Biofilter media mixture ratio of wood chips and compost treating swine odors

R.E. Nicolai and K.A. Janni
Research Fellow and Professor, Department of Biosystems and Agricultural Engineering,
University of Minnesota, St. Paul, MN, USA

Abstract Biofilter media mixtures were compared in 18 pilot-scale biofilters treating pit gases from a swine facility. The compost and wood chips mixtures ranged from 100% wood chips to a 50–50 blend in 10% increments. The effect of three media moisture contents (low, medium, and high) on biofilter performance was also evaluated. Odor and hydrogen sulfide reduction did not change significantly for mixtures with greater than 20% compost. For efficient odor, hydrogen sulfide, and ammonia reduction media moisture must be greater than 40% wb. Media moisture content influenced odor, hydrogen sulfide, and ammonia reduction more than the ratio of compost and wood chips. The count of heterotrophic or sulfur-oxidizing bacteria did not change in a discernable pattern with respect to media mixture or moisture content. As the amount of compost increased in the media mixtures, the pressure drop also increased. Based on this experiment, the recommended mixing ratio of compost to wood chips for biofilters on swine facilities is minimum 30% compost and 70% wood chips by weight.

Keywords Biofilter media; biofilters; odor; swine odors

Introduction
Biofilters are an effective air pollution control technology that uses micro-organisms to break down gaseous contaminants and produce innocuous end products. Its use as an odor reduction technique for livestock was investigated in Germany during the early 1980s (Zeisig, 1987). Recent research in the United States documents a growing interest in biofilters and their effectiveness as an odor control technology for livestock facilities (Li et al., 1996; Nicolai and Janni, 1997, 1998, 1999, 2000; Liberty and Taraba, 1999; Sun et al., 1999; von Bernuth et al., 1999; Zhang et al., 1999).

Biofilter media selection is critical in biofilter design and performance. The bacteria and fungi living on the media oxidize volatile organic compounds (VOCs) and oxidizable inorganic gases and vapors. The by-products of microbial oxidation are primarily water, carbon dioxide, mineral salts, some VOCs, and microbial biomass. This reliance on micro-organisms requires consideration of ecological concepts in biofilter design of the media. Environmental and nutritional requirements for microbial growth i.e. moisture, temperature, and nutrients, must be considered in both selection and management of the media. The media must also have a high porosity for minimizing pressure drop across the biofilter, good moisture holding capacity, and a sufficiently long useful life.

Construction costs are a major consideration when adapting biofilters to livestock facilities. To reduce costs, media materials should be locally available. Mixtures of wood chips and compost have been widely used since they are generally locally available and of low cost (Zeisig and Munchen, 1987; Nicolai and Janni, 1998; von Bernuth et al., 1999). Nicolai (1998) recommended a 50:50 by weight ratio of compost and wood chips for biofilters installed on livestock facilities. The compost provides a source of micro-organism and micro-nutrients while the wood chips improve porosity, thus reducing pressure drop. Pressure drop could be reduced further by increasing the porosity by adding more wood chips and less compost. But with less compost being used, the source of micro-organism
and nutrients is also reduced which may affect start-up and on-going biofilter performance. The purpose of this project was to determine the effect of compost and wood chip mixtures, i.e., 50:50, 40:60, 30:70, 20:80, 10:90, and 0:100 by weight, and media moisture content, i.e. low, medium, and high, on odor, hydrogen sulfide, and ammonia reduction, pressure drop, and bacteria count.

Materials and methods

A six by three factorial experimental design was used to compare six compost and wood chips ratios, from 0:100 to a 50:50 compost:wood chip ratio in 10% increments. Three media moisture levels analyzed were low (10 – 35% wb), medium (35 – 55% wb), and high (55 – 65% wb). Figure 1 shows the layout for the 18 biofilter cells. Each cell was 0.6 m square and the media was 0.30 m deep. The biofilters treated odorous air from the head space of a collection pit that received manure from a pull plug swine gestation/farrowing/nursery facility. Each cell was equipped with an air blower, that was adjusted to provide 81.5 m³/hr airflow. Design empty bed contact time (EBCT) for each cell was 5 s. Actual airflow through each cell, measured with a Airflow model LCA-6000 VA anemometer, averaged 84.4 m³/hr, and standard deviation of 14.1 m³/hr. Airflow variation was probably caused by rust accumulation on motor shafts and dust on blowers. Inlet air was humidified with a high pressure water nozzle system to 90–100% RH. The six medium and the six high moisture cells were irrigated two and four times daily, respectively.

Media compost came from a municipal yard waste composting site. The wood chips were from chipped brush processed through a 7.6 cm square screen in the chipper and fines removed by a 1.3 cm screen. The particle size distribution was determined by passing a media sample through a stack of sieves arranged in decreasing mesh size. The mass medium diameter for each mixture from 50% compost to no compost was 0.484, 0.495, 0.496, 0.557, 0.623, and 0.715, respectively.

The biofilters were operated three months from 8 June, 2000 to 19 September, 2000. After a 30 day initial start-up, air samples were taken five times and analyzed for odor, hydrogen sulfide, and ammonia reduction. Air samples entering and exiting the biofilters were analyzed using a dynamic olfactometer to determine odor detection threshold (Nicolai et al., 1997). Hydrogen sulfide gas concentrations were measured with a
Ammonia gas concentrations were measured by bubbling through boric acid and titrated (Xue et al., 1998). Pressure drop was measured with a manometer. Moisture samples, airflow through each cell, hydrogen sulfide, and pressure drop across each media cell were taken weekly. Average moisture content for the low, medium, and high moisture grouped cells was 27.6%, 47.4%, and 54.7%, respectively (Table 1).

At the end of the experiment, 9 of the 18 biofilter cells were evaluated for bacteria population. Samples were taken from the 0%, 20% and 50% compost mixtures at all three moisture levels. Approximately 11 g of material was placed in a dilution bottle containing 99 ml of sterile 0.1% sodium pyrophosphate, pH 7.0 plus one drop of Tween 80, yielding an initial 1:10 dilution of the samples. After agitating vigorously, ten-fold serial dilutions were made in 9 ml sterile 0.1% sodium pyrophosphate, pH 7.0 and inoculated onto growth media. The two growth media used were plate count agar (PCA), which is non-selective for the enumeration of heterotrophic bacteria, and S6 broth, which is used for cultivating sulfur-oxidizing bacteria. After three weeks of growth, each tube was tested for acid production. The most probable numbers were calculated by comparing the pattern of positive tubes with a standard five-tube MPN table and adjusting for actual wet weight of material per tube (Atlas, 1997). Bacteria counts were converted to a dry matter basis.

**Results and discussion**

**Odor reduction**

Media moisture content was critical for adequate odor reduction and it influenced odor reduction more than the media mixture ratio. Odor reduction increased for all media mixtures as the moisture content increased. Average odor reduction for the low, medium, and high moisture contents were 42.3%, 69.1%, and 78.8%, respectively.

Table 2 shows the average odor reduction for the six different media mixtures of compost and wood chips averaged for medium and high moisture levels. The low moisture group values were not included since the average moisture was below the recommend operating range of 40% to 65% (Nicolai, 1998). Odor reduction improved as the percentage of compost in the mixture increased to 20% for the medium and high moisture levels. For all higher levels of compost in the mixture, odor reduction did not change. Since human odor sensation is on a log scale (Fechner, 1860), a reduction of more than 70% is needed before a significant reduction is expected to be observed by neighbors. Thus, a 20% to 30% compost mixture is the minimum that should be used to treat exhaust air from swine facilities with moist biofilters.

---

### Table 1 Media moisture content

<table>
<thead>
<tr>
<th>Percent compost in media</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low moisture group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>31.4%</td>
<td>21.7%</td>
<td>21.2%</td>
<td>24.4%</td>
<td>31.2%</td>
<td>35.8%</td>
</tr>
<tr>
<td>Max/min</td>
<td>41/13%</td>
<td>44/8%</td>
<td>48/6%</td>
<td>49/6%</td>
<td>53/8%</td>
<td>50/9%</td>
</tr>
<tr>
<td>Medium moisture group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>42.6%</td>
<td>38.4%</td>
<td>44.4%</td>
<td>47.9%</td>
<td>55.1%</td>
<td>54.0%</td>
</tr>
<tr>
<td>Max/min</td>
<td>59/20%</td>
<td>51/40%</td>
<td>61/22%</td>
<td>61/43%</td>
<td>58/42%</td>
<td>63/45%</td>
</tr>
<tr>
<td>High moisture group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>50.2%</td>
<td>56.5%</td>
<td>57.5%</td>
<td>54.3%</td>
<td>56.2%</td>
<td>53.8%</td>
</tr>
<tr>
<td>Max/min</td>
<td>65/36%</td>
<td>67/42%</td>
<td>64/47%</td>
<td>62/43%</td>
<td>63/42%</td>
<td>58/48%</td>
</tr>
</tbody>
</table>

### Table 2 Odor reduction of the six compost: wood chip media mixtures at medium and high moisture

<table>
<thead>
<tr>
<th>Percent compost in media</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average percent</td>
<td>67.5%</td>
<td>67.2%</td>
<td>84.3%</td>
<td>82.6%</td>
<td>81.6%</td>
<td>83.2%</td>
</tr>
<tr>
<td>Maximum</td>
<td>97.5%</td>
<td>93.3%</td>
<td>97.2%</td>
<td>95.8%</td>
<td>94.2%</td>
<td>95.9%</td>
</tr>
<tr>
<td>Minimum</td>
<td>−70.4%</td>
<td>−48.4%</td>
<td>−51.3%</td>
<td>−1.2%</td>
<td>43.0%</td>
<td>47.4%</td>
</tr>
<tr>
<td>Number of samples</td>
<td>20</td>
<td>20</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
</tbody>
</table>
Figure 2 shows the elimination capacity (reduced odor in OU per m$^3$ biofilter media per second) was influenced by the volumetric mass loading rate (odor load in OU per m$^3$ biofilter media per second). Since the airflow did fluctuate during the experiment, the elimination capacity allows for direct comparison of the results of two systems because it normalizes airflow and is a function of input concentrations (Devinny et al., 1999). The negative elimination capacity at the low volumetric mass loading rates may be explained by the media odor being a stronger than the source odor. The trend line for the 30%, 40%, or 50% compost media has a higher gradient than the 0% or 10% compost media.

Hydrogen sulfide

Hydrogen sulfide reduction results (Figure 3) at the high and medium moisture contents were similar for all media mixtures. The low moisture content biofilters had little hydrogen sulfide removal. Average hydrogen sulfide reduction for the low, medium, and high
moisture contents were 3%, 72%, and 87%, respectively. The error bars indicate one standard deviation. Data variation decreased as the moisture increased. The results indicate moisture is a critical factor in biofilter performance.

Media mixtures above 20% compost showed no significant difference (\( \alpha = 0.05 \)) at the high moisture level for hydrogen sulfide removal (91%, 90%, 95% and 91%, respectively). For medium moisture content the removal rates were lower than the high moisture (73%, 72%, 76% and 79%, respectively) but also no significant difference. At the 10% and no compost media mixtures, the data had a wider variation than at the higher percentage of compost in the mixture. A 20% to 30% compost mixture is the minimum that should be used to treat exhaust air from swine buildings for adequate hydrogen sulfide reduction.

Ammonia reduction
Percentage ammonia reduction is shown in Figure 4. The results indicate that ammonia reduction increased as the compost to wood chip ratio increased. Thirty percent by weight compost is recommended. Average ammonia reduction for the low, medium, and high moisture contents were 6%, 49%, and 81%, respectively. Media moisture content is critical for biofilters used to reduce ammonia emissions from swine facilities. More research is needed to determine the cause of the negative ammonia reduction at low moisture contents. Martinec et al. (2000) also reported negative ammonia reduction of –22% with a pellet plus bark media mixture.

Pressure drop
Figure 5 is a plot of the biofilter media pressure drop versus percentage compost for the low and high moisture content biofilters. The results indicate that the pressure drop increased as percentage compost increased. This was expected because the small compost particles would tend to reduce porosity and increase pressure drop. At low compost to wood chip ratios, moisture had an effect on the pressure drop. But as the compost: wood chip ratio approached one, i.e. 50% compost, moisture had less effect on pressure drop. As media pressure drop increases the ventilating fan energy input required increases. For low cost biofilters, the pressure drop should be kept to a minimum.
Bacteria count
Table 3 shows the bacteria count for 0%, 20%, and 50% compost in the media. The data did not indicate a pattern in either heterotrophic or sulfur-oxidizing bacteria population as a function of percentage compost or media moisture content. The heterotrophic bacteria count using the PCA growth media showed very little difference between the low, medium and high moisture contents across the media mixtures. The sulfur-oxidizing bacteria populations varied widely but did not follow a discernable pattern. More research is needed since there was not enough data for a statistical analysis.

Conclusions
An 18 cell pilot scale biofilter system was used to evaluate the performance of varying the media mixing ratio of compost and wood chips. Media moisture content influenced odor, hydrogen sulfide, and ammonia reduction more than changing the mixing ratio of compost and wood chips. For efficient odor, hydrogen sulfide, and ammonia reduction 35% to 65% media moisture must be maintained.

Percentage odor reduction increased as compost was added to the media up to 20%, but did not change for mixtures greater than 20% compost. The elimination capacity was mainly influenced by the level of odor concentration in the waste air, although for media with greater than 30% compost the rate of change was slightly improved.

At medium and high media moisture content, hydrogen sulfide reduction did not change as the percentage compost in the media was increased above 20%. The data variation did decrease as the moisture content was increased. Thus, a 20% to 30% compost mixture is the...
minimum that should be use to treat exhaust air from swine buildings for adequate hydrogen sulfide reduction.

Ammonia reduction did increase as more compost was included in the media mixture. The rate of increase was less for high moisture mixtures. Pressure drop across the biofilter media increased as more compost was included in the media mixture. The bacteria count did not indicate any pattern for changes in media mixture ratio or moisture content.

Based on this experiment, the recommended mixing ratio of compost to wood chips for biofilters on swine facilities is a minimum 30% compost and 70% wood chips by weight.

References


