow this pattern. Physical factors, which may have influenced this result, include dilution caused by airflow and reduction in convection and diffusion of odor caused by the biofilter matrix. Whatever factors reduced the odor emission and concentration beneath the biofilter appeared to strongly influence the results.

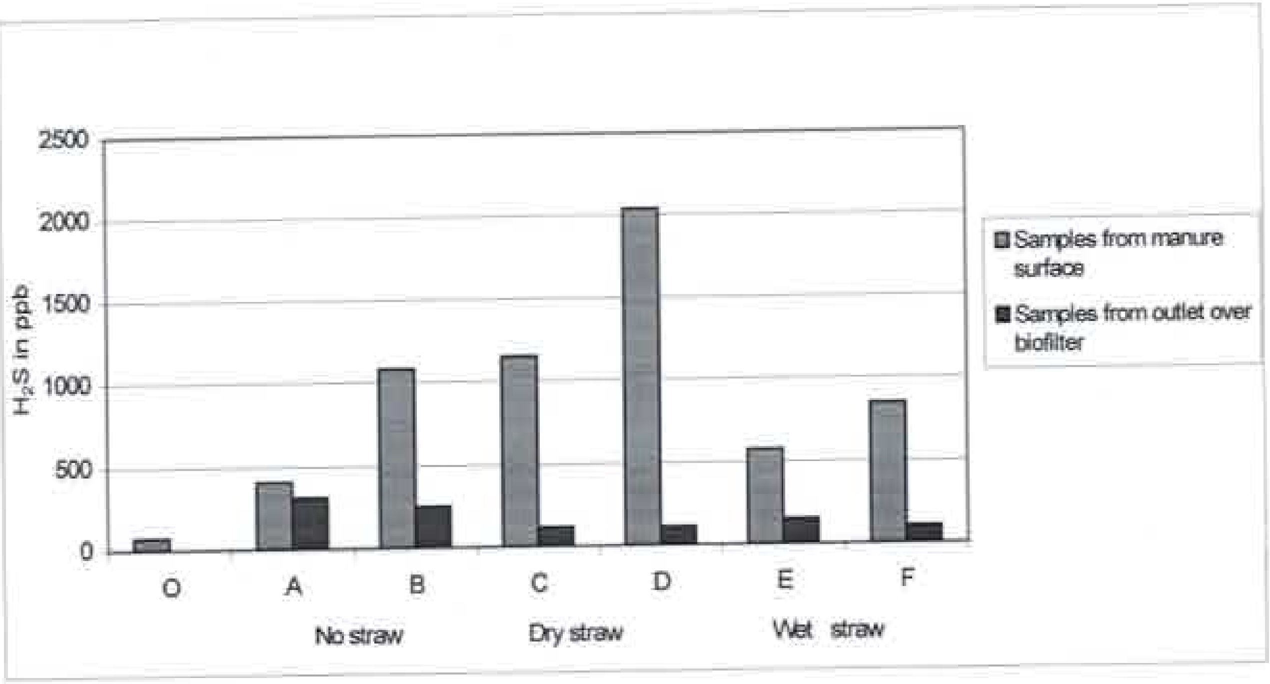


Figure 3. Plot of average effect of H_2 biofiltration with dry and wet straw of second trial.

Odor Threshold Levels

During the first and second trials, odors are measured by dilution olfactomety. The threshold odor number expresses the number of dilution of fresh air required to reduce the odor to a barely detectable level. Another way of expressing these results is with the odor intensity index, which is defined as the number of times an odor medium must be diluted by half with an odor-free medium until the odor threshold is reached. The odor intensity index (OII) is related to the threshold odor number (TON) by the following equation.

$$TON=2^{OII}$$

By definition, OII is the logarithm in base 2 of the TON equation:

$$OII=\log_2 TON$$

Because of the non-liner response of human olfactomety organs to odor, a simple arithmetic average of results from replicated treatments may skew the results. We calculate values from both manure and biofilter surface, average those, then transformed them back to a TON. This average TON was used to compute reduction efficiency, with the results shown in the Table 4 and 5 respectively.

Table 4. Odor results from first trial.

Items	Wet straw						Manure soaked straw					
	OA1	OA2	OB1	OB2	OC1	OC2	OD1	OD2	OE1	OE2	OF1	OF2
4/1 OII	11.18	9.17	10.15	8.55	10.13	8.29	9.73	9.68	9.68	9.67	9.94	8.55
4/5 OII	9.41	7.69	9.36	8.50	10.16	7.94	9.36	7.80	10.49	9.73	9.94	8.65
4/8 OII	10.79	8.01	10.19	8.38	9.94	6.82	9.88	9.36	9.94	6.62	10.17	8.56
4/12 OII	10.27	8.76	10.11	9.14	9.90	8.59	9.73	9.73	10.66	7.77	*9.00*	*9.94*
4/15 OII	9.46	8.85	10.34	8.25	*9.43*	*9.73*	9.48	7.97	9.92	7.62	9.23	8.63
4/25 OII	10.44	7.87	10.82	7.69	10.66	10.32	10.53	10.49	*9.57*	*9.90*	*10.44*	*10.61*
4/29 OII	8.04	7.65	8.51	7.58	*7.69*	*7.96*	8.18	7.25	9.94	8.04	9.01	7.90
5/4 OII	8.55	8.33	8.80	7.36	9.72	7.31	8.33	7.69	9.94	7.31	9.01	7.31
5/7 OII	*7.86*	*11.38*	*9.94*	*10.59*	10.98	6.97	6.97	6.62	10.78	8.33	7.69	6.94
5/13 OII	*6.98*	*10.08*	9.60	6.96	9.67	7.00	6.94	6.60	8.76	5.49	*7.81*	*10.34*
Ave. OII	9.30	8.78	9.79	8.30	9.83	8.09	8.92	8.32	9.97	8.05	9.22	8.74
Ave. TON	630.3	439.6	885.3	315.2	910.2	272.5	484.4	319.6	1002.9	265.0	596.3	427.6
Effi.	30.2		64.4		70.1		34.0		73.6		28.3	

Effi.*: Efficiency by outlet vs manure surface

Table 5. Odor results from second trial.

Items	Control(no filter)				Dry straw				Wet straw			
	OA1	OA2	OB1	OB2	OC1	OC2	OD1	OD2	OE1	OE2	OF1	OF2
6/4 OII	*6.30*	*6.32*	8.96	7.50	8.40	5.55	9.25	7.33	8.40	8.08	7.21	5.05
6/11 OII	7.58	7.41	*7.07*	*8.61*	8.29	7.11	8.10	6.60	7.44	7.26	8.01	4.54
6/18 OII	*7.71*	*8.01*	8.96	7.41	8.79	7.75	*7.72*	*8.54*	*7.78*	*8.08*	7.92	6.50
6/25 OII	9.00	7.72	*8.75*	*8.98*	8.33	8.01	8.22	7.39	8.22	6.71	8.70	8.01
7/2 OII	8.40	8.33	7.89	7.69	8.04	7.61	9.60	7.10	*8.18*	*8.40*	8.54	8.01
7/9 OII	8.18	7.53	8.01	7.65	8.96	7.69	9.18	7.71	*7.55*	*8.01*	8.04	7.87
7/16 OII	9.13	7.83	9.14	8.96	8.61	8.01	8.96	8.22	*8.01*	*8.40*	8.75	7.83
7/23 OII	5.94	5.80	8.54	8.18	7.08	5.14	8.36	5.29	5.47	4.28	5.18	4.38
Ave. OII	7.78	7.37	8.42	8.12	8.31	7.11	8.67	7.27	7.63	7.40	7.80	6.52
Ave. TON	219.8	165.4	342.5	278.2	317.4	138.1	407.3	154.3	198.1	168.9	222.9	91.8
Effi*	-------------		--------------		37.7		30.4		23.8		58.6	
Effi#	24.7 #		18.8 #		56.5		62.1		14.7		58.8	
Effi~	----------		----------		34.1				41.2			
Effi+	----------		----------		42				32			

OA1, OB1, OC1, OD1, OE1 and OF1: Samples above manure surface

OA2, OB2, OC2, OD2, OE2 and OF2: Samples above biofilter

Effi.*: Efficiency comparing outlet treatment vs outlet control

Effi.#: Efficiency comparing outlet vs surface

Effi.~: Efficiency of average outlet comparing with average outlet of control

#: The odor reduction efficiency in controls is related to dilution rather than diffusion reduction or treatment effects of the biofilter

Effi.+: Efficiency of average odor unit of outlet comparing that of control

Formulas for the various efficiencies calculated in Tables 4 and 5 are provided below:

$$\text{Efficiency (OII)}=\frac{(OII_{OC2}+OII_{OD2})/2-(OII_{OA2}+OII_{OB2})/2}{(OII_{OA2}+OII_{OB2})/2}$$

$$\text{Efficiency (OII)}=\frac{(OII_{OE2}+OII_{OF2})/2-(OII_{OA2}+OII_{OB2})/2}{(OII_{OA2}+OII_{OB2})/2}$$

$$\text{Efficiency (OU)}=\frac{(OU_{OCD}-OU_{OAB})}{OU_{OAB}}$$

$$OU_{OCD}=2\hat{}((OII_{OC2}+OII_{OD2})/2)$$

$$OU_{OAB}=2\hat{}((OII_{OA2}+OII_{OB2})/2)$$

where

OII_{OC2} : Odor intensity index from the outlet of tank C
OII_{OD2}: Odor intensity index from the outlet of tank D
OII_{OA2}: Odor intensity index from the outlet control from tank A
OII_{OB2}: Odor intensity index from the outlet control from tank B
OII_{OE2}: Odor intensity index from the outlet of tank E
OII_{OF2}: Odor intensity index from the outlet of tank F
OU_{OCD}: Threshold odor number at outlet for control C and D (Trial 2)
OU_{OAB}: Threshold odor number at outlet for control A and B (Trial 2)

Italicized data in the tables highlights cases where odor levels measured in the outlet were higher than at the manure surface. During the first trial, odor reduction with wet straw was about 55% while that with straw soaked with manure was only about 45%. In this first trial, odor reduction is calculated for the outlet vs. the manure surface since there were no control treatments. It is likely that the manure itself was contributing some odor, which would reduce the apparent odor reduction. In the second trial, odor reduction from dry straw was higher than that of wet straw. Average efficiency of dry straw was 34%, lower than that of wet straw (41%) comparing outlet treatment vs outlet control. The mass transfer flux for odor evaporation is proportional to the diffusion coefficient, which is also proportional to temperature. Since temperature went up when summer came, the temperature of manure also rose and gave off more odors. This complicates comparisons between two trials, and may explain why the odor reduction of the first trial with low loading was higher than that of the second trial.

Figures 4 and 5 present the odor data for the individual reactors in both trials. Note that there was considerable variability between the replicates for each treatment. While average values for the treatments are presented in this discussion, the high variability in odor emissions and olfactometry measurement led to few statistically significant results in this study. Additional replicates and measurements should be considered in future studies of this sort.

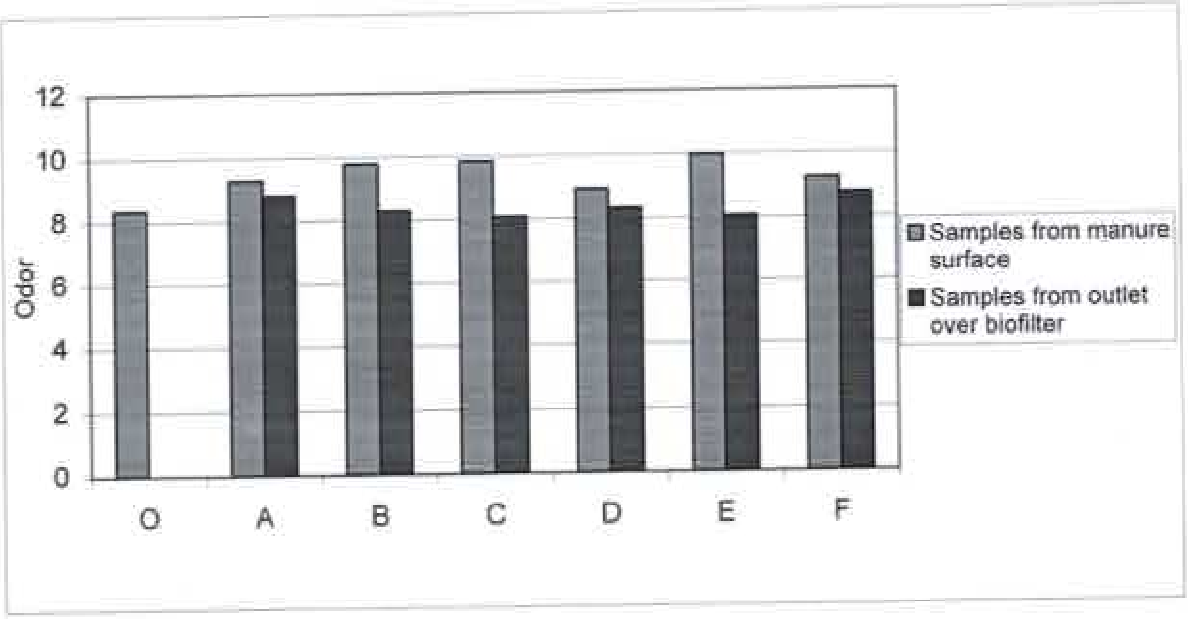


Figure 4. Plot of average odor intensity index in the first trial. Results are coded O: ambient A, B and C: wet straw, and D,E and F: manure soaked straw.

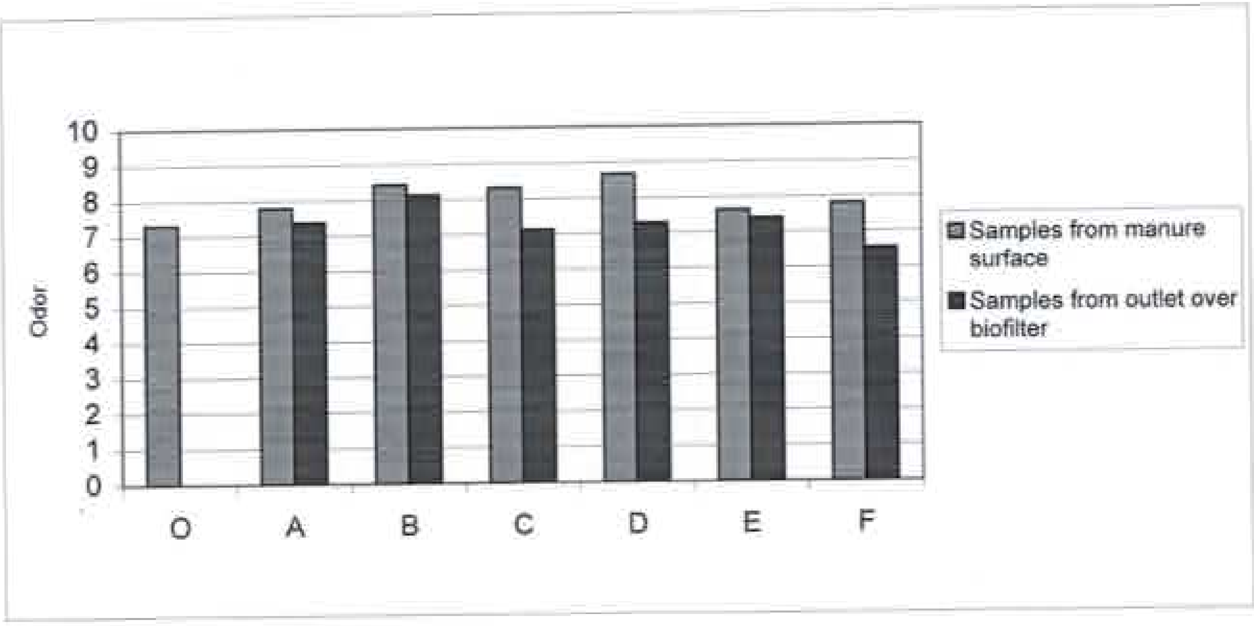


Figure 5. Plot of average odor intensity index in the second trial. The results are coded O: ambient, A and B: control (no biofilter), C and D: dry straw, and E and F: wet straw.

Conclusions

Low cost biofilters made of straw were effective at reducing hydrogen sulfide and odor emission. In the first trial, average H_2S reduction was 91% with wet straw and 95% for straw soaked with manure. In the second trial, H_2S reduction with straw soaked with water was 81%, lower than the 92% reduction achieved by dry straw. It is likely that higher H_2S reduction efficiency in the first trial was related to lower H_2S loading because of cooler temperature. In the first trial, average odor reduction with wet straw was 55%, higher than soaked with manure(45%). In the case of manure soaked straw, manure also gave off odor, increasing the loading which may have reduced the odor reduction efficiency. In the second trial, average odor reduction with dry straw was 59% while odor reduction with wet straw was 37% relative to levels at manure surface. As with H_2S, odor reduction with wet straw was higher at low temperature.

References

Bohn, H. L. and Bohn, R. K. 1986. Gas scrubbing by bio-washers and bio-filters. *Pollut.Eng.*:18(6):18-19.

Filson, H., T. William, and E. Brendan. 1996. Natural and biological odour contorl methods for swine earthen manure storage areas. pp. 371-374. In: International Conference on Air Pollution from Agricultural Operations Conference Proceedings. Midwest Plan Service, Ames, IA.

Hartenstein, H. U. and E. R. Allen. 1986. Biofiltration, An odor control technology for a wastewater treatment facility. Report to the City of Jacksonville, FL.

Hartung, E., T. Jungbluth, and W. Buscher. 1997. Reduction of ammonia and odor emission from a piggery with biofilters. ASAE Paper No.974126, ASAE, St. Joseph, MI.

Haug, R. T. 1993. Practical Handbook of Compost Engineering. Lewis Publishers. Boca Raton, FL. pp. 586-590.

Huang, W. H., D. S. Bundy, S. J. Hoff, and Q. Liu. 1996. Development of an automated forced-choice, dynamic-dilution olfactometer. pp. 239-244. In: International Conference on Air Pollution from Agricultural Operations Conference Proceedings. Midwest Plan Service, Ames, IA.

Nicolai, R. E. and K. A. Janni. 1997. Development of a low cost biofilter for swine production facilities. ASAE Paper No.974040, ASAE, St. Joseph, MI.

Ostojic, N., M. A. O'Brien, and R. A. Duffee. 1991. Limitation of incineration in odor control. In: Proceedings of the 84th Annual Air & Waste Management Conference, Vancouver, British Columbia, Paper No. 91-147.2.

Thompson, J. L. 1990. Effectiveness of odor controls system. Presented at the U.S. EPA Workshop on Controlling Sludge Composting Odors, Arlington, VA.

Zahn, J. A., J. L. Hatfield, Y. S. Do, A. A. Dispirito, D. A. Laird, and R. L. Pfeiffer 1997. Characterization of volatile organic emissions and waste from a swine production facility. *Journal of Environmental Quality* 26(6): 1687-1695.