RESEARCHREPORT
ENVIRONMENT

Title: Alternative Biofilter Media Testing- **NPB #07-034**

Investigator: Kevin Janni

Institution: University of Minnesota

Co-Investigator: David Schmidt

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Industry Summary:

Gas-phase biofilters are a proven method for reducing odor emissions from swine facilities and manure storage units. Woodchip and compost mixtures are commonly used as biofilter media. Widespread use of biofilters is stalled in part due to three issues: 1) the relatively large footprint needed to manage the media pressure drop; 2) concerns about the biofilter media harboring rats; and 3) long term biofilter media compaction. The purpose of this initial project on alternative biofilter media was to evaluate the media's ability to mitigate these issues. The alternative media were: bag mulch, lava rock, cedar chips, pine bark nuggets, western pine bark and wood shreds. Study results demonstrated that all six media, if seeded with compost and aerated manure, could support microbial organisms that reduced hydrogen sulfide, ammonia and odor emissions in air from a swine manure or gestation barn. The alternative media had larger particles and more porosity than typical woodchip and compost mixtures. The pressure drop, an indication of the amount of electrical energy needed to blow air through the media, across the wood shreds, pine bark and lava rock media were less than across woodchip media. These results are expected to lead to biofilter designs that will need less electrical energy for operation. Gas and odor reductions were variable in part because the air source concentrations were highly variable over a period of minutes. Common woodchip and compost biofilters typically have five seconds of contact in the media. Results from this study indicate that biofilters with media made up of larger particles and having contact times of one second can reduce hydrogen sulfide emissions by between 8 and 90% while those with five seconds of contact time can reduce emissions by between 77 to 100%. These results suggest that alternative media can be used to manage odor and gas emissions while using less energy that conventional biofilters. More research is needed before design and management recommendations can be developed. Contact information: Kevin Janni, kjanni@umn.edu 612-625-3108.

Scientific Abstract

Gas phase biofilters are a proven method for reducing odor and other gaseous emissions from swine facilities. Widespread adoption of biofiltration is stalled due to four issues: 1) the relatively large footprint needed to manage the media pressure drop; 2) concerns about the biofilter media harboring rats; and 3) long term biofilter media compaction. The purpose of this project was to identify and evaluate alternative biofilter media that would mitigate these issues. Six media were evaluated in phase 1. The media were: bag mulch, lava rock, cedar chips, pine bark nuggets, western pine bark and wood shreds. Media sieve analysis, porosity and unit pressure drop versus unit airflow relations were determined. Phase 1 testing was conducted in a biofilter media testing unit with six columns with individually controlled airflow rates and moisture control. In phase 1 the air cleaning performance and pressure drop characteristics of each media were evaluated based on hydrogen sulfide (H_2S) and ammonia (NH_3) removal. In phase 2, three media, wood shreds, pine bark nuggets and lava rock were placed in duplicate columns and evaluated for pressure drop and H_2S and NH_3 reductions. In phase 3, pine bark nuggets were used in all six columns with two empty bed contact times (EBCT) (i.e., 1 s and 5 s). The percent H_2S, NH_3 and odor removal were evaluated. Gas concentrations and odor threshold detection levels were very low and variable making consistent reduction measurement difficult. Pine bark nuggets and lava rock had the lowest unit pressure drops versus unit airflow rates. In phase 1, all of six media supported microbial growth if seeded and were effective reducing H_2S concentrations from between 21 and 75% and NH_3 concentrations from between 43 to 80%. In phase 2, all three media performed well using an average EBCT of 5 s. In phase 3, the biofilters with pine nuggets as media and 1 s EBCT reduced hydrogen sulfide emissions by between 8 and 90% and those with 5 s EBCT can reduce emissions by between 77 to 100%.

Introduction

Biofiltration is a proven technology for reducing odor and other gaseous emissions from swine facilities (Nicolai and Janni, 1998). Other industries have used biofiltration for many years (Janni et al., 2001). Widespread adoption of this technology by the swine industry is stalled due to four issues: 1) the relatively large footprint needed to manage the media pressure drop, which impacts operating costs; 2) concerns about biofilter media harboring rats; and 3) concerns about media compaction over time (personal correspondence with several farmers in MN). Despite these producer concerns, biofilter use is strongly encouraged in at least two Minnesota counties (through conditional use permits in Dodge and Carver counties) and is one of the few proven and cost effective air cleaning technologies available to reduce odor emissions. This regulatory pressure and current interest by the Minnesota Natural Resource Conservation Service (NRCS) in biofiltration will likely result in growing use of this technology.

Most biofilter installations on swine barns are based on University of Minnesota (UMN) design recommendations (Nicolai and Janni 2000; Schmidt et al., 2004). Field installations of systems based on these recommendations have shown significant success at reducing odor from swine facilities (personal communication, Ken Folie, Dodge County Feedlot Officer). One of the primary considerations of the UMN design guidance was maintaining low capital and operating costs. Commercial cost for biofilter installation on swine barns is approximately $0.075/cfm treated (Schmidt et al, 2004). Unfortunately, this low cost biofilter design and construction did not address concerns about the large footprint, rodent problems, and compaction. Design and construction of biofilter systems for industry (commercially available systems) that have small footprints, minimal rodent problems and collect any leachate have installation costs in the range of $20 to $70/cfm (ICAC, 1994). The goal of this research is to try to address these problems while maintaining low installation and management costs.

One option to reduce biofilter footprint is with a vertical biofilter being tested. Results of this design look promising (Nicolai, 2005) but issues of cost, airflow channeling, media longevity, rodent control, and moisture control are still concerns being investigated.

Research is needed identify and evaluate alternative biofilter media that will mitigate the swine produce concerns that are hampering adoptions of biofiltration for odor and gas emission management.

Objectives

Collect and disseminate data on economical alternative media for use in biofilters. This research will result in the development of biofilters with a lower pressure drops (which allow smaller biofilter footprints and lower operating costs), that are more resistant to rodents, and have an extended useful life (through reduced maintenance costs).

Materials and Methods

Six alternative media were selected. The media were: bag mulch, lava rock, cedar chips, pine bark nuggets, western pine bark and wood shreds. Five of the media were obtained from commercial sources. The wood shreds were taken from a pile of ground tree branches on the University of Minnesota St Paul campus.

Extensive physical property evaluations were conducted on representative media samples. The physical properties evaluated were: porosity, particle size and spherocity. These physical properties were measured to test the hypothesis that there is a relation between these characteristics and unit pressure drop versus unit airflow rate relation used in the biofilter design guide (Schmidt et al., 2004).

Media porosity was determined using a bucket test for estimating percent voids in the biofilter design guide (Schmidt et al., 2004). Media particle size distributions were determined by conducting a sieve analysis using seven sieves with different sized screens: 38.1mm, 26.67mm, 19.1mm, 15.9mm, 12.7mm, 9.423mm, 6.680mm, ending with a solid tray. Media samples weighing between 100g and 200g were placed on the top sieve with the largest sized screen in the stack and shaken for 5 minutes. After the shaking, the sieves were separated and the media on each screen weighed. Media spherocity was determined by measuring the length of ten particles. Particle volumes were determined using the same particles and a graduated cylinder to determine the volume displaced by the particles. The equivalent particle diameter was calculated using equation 1. Media spherocity indicates how the particle length compares to an equivalent particle diameter (Sower, 1979).

Equation 1

$$De = 10\sqrt[3]{\frac{6V}{\pi}}$$

Where De = equivalent particle diameter (mm)
V = average particle volume (mL)

Media unit pressure drop versus the unit airflow rate for the six media was evaluated using a new flow rate-pressure drop unit built using additional funding from the University of Minnesota. The procedure used was described by Nicolai and Janni (2001). The media test column was filled with media to five depths (4, 8, 12, 16, and 20 inches) and compacted by dropping the column as done in the method for determining porosity (Schmidt et al., 2004). After compaction at each media depth, the airflow rate was measured with a propeller anemometer and the static pressure measured across the media at four fan settings (i.e., 40%, 60%, 80%, and 100% power).

A biofilter media test unit with six columns taking air from a common plenum was built. The unit was capable of independent and simultaneous testing six different biofilter media, one in each column. Each column had an axial centrifugal fan and a sprinkling system so airflow through and moisture content in each column can be set and controlled independently. The unit has a data acquisition system capable of continuous monitoring of column pressures, relative humidity, and temperature.

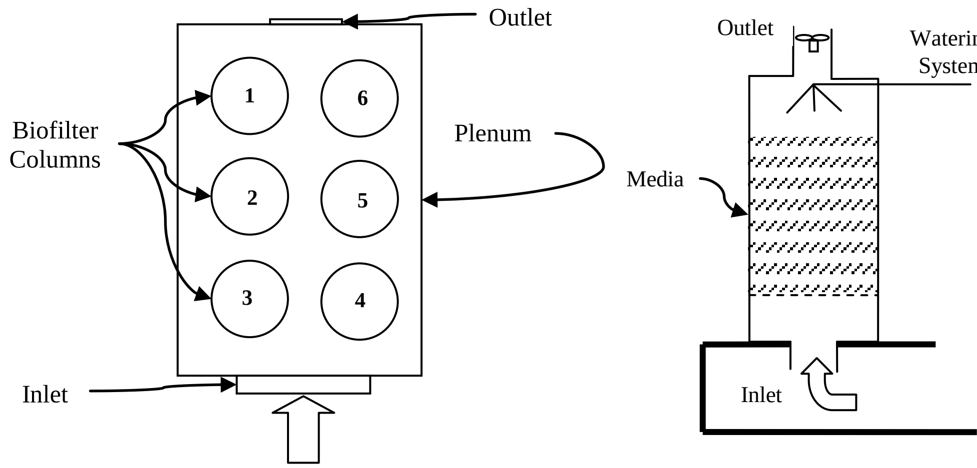

Figure 1. Top view of biofilter media test unit and a side view a column.

No sensor was found to automatically control the sprinkling system based on media moisture content. The sprinklers in each column were on separate timers. Water use was monitored with plans to develop a relation describing water needs based on airflow rates and relative humidity of the inlet and outlet air.

For phase 1 media testing, the six columns were each filled with a different biofilter media to a depth of 30 inches. Media was kept moist using the sprinkler system with nozzles mounted to the top of each column attached to water lines with individually controlled solenoid valves that managed the water addition. Airflow through each column was maintained at approximately 52 cubic feet per minute to produce Empty Bed Residence Times of approximately five seconds in each column. For the phase 1 testing, inlet gas was taken from a swine manure storage pit located under the Waste Treatment Building located on the University of Minnesota St. Paul Campus. This pit received flushed swine manure daily. The ventilation rate through the Waste Treatment Building was very high to protect employees and resulted in low inlet hydrogen sulfide concentrations entering the biofilter test columns.

Inlet and outlet concentrations were measured with a Jerome Meter™ hydrogen sulfide analyzer (Model 631-X, Arizona Instruments, Phoenix, AZ), which measures total reduced sulfur gasses. The inlet and outlet concentrations were used to calculate percent reductions through the test biofilter columns. On April 16, 2008 ammonia concentrations were measured using Tedlar bags filled with inlet or outlet air samples and analyzed using a chemiluminescence ammonia analyzer (TEI 17C, Thermo Environmental Instruments, Waltman MA).

Initial gas sampling results indicated that the media, which had not been seeded with compost or other microbial sources, were not reducing hydrogen sulfide or ammonia gas emissions. It was hypothesized that the columns had low microbial populations so approximately one gallon of aerated swine manure and one gallon of compost were added to the top of each column.

For phase 2 media testing three media from the initial test were mixed with new media and placed in two randomly selected columns to a depth of 28 inches. The three media used in phase 2 were pine bark nuggets, wood shreds and lava rock. Airflow through each column was maintained at approximately 52 cubic feet per minute to produce a typical EBCT of approximately five seconds in each column. Inlet and outlet hydrogen sulfide and ammonia concentrations were measured between May 20, 2008 and July 15, 2008 using the equipment and procedures used in phase 1. Inlet and outlet odor samples were collected in new Tedlar bags and analyzed within 24 hours to determine detection threshold following international olfactometry standards (CEN, 2003). Inlet air for phase 2 came from the barn exhaust from a flush gestation barn that is 42 ft x 50 ft housing approximately 46 sows or boars. The barn was flushed twice per day with recycle water. Air entering the biofilter media test unit came from a continuous exhaust fan mounted near the ceiling which was ducted down to the ground with a plywood duct on the outside of the barn. A variable speed fan blew air from the plywood duct into the biofilter media test unit plenum where the six columns withdrew air.

For phase 3 all six columns of the biofilter media test unit were filled with pine nuggets to a depth of 28 inches. Three columns were randomly assigned a one second EBCT and three columns were assigned a five second EBCT. Airflow rates through each column were adjusted to approximate the assigned EBCT. Inlet and outlet hydrogen sulfide and ammonia and gas concentrations odor detection threshold concentrations were measured between August 4, 2008 and October 10, 2008 using the equipment and procedures used in phase 2. The inlet air for phase 3 came from the same gestation barn used in phase 2 using the same fans and ducts.

Results

<u>Alternative Media Physical Characteristics</u>

The mean measured porosity and spherocity for the six media evaluated are reported in Table 1. Porosity for pine bark was not determined because there was not sufficient media after the column was filled.

Table 1. Measured media characteristics

Media	Porosity % voids	Spherocity
Cedar chips	77	0.380
Bag mulch	72	0.248
Pine nuggets	70	0.346
Lava rock	59	0.638
Western pine bark	-	0.680
Wood shreds	65	0.303

Mean sieve data for the six media evaluated is presented in Figure 2. The bag mulch had many small particles and few large particles. Less than 20% by mass of the bag mulch was retained above the 12.70 mm (0.5 inch) screen. The bag mulch contrasted with the pine bark and pine nuggets that were mostly large particles, where more than 75% of the media passed through the 19.10 mm (0.75 inch) sieve.

Figure 3 gives the unit pressure drop versus the unit airflow rate for the six media evaluated. All of the media exhibited increasing unit pressure drop as the unit airflow rate increased. The results also show that the bag mulch, which had mostly small particles, had a much higher unit static pressure drop than the wood shreds, lava rock and pine nuggets, which all had more large particles. Power equations that fit the data were plotted to highlight the trend of each media. Additional analysis is needed.

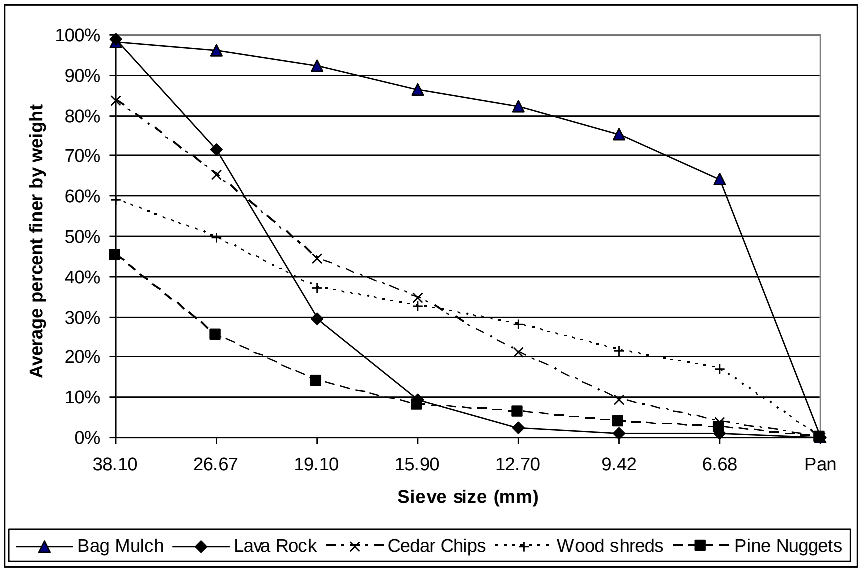

Figure 2. Sieve analysis of the six media tested in Phase 1.

Alternative Media Performance Testing Phase 1

The pressure drop across each media, except the bag mulch, was between 5 and 20 Pa (~0.02 to 0.08 inches). The bag mulch, which was a much denser material with mostly small particles, had a pressure drop of approximately 120 Pa (0.5 inches).

Table 2. Phase 1 hydrogen sulfide inlet and outlet concentration data (ppm).

	Average	Standard deviation	Maximum	Minimum
Inlet air	1.09	0.49	2.4	0.33
Column media				
Cedar chips	0.43	0.32	0.89	0.12
Bag mulch	0.43	0.38	1.53	0.06
Pine nuggets	0.25	0.14	0.53	0.06
Lava rock	0.28	0.37	1.65	0.06
Western pine bark	0.42	0.24	1.03	0.12
Wood shreds	0.34	0.35	1.31	0.01

Inlet hydrogen sulfide concentration ranged from 0.33 to 2.4 ppm, which was quite low. After seeding and acclimation the outlet hydrogen sulfide concentrations from the six columns ranged from 0.25 to 0.43 ppm.

Percent reductions of total reduced sulfur by the test columns over a four month period are given in Figure 4. All of the columns showed good reductions of hydrogen sulfide (> 60% reduction) towards the end of the phase 1 testing after April 20, 2008 (Figure 3).

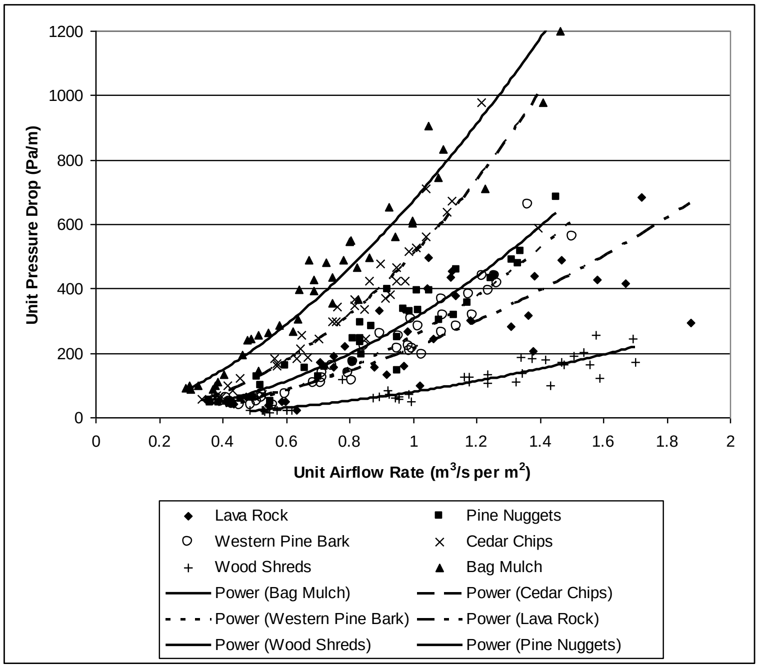

Figure 3. Unit pressure drop versus unit airflow rate for six media tested in phase 1.

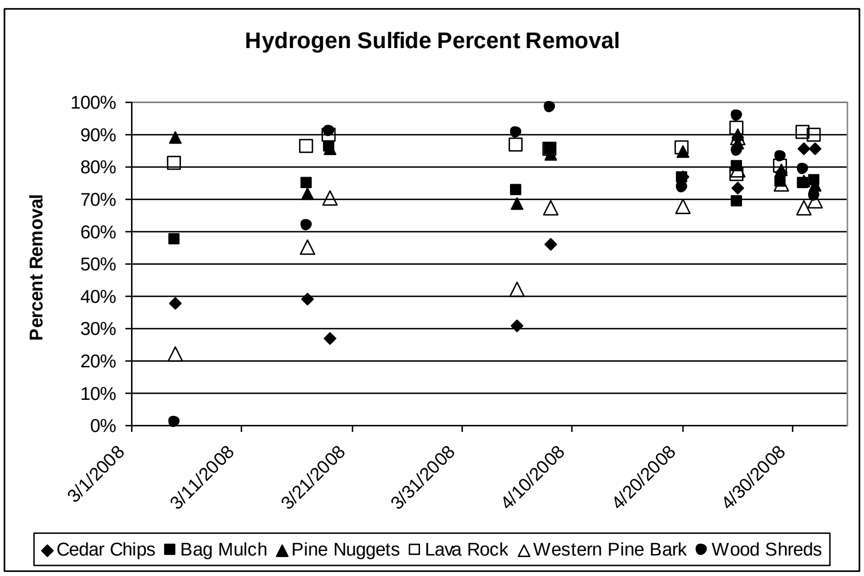

Figure 4. Hydrogen sulfide reduction in the media based on Jerome Meter® readings.

Figure 5 shows the percent ammonia reductions found on April 16, 2008 using Tedlar bag samples. Percent ammonia removal ranged from 32 to 77%. These results were typical for biofilters.

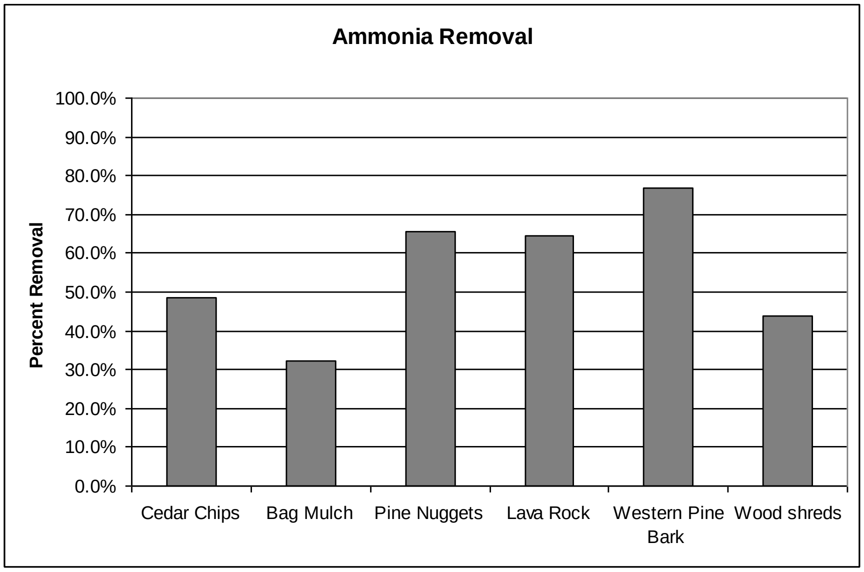

Figure 5. Percent ammonia reduction in the media on April 16, 2008 based on Tedlar bag samples analyzed using a chemiluminescence ammonia analyzer (TEI 17C, Thermo Environmental Instruments, Waltman MA).


Cedar Chips


Bag Mulch


Pine Bark (Nuggets)


Lava Rock


Western Pine Bark


Wood Shreds

Figure 6. Photos of the media removed from the biofilter columns after phase 1.

<u>Three Media Testing Phase 2</u>

Initial and final media depth data, Table 3, indicated that the wood shreds and pine bark settled 14% and 18%, respectively. The lava rock had no measurable settling. Pressure drops across the media ranged from 11 to 33 Pa. The lava rock pressure drops were the lowest. The western pine bark media had the largest variation in pressure drop. The target EBCT time for the six columns was 5 s. The average EBCT time after the first month was 4.7 s.

Table 3 Phase 2 initial and final media depth, typical measured pressure drop across the media and target empty bed contact time (EBCT)

Media Type	Media depth Initial (Final) inches	Typical Measured Pressure Drop (Pa)
Wood shreds	28 (24)	21
Wood shreds	28 (24)	26
Pine bark	28 (23)	33
Pine bark	28 (23)	19
Lava rock	28 (28)	11
Lava rock	28 (28)	16

Inlet air gas concentrations and odor detection threshold levels of the inlet air from the swine gestation barn were quite low and variable over periods of minutes (i.e. sampling periods), which made it difficult to document reliable percent reduction. Average inlet hydrogen sulfide and ammonia concentrations were 0.098 ppm and 1,340 ppm, respectively. The average odor detection threshold level of the inlet air was 780 odor units. Relatively large standard deviations indicate large variability in the inlet gas values.

Average outlet hydrogen sulfide concentrations from the biofilter columns ranged from 0.030 to 0.039 ppm so average percent reduction in hydrogen sulfide concentration ranged from 61 to 74% reduction. Average outlet ammonia concentrations ranged from 740 to 800 ppm and average percent reductions ranged from 34 to 37% reduction. Seven inlet odor samples were analyzed and five outlet odor samples (from each column) were analyzed. Average outlet detection thresholds ranged from 280 to 300 odor units.

Table 4 Phase 2 Average and standard deviation (SD) inlet and outlet concentration of hydrogen sulfide, ammonia and odor.

	Hydrogen sulfide (ppm) (SD)	Ammonia (ppm) (SD)	Detection threshold (odor units) (SD)
Inlet	0.098 (0.142)	1,340 (810)	780 (470)
Media type			
Wood shreds	0.030 (0.058)	760 (670)	280 (310)
Pine bark	0.037 (0.055)	800 (670)	320 (340)
Lava rock	0.039 (0.068)	740 (500)	300 (300)

The large standard deviations in the data led to conditions when outlet gas concentrations and odor detection thresholds were larger than inlet gas concentrations and odor detection thresholds. Figures 7 and 8 are plots the percent removal of hydrogen sulfide and ammonia by the biofilter columns using wood shreds, pine bark and lava rock. Figure 9 is a plot of the recent reduction in odor detection threshold levels. Negative percent removal values indicate that the outlet concentration or odor detection threshold was higher than the inlet.

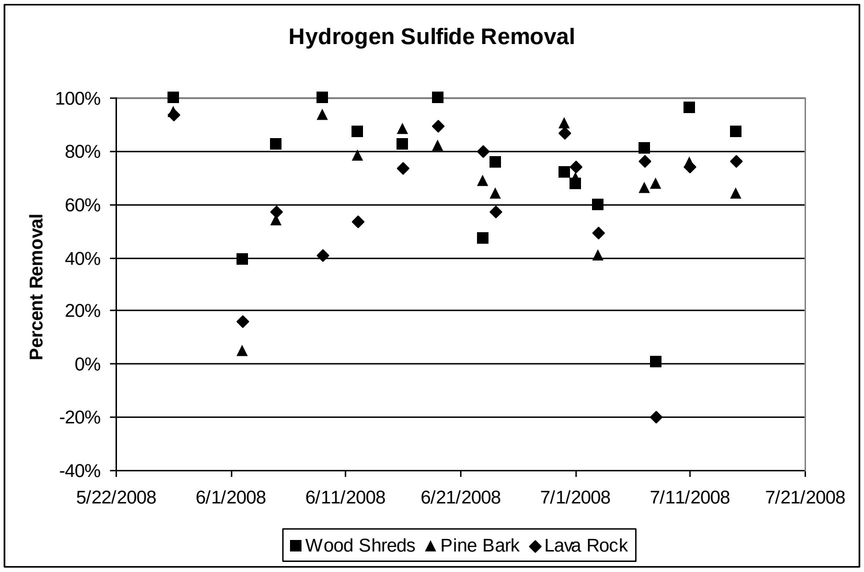

Figure 7. Percent hydrogen sulfide removal by biofilter columns with wood shreds, pine bark or lava rock media and 5 s EBCT.

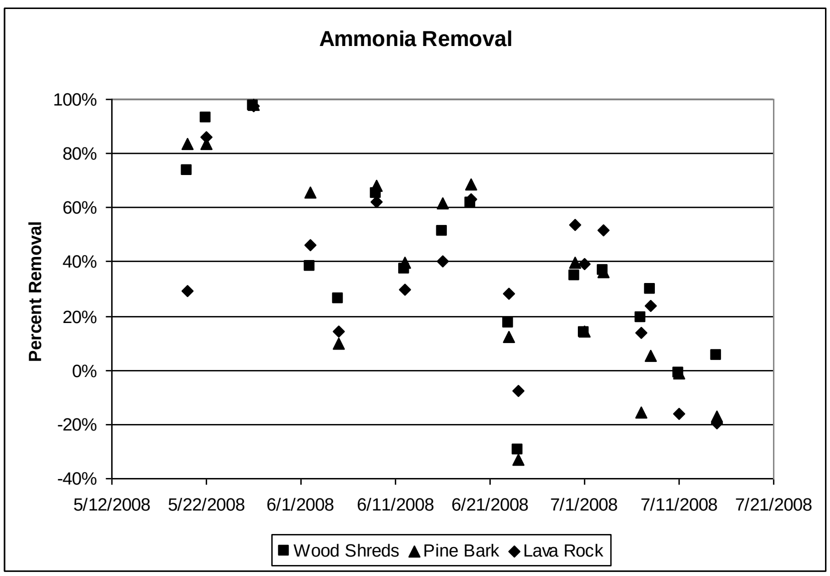

Figure 8. Percent ammonia removal by biofilter columns with wood shreds, pine bark or lava rock media and 5 s EBCT.

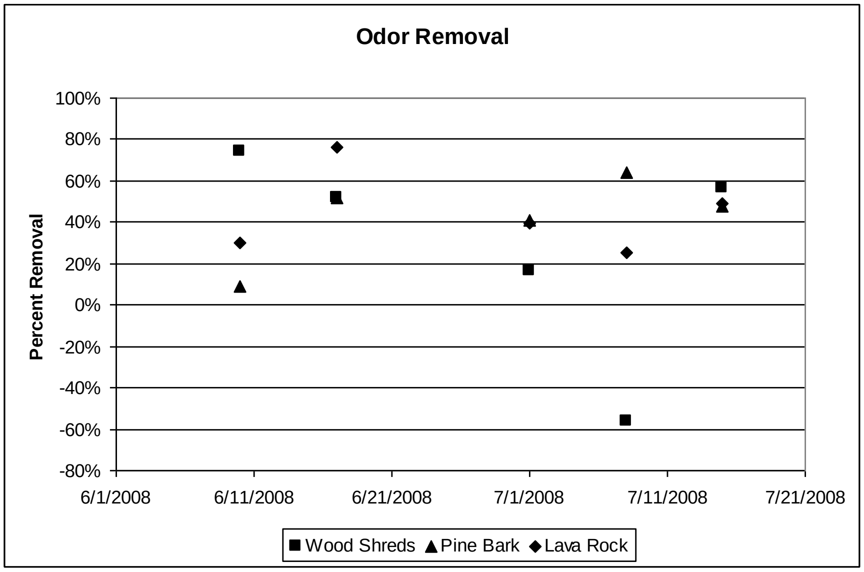

Figure 9. Percent odor detection threshold reduction by biofilter columns with wood shreds, pine bark or lava rock media and 5 s EBCT.

Two Empty Bed Contact Times Phase 3

The pine nugget media was 28 inches deep in the six columns in the biofilter media test unit. The target EBCT times were 1s and 5s. Average EBCT times were 1.2 s and 4.4s.

Gas concentrations and odor detection threshold levels of the inlet air from the swine gestation barn were quite low and variable. Table 3 gives average and standard deviations of the inlet and outlet hydrogen sulfide, ammonia concentrations and odor detection threshold levels. The limited data indicate that the biofilter columns with more contact time (i.e. 5 s EBCT) had lower outlet gas concentrations and odor detection thresholds.

Table 3 Phase 3 Average and standard deviation inlet and outlet concentration of hydrogen sulfide, ammonia and odor.

	Hydrogen sulfide (ppm) (SD)	Ammonia (ppm) (SD)	Detection threshold (odor units) (SD)
Inlet	0.12 (0.07)	1,680 (700)	1,200 (1,000)
EBCT			
1 s	0.07 (0.06)	1,160 (840)	770 (720)
5 s	0.01 (0.02)	480 (470)	480 (470)

The low inlet air concentrations and variability over the sampling period led to conditions when outlet gas concentrations and odor detection thresholds were larger than inlet gas concentrations and odor detection thresholds. Figures 10 and 11 are plots the percent removal of hydrogen sulfide and ammonia by the biofilter columns with pine nuggets and either 1 s or 5 s EBCT. Figure 12 is a plot of the recent reduction in odor detection threshold levels. Negative percent removal values indicate that the outlet concentration or odor detection threshold was higher than the inlet.

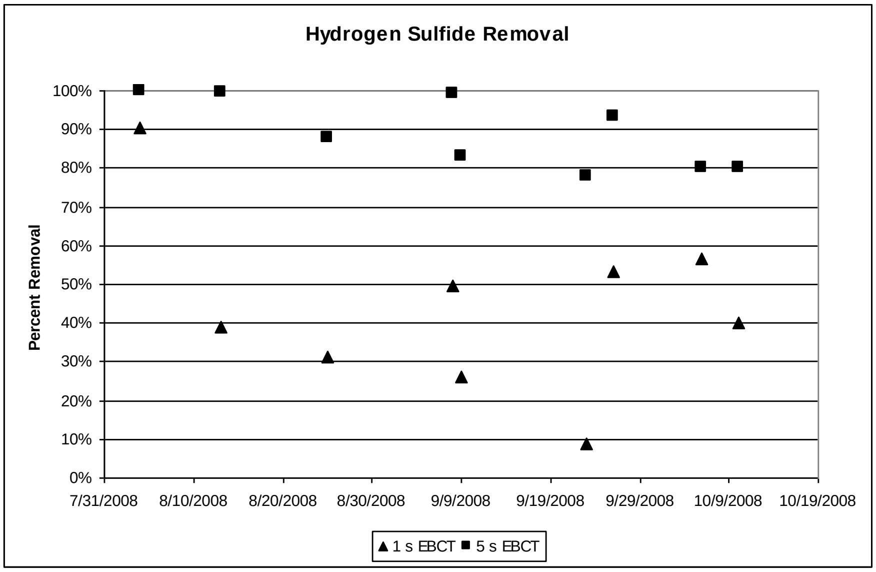

Figure 10. Percent hydrogen sulfide removal by biofilter columns with pine nuggets and either 1 s or 5 s EBCT.

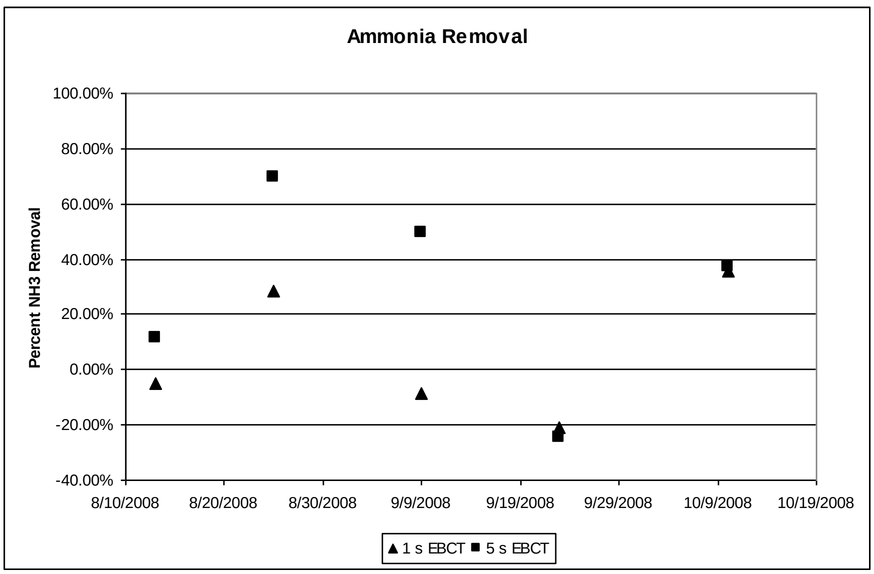

Figure 11. Percent ammonia removal by biofilter columns with pine nuggets and either 1 s or 5 s EBCT.

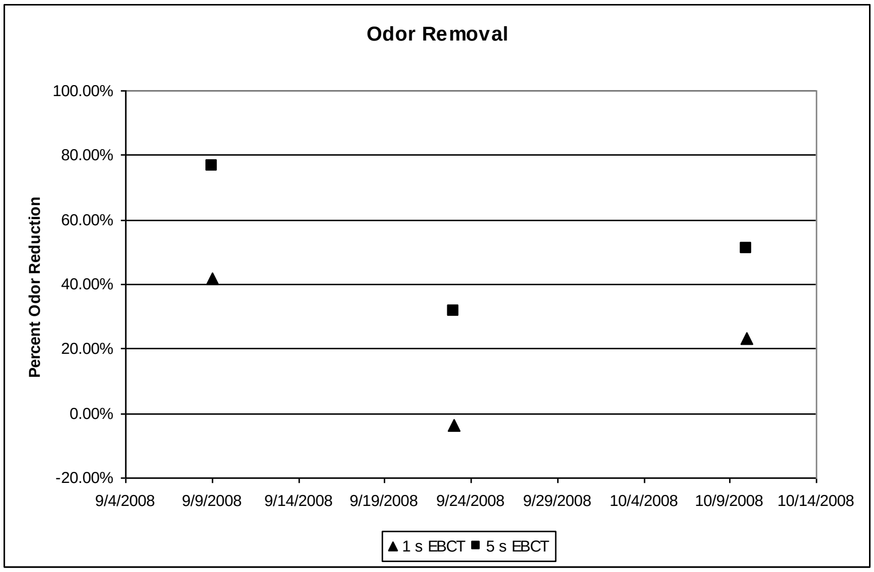

Figure 12. Percent odor detection threshold reduction by biofilter columns with pine nuggets and either 1 s or 5 s EBCT.

Discussion

Alternative Media Physical Characteristics

The University of Minnesota design guide for open-bed biofilters is based on woodchip and compost mixtures as the biofilter media (Schmidt et al., 2004). The porosities of these mixtures were commonly between 40 and 60%. Field experience suggests that media with higher porosity have lower pressure drops and are able to treat more air with greater energy efficiency. The media evaluated had porosities that ranged from 59% to 77%.

The unit pressure drop versus unit airflow rate results demonstrated that wood shreds and lava rock had much lower pressure drop requirements than bag mulch and cedar chips. Media with lower unit pressure drop requirements would be expected to require less electrical energy for gas-phase biofilter treatment compared to traditional woodchip and compost media for same airflow rate.

The unit pressure drop versus unit airflow rate data did not correlate directly with porosity. Some high porosity media had high unit pressure drops versus unit airflow rates and some low porosity media had low unit pressure drops versus unit airflow rates. These results suggest that other physical characteristics may be needed to correlate with the unit pressure drops versus unit airflow rates. Spherocity may be such a characteristic. More research is needed.

Alternative Media Performance Testing Phase 1

In the initial media screening phase the media were install without seeding with compost as recommended in the design guide (Schmidt et al., 2004). Initial hydrogen sulfide results indicated that the unseeded media were not able to reduce hydrogen sulfide concentrations as the air passed through the biofilter media. After seeding, all of the media evaluated were able to support microbial growth and remove airborne hydrogen sulfide and ammonia. Percent removal rates of hydrogen sulfide at the end of phase 1 ranged from 68 to 92%. The very low and variable inlet gas concentrations made it difficult to consistently document a percent removal.

Three Media Testing Phase 2

The media selected for additional evaluation in phase 2 had very low unit pressure drops per unit airflow rate. They were selected in anticipation that they would require less electrical energy to move air through the media and reduce biofilter operating costs. The media were wood shreds, pine bark and lava rock. After two months, the wood based media had compacted by 14 and 18% while the lava rock had no detectable compaction. Overall all three media were able to support microbial growth and reduce hydrogen sulfide and ammonia concentrations and odor detection threshold levels. Again very low and variable inlet gas concentrations made it difficult to consistently document a percent removal. On occasions negative reductions, or generation, was observed. Ammonia reduction was found to decline over time.

Two Empty Bed Contact Times Phase 3

Another method for reducing biofilter size is to reduce the empty bed contact time (EBCT). Biofilters using woodchips and compost and a 5 s EBCT typically can reduce odor detection thresholds by 78 to 95%, hydrogen sulfide concentrations by 86 to 97% and ammonia by 50 to 82% (Nicolai and Janni, 2000). The results from this study found that when using pine nuggets at a depth of 28 inches and a 1 s EBCT that percent hydrogen sulfide removal ranged from 8 to 90% while columns with a 5 s EBCT had percent hydrogen sulfide removals that ranged from 77 to 100%. Percent ammonia removal and odor detection threshold reduction were less and variable, some were even negative. In general the biofilters with 5 s EBCT removed more ammonia and reduced odor detection thresholds more than biofilters with 1 s EBCT. However, biofilters with 1 s EBCT did remove odors and gases and may be appropriate when partial odor control is needed. Energy requirements and biofilter size would be expected to be less for biofilters designed to provide 1 s EBCT.

Acknowledgements

This project was funded by the National Pork Checkoff.

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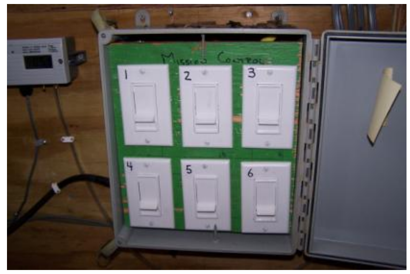
Project Photos

Biofilter media test unit

Data Logger



Variable Fan Controls

Water Control Solenoids