MITIGATING ODORS FROM ANIMAL FACILITIES USING WOOD-CHIP BASED BIOFILTERS

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ABSTRACT

A mobile biofilter testing laboratory was developed where one- and two-stage biofilters filled with western cedar (WC) and hardwood (HW) chips were examined to treat odor emissions from a deep-pit swine finishing facility in central Iowa. The biofilters were operated continuously for 12 weeks at different air flow rates resulting in variable empty bed residence times (EBRT). An automatically controlled water supply system was tested and used to control media moisture content. A dynamic forced-choice olfactometer was used to evaluate odor concentrations from both the control plenum and biofilter treatments, and other characteristics such as gas flow pressure drop, leachate pH and ammonia concentration, and water consumption were also monitored. Experiment results indicate that the water supply system tested in this study can keep wood chip media at a high and stable moisture range 72% ± 3% (WC) and 62% ± 3% (HW) with a 6.4 l/m³-day water supply, and two-stage biofilters have an advantage in potentially reducing media compaction. The effects of three different levels of media moisture content shows that proper moisture content is a key factor for the success of wood chip-based biofilters, but is not a substitute for inadequate EBRT.

INTRODUCTION

The reduction of odors emitted from animal production systems continues to present challenges for researchers. Most odors and gas emissions from building and manure storage sources are by-products of anaerobic decomposition and transformation of organic matter in manure by microorganisms (Nicolai et al., 2006). These compounds cover a broad spectrum and generally exist in low concentrations. Biofiltration, which has the ability to treat a broad spectrum of gaseous compounds (Janni et al., 2001), has been regarded as a promising odor and gas treatment technology that is gaining acceptance in agriculture. Several research studies using compost-based biofilters have been conducted with significant reductions in odor and specific gases (Nicolai and Janni, 1997; Sun et al., 2000). However, special care is needed to screen fines from compost/wood chip mixtures to reduce operating static pressure. A properly selected wood chip media eliminates the need for mixing multiple media but little is known about the performance of wood chip-based biofilters.

Biofilter media moisture content has been identified as the most important parameter in biofilter operation, along with residence time (Sun et al., 2000). Media compaction adds another challenge during biofilter operation. More efforts are needed to cope with media compaction. A two-stage biofilter with an automatically controlled water supply system tested in this study is one attempt to deal with these challenges.

The objectives of this research were to: (1) test an automatically controlled water supply system, (2) investigate the odor, hydrogen sulfide (H₂S) and ammonia (NH₃) reduction performance of two-stage biofilters at various moisture contents and empty bed residence times (EBRT), and (3) investigate pressure drop characteristics, and monitor pH and NH₃.
concentration of leachate from the wood chip-based biofilter 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 46 x 180 ft with 10 in. and 24 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 measure and store temperature, biofilter moisture content, and NH₃ and H₂S concentrations. The layout of the BTL is shown in Figure 1. The BTL consisted of eight parallel plastic reactor barrels, four of which were randomly selected (two of each two-stage and one-stage) to be filled with western cedar (WC) chips, and the remaining four were filled with 2-in. hardwood (HW) chips. Both wood chip types were purchased locally and were used in their acquired state without pre-preparation such as grading and screening. The characteristics of the two wood chip types are presented in Table 1. There was a common plenum below the reactor 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 reactor barrels.

![Figure 1. The layout of the biofilter testing laboratory.](image)

Table 1. Characteristics of two types of wood chips.

<table>
<thead>
<tr>
<th>Chips</th>
<th>Species</th>
<th>Phosphorus (ppm)</th>
<th>Potassium (ppm)</th>
<th>Total Nitrogen (%)</th>
<th>Total Carbon (%)</th>
<th>WRC (%)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC (shredded bark)</td>
<td>Thuja plicata</td>
<td>160 ± 6</td>
<td>1103 ± 48</td>
<td>0.27 ± 0.02</td>
<td>45.98 ± 0.47</td>
<td>74.8 ± 2.9</td>
<td>67.0 ± 0.5</td>
</tr>
<tr>
<td>HW (2-in. oak)</td>
<td>Quercus rubra</td>
<td>240 ± 21</td>
<td>2991 ± 121</td>
<td>0.35 ± 0.01</td>
<td>43.68 ± 0.35</td>
<td>67.3 ± 1.5</td>
<td>55.9 ± 0.5</td>
</tr>
</tbody>
</table>

Notes: *Water-holding capacity;  † Measured using bucket test method; ‡ Three samples were used for all measurements

The one-stage reactor barrels (22 in. inside diameter, 34 in. in depth) were designed with a 10 in. air space at the bottom of the barrels, with a 15 in. biofilter media depth located above this airspace separated by a metal mesh support. The two-stage reactor barrels (22 in. inside diameter, 34 in. in depth) were designed with a 10 in. air space at the bottom of the barrels, with
a 8 in. deep first-stage biofilter media located above this airspace separated by a metal mesh support. There was another 7 in. air space above the first-stage biofilter, with a 7 in. deep second-stage biofilter media above this airspace separated by another metal mesh support. Water was added at the top of each barrel using solid cone mist nozzles controlled automatically via solenoids at adjustable time periods. Water use was monitored by commercially available water meters connected with each barrel reactor. Biofilter media moisture was measured with commercially available soil moisture sensors (Model ECH2O EC-20; Decagon Devices, Inc. Pullman, WA) combined with a gravimetric method. The soil moisture sensors were first calibrated in the laboratory. The variable speed fans were used to adjust the EBRT.

The biofilter media in each reactor was allowed to stabilize by passing pit-gas air through each reactor for one month. During the stabilization period, the water supply system was tested and adjustable periods between 9 s on/30 min off and 9 s on/50 min off were established suitable to keep the wood chip media at a high and stable moisture content of 72% ± 3% (WC) and 62% ± 3% (HW). At a setting of 9 s on/45 min off, about 8 L/day of water was added resulting in 6.4 L/m³-day of biofilter water supply which was half compared to a manually controlled method previously tested in the same situations (Chen et al., 2009). After the one month stabilization period, three levels of air flow rate (36cfm, 48cfm, and 53cfm) were randomly set to run in specified reactors for about one week during which static odor samples were collected and analyzed. Three levels of media moisture content with a fixed 4.1 s EBRT were also tested.

A dynamic forced-choice olfactometer (AC’SCENT International Olfactometer; St. Croix Sensory, Inc. Stillwater, MN) was used to evaluate odor concentration based on ASTM E679-04 (ASTM, 2004). The concentrations of NH₃ and an H₂S equivalent measure were also evaluated from the static bag samples by using NH₃ (Model Drager Pac III; Drager Safety, Inc., Pittsburgh, PA) and H₂S (Model Jerome 631 X; Arizona Instrument LLC, Tempe, AZ) analyzers.

Leachate was collected once a week for 10 continuous weeks. The pH and NH₃ concentration of the leachate were analyzed based on the Standard Methods for the Examination of Water and Wastewater (21st Edition, 2005). The gas flow pressure drop was measured by TSI VelociCalc® Plus Multi-Parameter Ventilation Meter (model: 8385(A), TSI Incorporated, Shoreview, MN).

RESULTS AND DISCUSSION

The odor concentration results for WC two-stage biofilters with a 72 ± 3% media moisture content (wet basis) are given in figure 2a. The treated odor concentration remained stable when EBRT was from 3.7 to 5.5 s. The reduction efficiency was 47%, 52% and 54% for 3.7, 4.1, and 5.5 s EBRT, respectively. The average reduction efficiency was 51.2% which was lower than the average of 78% reported by Nicolai and Janni (1997) where they used 50:50 by weight mixture of compost and bean straw with an EBRT of 8.8 s. The average EBRT from this present study was 4.4 s. The biofilter effects on H₂S and NH₃ concentration are shown in figures 2b and 2c, respectively. The treated H₂S concentration decreased with increasing EBRT (figure 2b). The reduction efficiency for H₂S was 85%, 78%, and 87% for 3.7, 4.1, and 5.5 s EBRT, respectively. These results were similar to the result of 86% reduction efficiency reported by Nicolai and Janni (1997). The treated NH₃ concentration and reduction efficiency fluctuated as shown in figure 2c. The average reduction efficiency for NH₃ was 41% (minimum 29%, maximum 57%). Nicolai and Janni (1997) indicated an average of 50% reduction efficiency ranging from 28% to 100% for their compost-based biofilter.
Figure 2. Static sample results (a) odor, (b) H₂S, and (c) NH₃ concentration. The reduction efficiencies of odor, NH₃ and H₂S at three levels of media moisture content with an EBRT fixed at 4.1 s are shown in figures 3a, b and c, respectively. The odor reduction efficiencies at moisture levels of 17%, 48% and 75% were 37%, 49% and 52%, respectively.

Figure 3. At a EBRT of 4.1 s (a) odor, (b) H₂S, and (c) NH₃ concentration.
The H₂S reduction efficiency at moisture levels of 17%, 48% and 75% were 5%, 76% and 78%, respectively. Sun et al. (2000) reported that a higher media moisture content resulted in a higher removal efficiency for H₂S (47%-94%) corresponding to moisture contents of 30-50% at 5, 10 and 20 s EBRTs, respectively, when their compost-based biofilter was used to treat odorous gas. Nicolai and Janni (2001b) reported that an average H₂S reduction for the low (27.6%), medium (47.4%) and high (54.7%) moisture contents at 5 s empty bed contact times were 3%, 72% and 87% respectively, when evaluating treatment effects of different biofilter media mixture ratio of wood chips and compost (ratio from 0% to 50% by weight).

The NH₃ reduction efficiency of WC at moisture levels of 17%, 48% and 75% was -26%, 20% and 57%, respectively. Sun et al. (2000) reported that a higher media moisture content resulted in a higher removal efficiency for NH₃ (25%-90%) corresponding to moisture contents of 30-50% at 5, 10 and 20 s EBRTs, respectively, when their compost-based biofilter was used to treat odorous gas. Nicolai et al. (2006) observed that increasing the moisture content from 40% to 50% (wet basis) increased removal efficiency of NH₃ from an average of 76.7% to 82.3% and increasing the moisture content to 60% did not significantly change the removal efficiency with a compost/wood chip biofilter at a 5 s EBRT. The results from this study show that NH₃ removal efficiency increases with increasing media moisture content from 17% to 75%.

For the two-stage WC biofilter, the reduction efficiency of odor, H₂S, and NH₃ increases with increasing media moisture content from 17% to 75% at the EBRT of 4.1 s. It is worth mentioning that a previous study showed that increasing media moisture content cannot improve reduction efficiency of odor, H₂S and NH₃ for wood chip-based biofilters at a shorter EBRT of 1.6 s (Chen et al., 2009). These results together indicate that a higher media moisture content is not a substitute for inadequate EBRT and the reduction efficiency is more sensitive to media moisture content given a minimum EBRT.

Pressure drop is one of the main considerations for practical biofilter operation. It is commonly believed that the pressure drop through a full-scale biofilter media should be less than 50 Pa to allow existing ventilation fans to remain operational. In this research, the pressure drops at different levels of air flow rate are given in Table 2. No sharp changes in pressure drop occurred through WC and HW for each level of air flow rate during the test period. The pressure drop was less than 35 Pa at all the levels of EBRT for both WC and HW, which implies that the existing ventilation fans will not need to be replaced when the wood chip-based biofilter is installed and operated under these conditions. Also, the two-stage biofilter structure intuitively reduces media compaction compared to a one-stage biofilter even though no media compaction data were monitored in this study. However, comparing the pressure drop between one-stage and two-stage under same situations (see Table 2) indicated that the one-stage biofilter had more compaction than the two-stage biofilter resulting in a higher pressure drop for one-stage biofilters. The lower pressure drop from two-stage biofilter will reduce overall power consumption for operation and potential fan replacement costs.

<table>
<thead>
<tr>
<th>Air flow rate (L/min)</th>
<th>Media depth (cm)</th>
<th>EBRT (s)</th>
<th>Pressure drop for WC (Pa)</th>
<th>Pressure drop for HW (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1014</td>
<td>38</td>
<td>5.5</td>
<td>12.4/16.0*</td>
<td>7.4/12.0</td>
</tr>
<tr>
<td>1354</td>
<td>38</td>
<td>4.1</td>
<td>22.3/26.0</td>
<td>12.4/21.0</td>
</tr>
<tr>
<td>1512</td>
<td>38</td>
<td>3.7</td>
<td>24.8</td>
<td>14.9</td>
</tr>
<tr>
<td>1804</td>
<td>38</td>
<td>3.1</td>
<td>34.7</td>
<td>22.3</td>
</tr>
</tbody>
</table>

Note: *one-stage biofilter
A linear relationship between media unit pressure drop and unit airflow rate for both WC and HW was observed and is shown in figure 4. HW performed better than WC in terms of media unit pressure drop which was similar with the one-stage biofilter previously tested (Chen et al., 2009).

![Graph showing media unit pressure drop vs. unit airflow rate.](image)

**Figure 4. Media unit pressure drop vs. unit airflow rate. **Nicolai and Janni (2001a) predicted values.

Optimal pH for biofilter operation is in the 7-8 range (Williams and Miller, 1992). Sulfur- and nitrogen-containing compounds commonly exist in animal house exhaust air. As the filter entrap these compounds from the inlet air, it eventually leads to sulfuric acid (H₂SO₄) and nitric acid (HNO₃) buildup which can cause a drop in pH (Swanson and Loehr, 1997). Water leachate from the biofilter reactors was analyzed for pH and NH₃ concentration once a week for ten weeks. The leachate pH and NH₃ concentrations are shown in figures 5a and b, respectively.

![Graph showing pH and NH₃ concentrations in leachate.](image)

**Figure 5. (a) pH and (b) NH₃ in the leachate.**

The leachate pH from both WC and HW media were between 7.2 and 7.9 during the ten weeks of monitoring without any supplementary attempts to alter the pH. The NH₃ concentration of the leachate was between 198 and 1300 mg/L. The NH₃ concentration from the WC media was always higher than HW during the test period which can partly explain the higher NH₃ reduction efficiency of WC compared to HW.
CONCLUSIONS

The results of this study demonstrated that WC chips achieved average reduction efficiency of 51%, 83%, and 41% for odor, H₂S, and NH₃ (respectively) when keeping the WC media moisture content at 72% and EBRT between 3.7 and 5.5 s. The reduction efficiencies at three media moisture levels indicated that the biofilter was more sensitive to the media moisture content than EBRT. Therefore, maintaining proper moisture content is critical to the success of wood chip-based biofilters given an enough minimum EBRT. The leachate pH was found to be in the 7.2 to 7.9 range with the NH₃ concentration in the 198 to 1300 mg/l range. A linear relationship between media unit pressure drop and unit airflow rate for both WC and HW was observed. The water supply system tested in this study showed that this method was successful. The reduction efficiency and pressure drop characteristics obtained with the wood chip-based biofilters studied in this research indicate the feasibility of farm-level applications of wood chip-based biofilters for reducing swine building odors. Two-stage biofilters showed an advantage in reducing media compaction. However, more studies at full scale biofilters are needed.

REFERENCES


