Odor from livestock facilities is a major issue in the United States. Odor sources for livestock production systems include buildings, manure storage, and land application of manure. Biofilters are an effective technology for reducing odors. The adaptation of this technology to the livestock industry was demonstrated by the construction and monitoring a full size open face biofilter on a 700 sow gestation/farrowing swine facility. Average odor and hydrogen sulfide reductions of 82% were measured over a 10 month period. This paper outlines design, construction, costs, and removal efficiency of the open face biofilter. The amortized construction and operating cost for three years is $0.22 per piglet produced.

Keywords: biofilter, swine, odor, odor reduction.

Odors from livestock facilities are an issue for many communities and livestock producers. Odor sources for livestock production systems include buildings, manure storage, and land application of manure. Most complaints have focused on emissions from uncovered outside manure storages. Therefore the current trend in swine production is to use deep pit manure storage beneath a slatted floor. In this situation the livestock building becomes a major odor source. Biofiltration is an odor reduction technique that can be adapted to reduce emissions from these mechanically ventilated facilities (Nicolai et al., 1997).

Biofiltration is an air pollution control technology adapted from naturally occurring soil processes that use microorganisms to oxidize volatile organic compounds (VOCS) and oxidizable inorganic gases and vapors contained in the air (Janni et al., 1996). Biofiltration is an effective and efficient means for removing low concentrations of biodegradable compounds from air. For these reasons, industrial applications have gained acceptance and are increasing in numbers over the past 15 years. Biofilter use as an odor reduction technique for livestock was investigated in Germany during the early 1980's (Zeisig, 1988). The results of these studies indicated that biofilters, although effective in their performance, were not economical in the livestock industry (Barrington et al., 1995 and Perason, 1990).

To determine the biofilter feasibility and operating parameters, a 6.4 m by 6.4 m surface area by 0.3 m deep (21 ft x 21 ft x 11 in) experimental low cost biofilter was built using compost and kidney bean straw as media. The biofilter treated exhaust ventilation air from a continuous operating pit fan on a farrowing barn. Nicolai et al. (1997) reported 78% odor, 86% hydrogen sulfide removal.
sulfide, and 50% ammonia reduction through the biofilter with 35 to 47 pa (.14 to .19 in. H₂O) pressure drop across the media.

Based on these results, a experimental biofilter, a full-scale biofilter was built on a 700 sow gestation/farrowing building. Both minimum and maximum air flow rates are treated through the biofilter. This paper reports on the design, construction, operation, cost, and effectiveness of the full-scale biofilter based on the experimental design.

**MATERIALS AND METHODS**

**Design**

The site and building layout (Fig. 1) required three biofilters, i.e. two on the gestation barn and one on the farrowing barn. The manure handling system consists of a pull plug in each farrowing which discharges to a deep pit beneath the gestation barn slatted floor. Since manure is removed from the farrowing rooms every 2.5 weeks there is less odor emission.

The biofilter size is based upon an average residence time of 5 s (Zeisig, 1987). Residence time or empty bed contact time (EBCT) was determined by dividing the volume of the empty (unpacked) biofilter bed by the air flow rate. Ventilation rates for livestock facilities vary through out the year. The air exchange rate is minimal during the cooler winter months, moderate during fall and spring, and reaches a maximum during the hot summer months. Thus, residence time is variable during the year, beginning at 18 s for minimum ventilation and decreasing to less then 3 s for maximum ventilation. The time spent at the maximum rate is small and thus a compromise was made. Table 1 summarizes the design data for each biofilter at the three ventilation rates for winter (minimum), spring/fall (mild), and summer (maximum).

<table>
<thead>
<tr>
<th>Biofilter</th>
<th>South Gestation</th>
<th>West Gestation</th>
<th>Farrowing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Mild</td>
<td>Max</td>
</tr>
<tr>
<td>Number of Fans</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Flow per fan (m³/min)</td>
<td>112</td>
<td>140</td>
<td>538</td>
</tr>
<tr>
<td>Total Air Flow (m³/min)</td>
<td>337</td>
<td>759</td>
<td>2373</td>
</tr>
<tr>
<td>Biofilter Volume (m³)</td>
<td>98</td>
<td>33</td>
<td>58</td>
</tr>
<tr>
<td>Residence Time (s)</td>
<td>17.5</td>
<td>7.8</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 1. Biofilter design data

Biofilters with the same media volume but various dimensions (width, length, and thickness) will have similar odor reduction capabilities. Thus, the dimensions chosen were based on the available area and allowable pressure drop through the biofilter. Agricultural ventilation fans are
typically designed not to operate against static pressures exceeding 62Pa (0.25 in H₂O). Data from unpublished laboratory tests were used to plot the relationship between unit pressure drop per meter of media depth and unit air flow rate (m³/min-m² of surface area) for a 50-50 by weight mixture of compost and wood chips. Test were conducted on loose fill (not packet) and packed media. The loose fill and packed media relations are shown in Figure 5. This figure was used to set the bed thickness. A thickness of 28 cm (11 in) was selected with an expected pressure drop of 50Pa (0.2 in H₂O).

**Construction**

The open bed biofilter built was a modification of a design outlined by Zeisig et al. (1982). Figure 2 illustrates the construction and operation mode of the biofilter. The minimum and mild weather ventilating air is exhausted from the building through the manure storage pit beneath the floor. Fans located on pit extensions outside the building move the air through a plywood duct to an air plenum beneath the biofilter media. Summer ventilation fans located in the barn wall exhaust air through a duct to the same plenum. Shutters on the fans prevent air recirculation when only some fans are operating.

Shipping pallets covered with a plastic net were used as the support structure for the media and to create a plenum for the exhaust air to reach all areas of the biofilter. The first row of pallets adjacent to the barn was raised 15.2 cm (6 in.) to allow for air distribution parallel to the barn before entering the pallets which were aligned perpendicular to the barn. The plastic netting with 1.27 cm by 1.27 cm (0.5 by 0.5 in.) grid was placed over the pallets to prevent the media from dropping through the pallet openings and plugging the air plenum.

![Figure 2. Biofilter construction and operation.](image-url)
The biofilter media used was a mixture of 50% yard waste compost and 50% brush chips by weight. This mixture was locally available and relatively inexpensive. The biofilter was built by preparing a mixture of media in a "total mixed ration" (TMR) mixer and placing it on one row of pallets. This type of portable mixer is used in the cattle and dairy industry to mix and deliver feed through a side discharge. After the media was mixed the TMR mixer was driven past a row of pallets and placed over the pallets and netting. After one row is complete another row of pallets was laid down and covered with netting and media. This procedure was repeated for all six rows of pallets. An additional pass with the mixer was made to cover the end of the last pallet row.

The biofilter was put into operation in November, 1997. No moisture was added to the biofilter during the winter months in Minnesota since cool temperatures, lower airflow rates, moisture from the livestock, and normal precipitation prevent excessive media drying. A surface irrigation system was added at the end of May. With an early spring in Minnesota in 1998, the biofilter media became dry before the irrigation system was installed.

**Sampling Procedures**

The first air samples were taken seven weeks after hogs were placed into the newly constructed barn. After the initial samples were taken, air samples were collected every 5 to 8 weeks. Two samples (air entering and exhausting the biofilter) were taken from each of the three biofilters. Exhaust air samples were collected through a 5 cm exhaust port in the center of a one meter square hood placed on top of the biofilter media. Inlet air samples were collected by placing the sampling hose in the plenum beneath the media near the air duct.

The air samples were analyzed for odor threshold, hydrogen sulfide, and ammonia concentration. Odor threshold level was determined using an odor panel and a triangular forced choice olfactometer (Nicolai et al., 1997). Hydrogen sulfide was measured with a Jerome™ meter. Ammonia concentration was measured using colorimetric gas detector tubes.

Pressure differentials across the fans and media were measured using a manometer.

**RESULTS**

Average odor reduction was 82% from the three biofilters over the first 10 months of operation. Fig. 3 is a line graph of the odor detection thresholds obtained from the inlet and exhaust air for all biofilters during the 10 month sampling period. Odor threshold is expressed in odor units which is the lowest volumetric ratio of the total sample (odorous plus odor-free air) over the odorous sample at detection.

Since the biofilter was placed on a new facility, building air odor levels increased during the first three months. This odor emission increase was expected as manure accumulated in the pit and microbial action increased. Limited manure storage time means less time for microorganisms to produce odorous gases.

Odor removal efficiency increased over the same time period as the biofilter microorganisms, which oxidize the odorous compounds, multiplied and adapted to their new environment. Even though the inlet odor threshold increased during the sampling period, the exhaust odor threshold remained constant.

Building air odor levels decreased during the summer months as air flow rate increased. Moisture content of the media affected the odor removal efficiency during the summer months.
The surface irrigation system was not in place for the early spring which resulted in media drying and lower odor removal efficiency.

Figure 3. Biofilter odor reduction.

Figure 4. Hydrogen sulfide reduction.
The farrowing barn odor threshold was less than the odor from the gestation deep pit. The pull plug manure removal system used in the farrowing part of the barn results in less manure being stored. Also more wash water from cleaning the farrowing rooms dilute this manure.

The biofilter exhaust air, after being treated by the biofilter, has a earthy or peat-like character rather than swine odor character.

Hydrogen sulfide concentration (Fig. 4) showed similar results. The average H$_2$S reduction of all the biofilters for the ten month sampling period was 80%. The data indicated a conditioning period existed in the biofilters as the microorganisms adapted to a new environment and improved removal efficiency.

Average ammonia reduction was 53% during the ten month sampling period. Ammonia removal was reduced to nothing during the spring period when the biofilter media dried out and before surface irrigation was installed.

![Figure 5](image)

Fig. 5 shows the unit pressure drop in pascals through the south and west gestation barn biofilters for various ventilation air flow rates in cubic meters per minute. Different air flow rates were achieved by operating one minimum fan and then adding mild weather and summer ventilation fans one at a time. The packed and unpacked lines were predicted values based upon lab studies.

Total pressure drop across the ventilation fans reached a maximum of 101 Pa (0.41 in. H$_2$O) of which 49 Pa (0.20 in. H$_2$O) is attributed to the ventilation inlet system in the building. Table 2 summarizes the costs to add the three biofilters to this 700 sow farrow/gestation facility. These costs include increasing the fan power requirements to handle the added pressure drop through the biofilter, air ducts, media support structure, and a sprinkler system to add moisture to the biofilter. Transportation and mixing are included in the biofilter media costs. Amortized cost of $0.22 per piglet was based on three year life and a production of 20 pigs per sow per year (i.e. 42,000 piglets). Although three years was used for amortization, parts of the system, such as the fans, ducts, and support structure, would be expected to last longer. Thus,
the amortized cost could be reduced. Based on a total air flow of 15,000 cfm, the amortized cost is $0.062 per cfm of treated ventilation air.

Table 2 Biofilter construction costs

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Total Costs</th>
<th>Cost per piglet</th>
<th>Cost per cfm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased fan power for higher pressure</td>
<td>$1,000</td>
<td>$0.024</td>
<td>$0.007</td>
</tr>
<tr>
<td>Air ducts from fans to biofilter</td>
<td>$3,400</td>
<td>$0.081</td>
<td>$0.023</td>
</tr>
<tr>
<td>Structural support for biofilter media</td>
<td>$1,325</td>
<td>$0.032</td>
<td>$0.009</td>
</tr>
<tr>
<td>Biofilter media</td>
<td>$2,975</td>
<td>$0.071</td>
<td>$0.020</td>
</tr>
<tr>
<td>Sprinkler system for wetting biofilter</td>
<td>$525</td>
<td>$0.013</td>
<td>$0.004</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$9,225</strong></td>
<td><strong>$0.220</strong></td>
<td><strong>$0.062</strong></td>
</tr>
</tbody>
</table>

Operating costs have been $275 per year for rodent control. During the winter months the warm media provides a good nesting environment for rodents. A good rodent control program is required. During the summer months additional operating cost of $125 per year includes sprinkling and operating the higher power ventilation fans.

SUMMARY AND CONCLUSIONS

This project demonstrates that biofilters can be developed for full scale mechanically ventilated production swine units with manure pits. Removal of 82% of the odor and 80% of the hydrogen sulfide were comparable to expected results from other biofilter studies (Nicolai et al., 1997). Odor reduction efficiency was mainly influenced by the odor concentration before the filter bed, since the treated air odor concentration after the biofilter remained constant.

Personal communication with pork producers in Minnesota and Iowa have indicated they are willing to spend up to $1.00 per pig marketed for odor control technology if the pork industry is profitable. The amortized biofilter construction cost of $0.22 per piglet at this demonstration site is only for the farrowing through weaning part of the pigs life; which leaves $0.78 available for constructing and operating odor control technology for the nursery and finishing phases.

REFERENCES


