REDUCING ODOROUS COMPOUND EMISSIONS FROM ANIMAL FACILITIES USING WOOD-CHIP BASED BIOFILTERS

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ABSTRACT

A mobile biofilter was developed where two types of wood chips (western cedar and 2 inch hardwood) were examined to treat odor emissions from a deep-pit swine finishing facility in central Iowa. The biofilters were operated continuously for 13 weeks at different air flow rates resulting in a variable empty bed residence time (EBRT) from 1.6 to 7.3 s. During this test period, solid-phase microextraction (SPME) PDMS/DVB 65 µm fibers were used to extract volatile organic compounds (VOCs) from both the control plenum and biofilter treatments. Analyses of VOCs were carried out using a multidimensional gas chromatography-mass spectrometry-olfactometry (MDGC-MS-O) system. Results indicated that both types of chips achieved significant reductions in p-cresol, phenol, indole and skatole which represent some of the most odorous and odor-defining compounds known for swine facilities. The results also showed that maintaining proper moisture content is critical to the success of wood chip-based biofilters and that this factor is more important than media depth and residence time.

INTRODUCTION

The reduction of odors emitted from livestock and poultry production systems represents a significant challenge for researchers. Biofiltration is a versatile odor and gas treatment technology that has gained much acceptance in agriculture. The mixture of wood chips and compost (75:25 to 50:50 percent by weight) has been recommended as biofilter media (Nicolai and Janni 2001). However, the mixture media can cause a high air flow resistance that must be overcome, often with the use of large expensive fans (Devinny et al., 1999) which in turn results in excessive electrical energy use. A wood chip-based biofilter can reduce the pressure drop but little is known about the performance of wood chip-based biofilters on reduction of malodor and VOCs emitted from swine facilities.

To date, studies have mainly focused on NH_3 and H_2S reductions when evaluating biofilters. More studies are needed to better understand the biofilter's effects on volatile organic compounds (VOCs). The objective of this research was to investigate the fate of selected chemicals when subjected to two distinct wood chip-based biofilters operating at various moisture content and empty bed residence time (EBRT), defined as the volume of the biofilter media divided by the air flow rate passing through the media.

MATERIALS AND METHODS

This research project was conducted at a 1,000-head curtain-sided deep-pit swine finishing facility located in central Iowa. The building monitored was approximately 48 x 180 ft with 10 in. and 25 in. diameter fans pulling pit-gases from the barn pump-out locations.

A mobile pilot-scale biofilter system, which consisted of a biofilter testing laboratory (BTL) and a biofilter monitoring laboratory (BML), was constructed for this research project. The BML was used to house all instrumentation hardware, calibration gases, and data acquisition hardware required to collect data associated with this project such as biofilter moisture content, temperature, and NH_3 and H_2S concentrations. The layout of the BTL is shown in figure 1. The BTL consisted of eight parallel barrels, four of which were randomly selected to be filled with western cedar (WC) chips and the remaining four filled with 2 in. hardwood (HW) chips. The WC and HW media porosity was 67.0%±0.5% and 55.9%±0.5%, respectively. There was a common plenum below the barrels directly connected to a fan from one of the barn pump-out locations. Eight adjustable fans (AXC 100b; Continental Fan Manufacturing, Buffalo, New York) and 4 in. PVC pipes were used to connect the common plenum with the eight barrels.

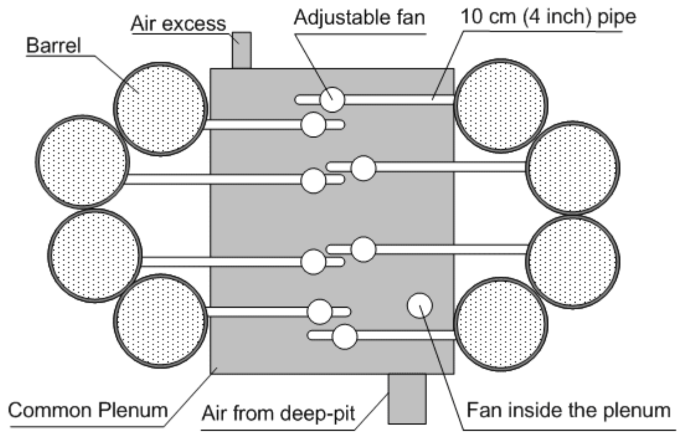

Figure 1. The layout of the biofilter testing laboratory.

The barrels (22 in. inside diameter, 34 in. in depth) were designed with a 10 in. air space at the bottom of the barrel, with the biofilter media located above this airspace, separated by a metal mesh support. Each of the eight reactors was initially filled to a depth of 20 in. Water was added via a spray nozzle at the top of each barrel. Biofilter media moisture was measured with commercially available soil moisture sensors (model ECH2O EC-20; Decagon Devices, Inc., Pullman, WA) which were first calibrated in the laboratory. Each of the eight reactors had its own variable speed fan which was used to adjust EBRT to 1.6, 2.5, 2.6, 3.3, 3.6, 4.0, 5.3, 5.5, and 7.3 s.

The biofilter media in each reactor was allowed to stabilize by passing pit-gas air through each reactor with the media at an initial depth of 20 in., a maintained moisture content in the 50~60% range (wet basis) and at an air flow rate of 80 cfm for one month. After the stabilization period, the media depth was changed from 20 in. to 15 in. and then to 10 in. over a period of nine weeks, in three week increments. At each depth tested, three levels of air flow rate (80 cfm, 50 cfm and 36cfm) were randomly set to run in each reactor for about one week during which solid-phase microextraction (SPME) samples were collected and analyzed. At the final period of this project where the media depth was 10 in., SPME samples were collected at three different media moisture levels (20%, 40%, 60% wet basis) with a fixed air flow rate of 80 cfm.

The compounds attracted by the SPME fiber were analyzed using a multidimensional gas chromatography-mass spectrometry-olfactometer (MDGC-MS-O) (Microanalytics, Round Rock, TX).

RESULTS AND DISCUSSION

There are several chemical compounds which are the main sources of offensive odors from swine buildings. Generally there are four chemical groups of odorous compounds: VFAs, sulfur containing compounds, phenolics and indolics (Van Gemert and Nettenbreijie, 1977; Lo et al., 2008; Schaefer, 1977; Yasuhara, et al., 1984). In this study, SPME fibers were used to identify the odorous compounds exhausted from both the control plenum and biofilter treatments (WC, HW). The mean peak area counts, which were calculated using the integrated area of a single ion, of the odorous compounds detected in the control plenum and from the treatment reactors were used to compare the reduction efficiency between treatments as percent reduction, i.e., as the ratio of the difference between the control and treatment to the control.

A summary of the reduction efficiency for the four groups of characteristic compounds is given in Tables 1a and 1b. The compound removal efficiencies, based on overall average, were very good for both types of biofilter media ranging from 76% to 92.6%. Particularly noteworthy is the removal of p-cresol which has been cited as the major odorant responsible for downwind swine odor (Koziel et al., 2006). The reduction of p-cresol, averaged over all EBRTs, was 99.9% and 95.3 % for WC and HW, respectively. The reduction efficiencies shown in Tables 1a and 1b have no discernable trend relative to EBRT. The most likely reason for this was that the media was maintained at a high moisture content of 60%. These results indicate that for biofilter design and operation, a higher media moisture content is most important. The relationship between moisture content, EBRT and reduction efficiencies for the characteristic compounds need to be further investigated.

Table 1a. Reduction efficiencies of characteristic compounds for western cedar at moisture level of 60%.

Compounds/EBRT (s)	1.6	2.5	2.6	3.3	3.6	4	5.3	5.5	7.3	Average over EBRT (%)
VFAs										
Acetic acid (%)	76.7	95.2	92.5	100.0[a]	92.8	90.6	98.6	97.6	76.3	91.1
Propanoic acid (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Butanoic acid (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	100.0	100.0
Isovaleric acid (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pentanoic acid (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Hexanoic acid (%)	100.0	100.0	100.0	[a]	100.0	100.0	100.0	100.0	100.0	100.0
Average for VFAs	96.1	99.2	98.8	100.0	98.8	98.4	99.8	99.6	96.1	98.5
Sulfide compounds										
Methyl mercaptan (%)	−44.2	17.2	29.0	32.6	63.5	48.3	−91.8	52.3	43.1	16.7
Dimethyl sulfide (%)	100.0	[b]	[b]	[b]	100.0	[b]	100.0	[b]	[b]	100.0
Dimethyl disulfide (%)	[b]	[b]	[b]	[b]	100.0	[b]	[b]	100.0	80.6	93.5
3-Methyl thiophene (%)	39.0	49.8	76.7	46.4	36.5	1.3	52.9	63.5	[b]	45.8
Dimethyl trisulfide (%)	−27.3	37.0	86.5	14.0	58.2	47.5	21.0	83.9	[b]	40.1
Average for sulfide compounds	16.9	34.7	64.1	31.0	71.6	32.4	20.5	74.9	61.8	59.2
Phenolics										
Phenol (%)	95.6	95.5	95.2	95.8	95.1	93.2	95.9	92.3	83.9	93.6
p-Cresol (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.9	100.0	99.9
4-Ethyl phenol (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average for phenolics	98.5	98.5	98.4	98.6	98.4	97.7	98.6	97.1	94.6	97.8
Indolics										
Indole (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Skatole (%)	100.0	100.0	100.0	96.7	100.0	100.0	100.0	100.0	100.0	99.6
Average for indolics	100.0	100.0	100.0	98.3	100.0	100.0	100.0	100.0	100.0	99.8
Overall average	76.0	85.3	91.4	83.5	90.4	84.3	78.4	92.6	91.1	86.3

[a] 100% reduction efficiency signifies that a compound was not detected in treated exhaust.
[b] This compound was not detected in both the control plenum and treated exhaust.

Table 1b. Reduction efficiencies of characteristic compounds based for hardwood chips at moisture level of 60%.

Compounds/EBRT (s)	1.6	2.5	2.6	3.3	3.6	4	5.3	5.5	7.3	Average over EBRT (%)
VFAs										
Acetic acid (%)	76.8	88.2	87.5	100.0[a]	88.6	80.0	98.4	96.1	34.8	83.4
Propanoic acid (%)	100.0	100.0	100.0	100.0	94.9	100.0	100.0	98.2	100.0	99.2
Butanoic acid (%)	100.0	99.2	99.0	100.0	94.8	98.0	99.8	99.0	86.2	97.3
Isovaleric acid (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pentanoic acid (%)	100.0	100.0	100.0	100.0	95.4	100.0	100.0	99.3	100.0	99.4
Hexanoic acid (%)	100.0	100.0	100.0	[b]	100.0	100.0	100.0	100.0	100.0	100.0
Average for VFAs	96.1	97.9	97.8	100.0	95.6	96.3	99.7	98.8	86.8	96.6
Sulfide compounds										
Methyl mercaptan (%)	30.9	1.2	27.1	33.4	5.8	−44.1	−30.5	35.8	6.7	7.4
Dimethyl sulfide (%)	100.0	[b]	[b]	28.6	19.0	[b]	100.0	[b]	100.0	69.5
Dimethyl disulfide (%)	[b]	[b]	[b]	22.7	100.0	[b]	[b]	100.0	64.8	71.9
3-Methyl thiophene (%)	39.4	27.9	39.4	69.6	43.1	34.6	−3.7	45.2	100.0	43.9
Dimethyl trisulfide (%)	−38.8	40.4	30.7	32.0	64.5	47.9	11.2	46.1	[b]	29.3
Average for sulfide compounds	32.9	23.2	32.4	37.3	46.5	12.8	19.2	56.8	67.9	44.4
Phenolics										
Phenol (%)	92.8	94.4	93.5	94.2	90.4	93.8	94.9	89.3	75.5	91.0
p-Cresol (%)	97.7	99.3	97.7	100.0	90.3	98.8	98.8	93.9	81.1	95.3
4-Ethyl phenol (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	93.2	100.0	99.2
Average for phenolics	96.8	97.9	97.1	98.1	93.6	97.5	97.9	92.1	85.5	95.2
Indolics										
Indole (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Skatole (%)	95.6	100.0	100.0	95.6	100.0	96.6	94.9	100.0	100.0	98.1
Average for indolics	97.8	100.0	100.0	97.8	100.0	98.3	97.5	100.0	100.0	99.0
Overall average	79.6	82.2	83.9	78.4	80.4	79.0	77.6	86.4	83.3	80.3

[a] 100% reduction efficiency signifies that a compound was not detected in treated exhaust.
[b] This compound was not detected in both the control plenum and treated exhaust.

The ANOVA analysis results of reduction efficiencies for eight target compounds are shown in Table 2 which indicates that there were significant differences between the two media treatments among the 9 EBRT levels except for hexanoic acid, indole and isovaleric acid. These three compounds were below the GC-MS detection limit for both the WC and HW treatments indicating that the removal efficiency was nevertheless very high.

Table 2. P-values of ANOVA analysis of reduction efficiencies for 8 characteristic compounds.

Factors	4-Ethyl phenol	Acetic acid	Butanoic acid	Pentanoic acid	Phenol	Propanoic acid	Skatole	*p*-Cresol
Media	<.0001	0.027	<.0001	<.0001	0.0003	<.0001	<.0001	<.0001
EBRT	<.0001	0.0007	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Media*EBRT	<.0001	0.019	<.0001	<.0001	0.054	<.0001	<.0001	<.0001

Several studies have reported that biofilter media moisture is one of the key factors when biofilters are used for treating odors (Hartung et al., 2001; Nicolai et al., 2006; Sun et al., 2000). In this study, SPME samples were also collected and analyzed at three levels of media moisture content (20%, 40% and 60%) with a EBRT of 1.6 s.

A summary of the reduction efficiencies at three levels of media moisture content for different compounds arranged by the four groups of characteristic compounds is given in Tables 3a and 3b. The reduction efficiencies for VFAs, phenolics, indolics and the overall average for all compounds increased with higher media moisture level. There was no significant improvement when the moisture level was raised from 40% to 60% for WC but there was significant improvement for HW over this same range. For the sulfur-containing compounds, the reduction efficiency decreased when the media moisture level increased above 20% for both WC and HW. The most likely reason was the development of anaerobic zones as proposed by Devinny et al. (1999).

Table 3a. Reduction efficiencies at 1.6 s EBRT for western cedar.

Compounds/moisture content (%)	20	40	60	Average over all moisture content (%)
VFAs				
Acetic acid	32.2	62.6	76.7	57.1
Propanoic acid	−6.5	100.0[a]	100.0	64.5
Butanoic acid	2.4	100.0	100.0	67.5
Isovaleric acid	14.5	100.0	100.0	71.5
Pentanoic acid	3.5	100.0	100.0	67.8
Hexanoic acid	100.0	100.0	100.0	100.0
Average for VFAs	24.3	93.8	96.1	71.4
Sulfide compounds				
Methyl mercaptan	5.6	1.7	−44.2	−12.3
Dimethyl sulfide	56.2	100.0	100.0	78.1
Dimethyl disulfide	100.0	50.8	[b]	75.4
3-Methyl thiophene	31.2	−27.4	39.0	14.3
Dimethyl trisulfide	23.9	35.2	−27.3	10.6
Average for sulfide compounds	43.4	15.1	16.9	25.1
Phenolics				
Phenol	18.8	92.7	95.6	69.0
p-Cresol	48.7	99.0	100.0	82.6
4-Ethyl phenol	58.1	100.0	100.0	86.0
Average for phenolic!	41.9	97.2	98.5	79.2
Indolics				
Indole	73.3	100.0	100.0	91.1
Skatole	52.5	95.5	100.0	82.7
Average for indolics	62.9	97.8	100.0	86.9
Overall average	38.4	74.0	76.0	62.8

[a] 100% reduction efficiency signifies that a compound was not detected in treated exhaust.
[b] This compound was not detected in both the control plenum and treated exhaust.

Table 3b. Reduction efficiencies at 1.6 s EBRT for hardwood chips.

Compounds/Moisture content (%)	20	40	60	Average over all moisture content (%)
VFAs				
Acetic acid	13.8	31.6	76.8	40.8
Propanoic acid	35.7	66.9	100.0[a]	67.5
Butanoic acid	45.2	72.0	100.0	72.4
Isovaleric acid	47.4	100.0	100.0	82.5
Pentanoic acid	55.3	100.0	100.0	85.1
Hexanoic acid	100.0	100.0	100.0	100.0
Average for VFAs	49.6	78.4	96.1	74.7
Sulfide compounds				
Methyl mercaptan	36.9	29.0	30.9	32.3
Dimethyl sulfide	41.6	37.3	100.0	59.6
Dimethyl disulfide	100.0	58.9	[b]	79.4
3-Methyl thiophene	11.8	9.9	39.4	20.4
Dimethyl trisulfide	59.5	16.6	−38.8	12.4
Average for sulfide compounds	50.0	30.3	32.9	37.7
Phenolics				
Phenol	54.7	58.2	92.8	68.5
p-Cresol	72.3	70.8	97.7	80.3
4-Ethyl phenol	68.6	67.2	100.0	78.6
Average for phenolics	65.2	65.4	96.8	75.8
Indolics				
Indole	75.4	75.3	100.0	83.6
Skatole	51.6	57.1	95.6	68.1
Average for indolics	63.5	66.2	97.8	75.8
Overall average	54.4	59.4	79.6	64.5

[a] 100% reduction efficiency signifies that a compound was not detected in treated exhaust.
[b] This compound was not detected in both the control plenum and treated exhaust.

The WC biofilter can achieve relatively high removal efficiencies (93.8%, 97.2%, 97.8%, and 74% for VFAs, phenolics, indolics and overall average for all compounds, respectively) at a lower moisture content (40%) while the HW biofilter needed a higher moisture content (60%) to achieve the same reduction efficiencies for these compounds (Tables 3a and 3b). For the sulfur-containing compounds, HW performed better than WC at all levels of media moisture.

CONCLUSIONS

A pilot-scale mobile biofilter was developed where WC and HW chips were examined to treat odor emissions from a deep-pit swine finishing facility in central Iowa. The fate of characteristic odorous compounds was investigated. The results of this study demonstrated that both the WC and HW chips achieved high overall average reduction efficiency (at least 76% and as high as 93%) for treating characteristic compounds when the biofilter media moisture content was kept at 60% (wet basis). The reduction efficiency testing at three media moisture levels indicated that the biofilter, whether WC or HW, was more sensitive to the media moisture content than media depth or EBRT. Therefore, maintaining proper moisture content is critical to the proper operation of wood chip-based biofilters. Moisture content is more important than media depth and EBRT when a wood chip-based biofilter is operated. The high reduction efficiency obtained with the wood chip-based biofilter media studied in this research suggests that these materials can be used effectively as biofilter media for reducing swine building odors. However, more studies at full scale biofilters are needed.

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