RESEARCHREPORT

ENVIRONMENT

**TITLE:** DESIGN SPECIFICATION FOR A VERTICAL BED BIOFILTER - **NPB #04-039**

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**ABSTRACT:** Biofilters have been demonstrated to be an effective technology in reducing odor and gas emissions from these facilities. Large horizontal biofilter media beds sometimes prevent application of this technology to building layouts. A vertical biofilter bed may be an effective alternative. The objective of this research was to determine optimum vertical bed biofilter construction configuration to achieve uniform airflow that would compensate for media settling. Media thickness was determined to be a factor in achieving uniform airflow. For biofilters of 12 inches and 24 inches thick, a 9.6 degree wall construction produced the least airflow variation at the end of one year as compared to a wall slope of 0 degrees and 4.8 degrees. Improved media moisture distribution was achieved when the water soaker hose was placed on top of the media versus being suspended vertically through the media. The value of this research leads to a more efficient vertical biofilter design configuration.

## Introduction

Odor and airborne contaminant emissions have always been a part of the livestock and poultry industry (NRC, 2003). In the past, however, sparse human population and livestock spread out over a large land area had made odor less of an issue. Now, with the advent of farms containing large numbers of animals confined to smaller area; the odor and contaminants are becoming concentrated. Additionally many areas formerly zoned for agriculture are being inhabited by more non-farm rural residents. This trend results in odor issues for livestock producers that in the past were minor or even a non issue.

Solutions are needed to reduce the nuisance value of these odors. One of the more recent practices to reduce odor emissions is the use of biofilters. Biofilters are an air pollution control technology that uses microorganisms to breakdown gaseous contaminants and produce innocuous end products. They are effective in reducing odor and hydrogen sulfide emissions from livestock facilities (Nicolai and Janni, 2000). Biofilters use a porous solid medium to support microorganisms and allow access to the contaminants in the airflow. Media may consist of peat, soil, compost, wood chips, straw, or a combination of two or more. A proven mixture for animal agriculture biofilters ranges from approximately 20:80 to 40:60 ratio by weight of compost and wood chips or wood shreds (Nicolai and Janni, 2001).

Horizontal biofilters have been demonstrated to reduce odors from swine barns (Nicolai and Janni, 2000). But in some situations especially in retrofitting existing barns, there is not enough area to construct a large horizontal biofilter. Vertical biofilters offer an advantage over horizontal biofilters because they utilize less surface area. The media in a vertical biofilter is placed vertical between two support structures with the inlet air plenum on one side and the other side exposed to the atmosphere allowing the air to pass through horizontally (Figures 1 and 2).

One major disadvantages of vertical biofilters is that the media tends to settle over time (Garlinski and Mann, 2004). Media settling causes compaction at the base of the filter, reducing air flow through the bottom portion of the filter and increasing air flow through the top portion of the filter. Therefore the empty bed contact time (EBCT) increases at the base of the filter while decreasing it at the top of the filter. This leads to poorly treated air exiting at the top of the filter. A solution to overcome variable airflow through the biofilter is to taper one biofilter side, i.e. the width decreases from top to the bottom.

## OBJECTIVES

The overall objective is to develop a biofiltration design strategy for vertical biofilters by measuring air flow differences from top to bottom at the outlet of the vertical biofilter for six different cell configurations. Specific objectives of this research project are to:

1) Compare two media thickness (12" and 24") and three side wall configurations by tapering the vertical bed side wall at three angles (0°, 4.8°, and 9.5°),

2). Monitor pressure drop through the biofilter, media moisture, media compaction, and emissions of hydrogen sulfide and odor from a swine barn and compare these emissions before and after biofiltration and,

3). Determine vertical bed biofilter performance during both hot summer and cold winter weather conditions.

### Materials and Methods

#### Biofilter Design

To understand airflow characteristics in a vertical biofilter, a circular vertical biofilter was constructed and placed to receive pit exhaust air from a swine building in South Dakota. The biofilter (Figure 1) was constructed with six vertical wall biofilters in a circular design to meet the specifications of the research project .

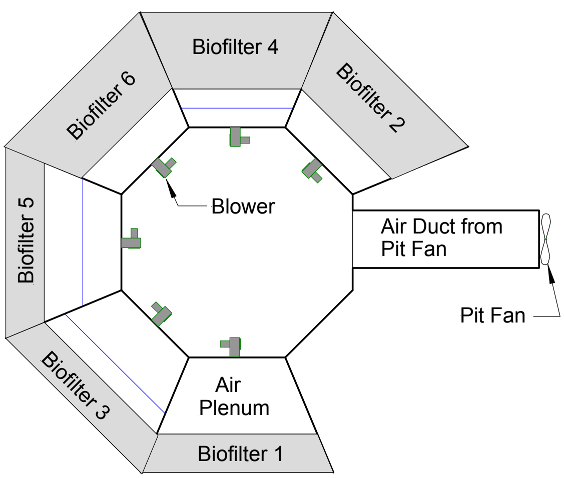


**Figure 1. Top View and picture of experimental biofilters.**

The minimum inlet air surface for each biofilter was 36 inches wide x 60 inches high. The cross-sectional design of each biofilter was:

1. Parallel inlet and outlet walls 12 in. thick (0° taper).
2. Parallel inlet and outlet walls 24 in. thick (0° taper).
3. Taper inlet and outlet walls 12 in. at the bottom and 18 in. at the top (4.8° taper).
4. Taper inlet and outlet walls 24 in. at the bottom and 30 in. at the top (4.8° taper).
5. Taper inlet and outlet walls 12 in. at the bottom and 24 in. at the top (9.5° taper).
6. Taper inlet and outlet walls 24 in. at the bottom and 36 in. at the top (9.5° taper).

This biofilter was placed on a swine finishing barn near Brookings, SD using the pit exhaust fan as the air source for the biofilter. The biofilter operated continuously for one year to allow comparison of biofilter performance during the cold winter and hot summer months as well as to allow for media settling.

Each biofilter had its own fan which was set to deliver 5 seconds EBCT airflow calculated using the base biofilter dimension. Biofilter media consisted of a 30:70 mixture of compost and wood chips. Moisture was applied with three vertical suspended drip hoses in each biofilter cell. After 1.5 months of poor moisture distribution this system was removed and a drip hose system was placed on the top of the biofilter (Figures 3 and 4). Water was only applied during the spring, summer and fall months. During winter months, water was turned off to prevent freezing.

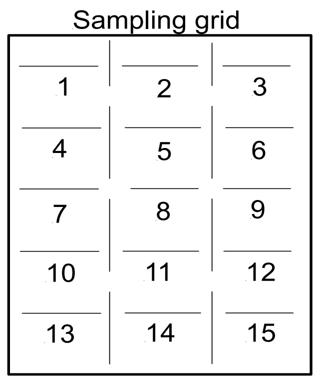


**Figure 2. Sampling locations.**

To evaluate the airflow passing through the media bed, a grid of 15 sampling locations on the biofilter outlet wall was used (Figure 2). An air collection apparatus was used to concentrate the treated air from each grid and an anemometer measured the air flow. At each sample grid location, airflow was measured every 15 seconds for 15 minutes then the averaged. The three samples taken on each grid row were also averaged to give a profile of vertical airflow rates.

Pressure drop across each biofilter was recorded biweekly. Media moisture was monitored with a Water Mark sensor and recorded with a Spectrum 200 Watch Dog data logger. The sensor was positioned in the biofilter center approximately 18 inches below the top media surface. The moisture profile was determined with a Delmhorst hay bale moisture tester.

Odor samples were collected every nine weeks in 10-L tedlar bags. Samples were analyzed at the University of Minnesota Olfactometry Laboratory within 24 hours of collection. Two odor samples were collected from the common air inlet before biofilter treatment and one sample collected from each of the six biofilters. Therefore, a total of eight odor samples were collected and analyzed for each measurement period, resulting in a total of 64 odor samples for this research project. Each sample bag was evaluated for hydrogen sulfide to determine biofilter removal efficiency and emissions.

## Results and Discussion

After two months of operation each biofilter had settled between 12 and 18 inches. Additional compost and woodchip media mixture was then added to bring each biofilter cell back to its original height. After this period less settling was observed in the biofilter, especially during the winter months. After 10 months, the biofilter media settled an additional six inches.

### Airflow

A research objectives was to determine which biofilter configuration would have the least airflow variation across the biofilter face from bottom to top. The lowest standard deviation of the air velocity values from the various vertical grid locations on the biofilter face was used to determine which biofilter configuration had the most uniform airflow. The least standard deviation indicates a more uniform airflow. Table 1 shows the standard deviation of the airflow variation as analyzed from top to bottom through the six biofilters. Data values listed in the table are based on the third and last (fourth) quarter of operation thereby accounting for settling.

A 9.6 degree taper had the lowest standard deviation for both the 12 and 24 inch thick bases (standard deviation of .16 ft/min for the 24 inch thick configuration and a standard deviation of .39 ft/min for the 12 inch thick configuration. Therefore, these two filters had the most uniform airflow in their respective thickness categories. It should also be noted that the 0.0 degree slope gave a .39 standard deviation at 12 inches, tying the 9.6 degree filter during the last quarter of operation. This was not true during the third quarter of operation, and can probably be explained by an unequal moisture distribution observed during the fourth quarter as compared with the third quarter. The third quarter moisture was maintained by humidity from the hog barn exhaust only, keeping all filters at the same moisture content. The fourth quarter was characterized by periodic rainfall and less humid air being exhausted from the hog barn, leading to an unequal moisture distribution between the filters.

**Table 1: Airflow standard deviation through six differently configured biofilters in the last two quarters of operation.**

| Slope | Thickness | Standard Deviation Third Quarter | Standard Deviation Fourth Quarter |
|---|---|---|---|
| 0 | 12 in | 0.37 | 0.39 |
| | 24 in | 0.22 | 0.64 |
| 4.6 | 12 in | 0.34 | 0.57 |
| | 24 in | 0.22 | 0.4 |
| 9.6 | 12 in | 0.17 | 0.39 |
| | 24 in | 0.08 | 0.16 |

Media moisture

Media moisture at the start of the research was maintained by adding water through soaker hoses placed vertically through the media (Figure 3). There were three hoses per biofilter cell. Immediately after placing the biofilter in operation excess moisture was leaching from the bottom of the biofilter while the top ⅓ to ⅔ of the media was dry. The wicking action of the soaker hose was greater than the water flow rate thus all the water was seeping out the lower part of the hose. Figure 3 shows a profile of the moisture distribution obtained with the hay bale moisture probe.

After one month operation the soaker hose was placed on the top surface of the biofilter media. The redistribution of the moisture profile after the hose location change is shown in Figure 4. It should be noted that the biofilter was wetted using the soaker hose only until November 15, or for the first four and a half months of operation. The water was not turned back on again in the spring until the end of May because of large amounts of rainfall in the spring.

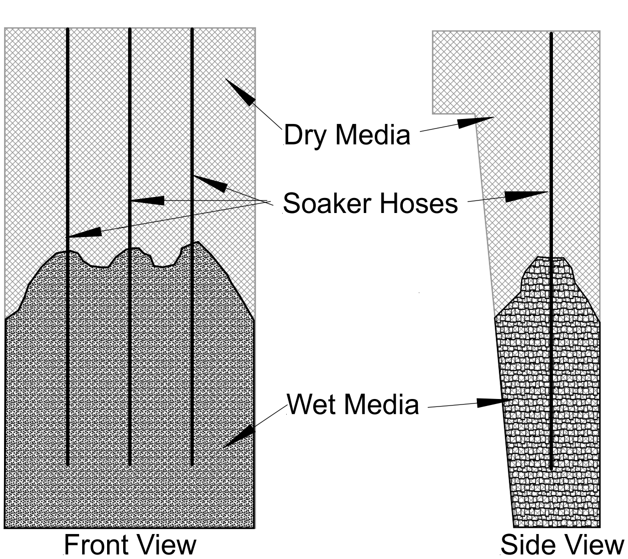


**Figure 3. Moisture profile with vertical soaker hoses.**

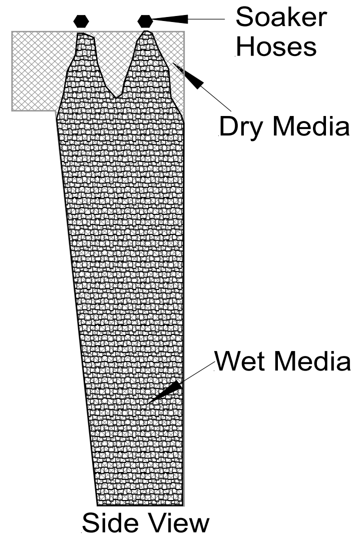


**Figure 4. Moisture profile with soaker hose on biofilter top.**

Pressure, Odor, and Hydrogen Sulfide Emissions

Pressure drop was found to increase as the temperature decreased. Figure 5 shows the pressure drop measured at different temperatures throughout the year for the filter having a 9.6 degree slope and a 24 in thick base. Pressure drop ranged from 0.07 to 0.31 inches of water and the temperature ranged from 20 to 80° F. For a two week period of low media temperature (January) the barn was empty of pigs resulting in lower humidity in the barn exhaust air.

Moisture content of the media may explain the relationship between temperature and pressure drop through the biofilter, since wetter media has been shown to have a higher pressure drop. The filter media may have had a higher in moisture content during the winter as indicated by the humidity in the pit exhaust air. However, moisture content was not measured directly throughout the year, and therefore more research needs to be done.

Odor and hydrogen sulfide were reduced an average of 65% and 70% respectively for all biofilter cells. The three 24 in base cells had a greater reduction than the 12 in thick biofilters for odor and hydrogen sulfide (Table 2).

**Table 2. Odor and Hydrogen Sulfide Reduction for 12 and 24 in thickness cells.**

| | All Cells | 24 in thick base cells | 12 in thick base cells |
|---|---|---|---|
| Odor Reduction | 65 % | 70 % | 60 % |
| Hydrogen Sulfide Reduction | 70 % | 75 % | 65 % |

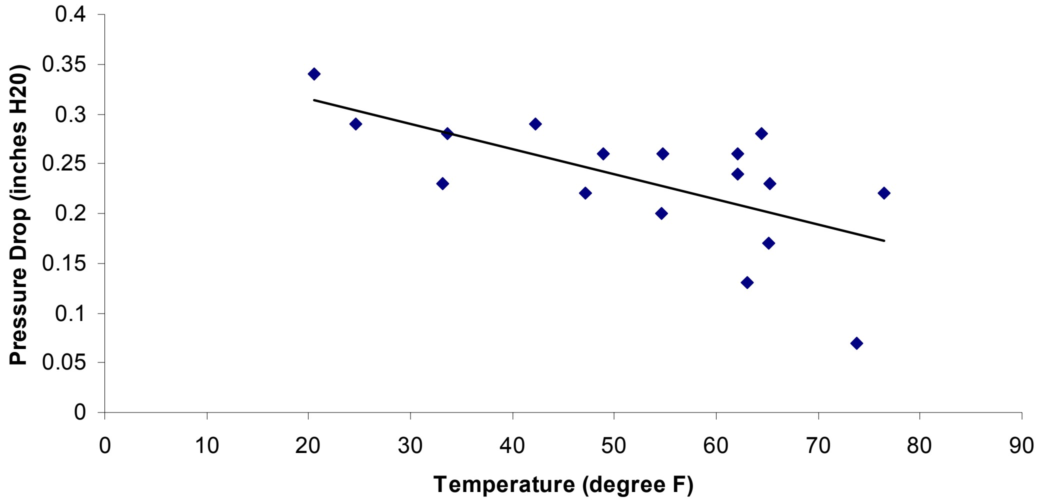


**Figure 5: Pressure Drop Measured vs. Average Daily Temperature for the day it was measured.**

Cold Weather Results

During extreme cold weather during the winter months, freezing occurred in the biofilter media causing air channeling and an uneven flow across the vertical face of the filter. Table 3 shows average filter media temperatures for the six cells for January 14, 2005 and five days later on January 19, 2005. On January 14 frost patches were observed on the face of the biofilter when the ambient air temperature was below -20° F. Where frost had not formed on the face of the biofilter, a media temperature of 32 °F or above was measured. However, during a normal winter day (i.e. similar to January 19 with the outside average temperature 20 °F), the biofilter was not frozen and no frost observed. The data shows that even though the biofilter developed frost, thawing will occur quickly when the weather becomes more normal again. If an insulated duct had been used between the barn ventilation fan and the biofilter inlet the biofilter inlet temperature may have been higher thus preventing frost build-up.

**Table 3. Biofilter temperature (°F) during cold weather**

| Date | Outside Temp | Biofilter Inlet | Filter 1 | Filter 2 | Filter 3 | Filter 4 | Filter 5 | Filter 6 |
|---|---|---|---|---|---|---|---|---|
| **Jan 14** | -20.4 | 31.6 | 33.3 | 33.1 | 33.1 | 30.7 | 35.4 | 33.3 |
| **Jan 19** | 20.8 | 53.1 | 50.0 | 53.8 | 39.9 | 42.1 | 42.1 | 46.9 |

**Conclusions**

To achieve uniform airflow through a vertical biofilter at the end of one year of operation (after settling has taken place) the support walls should be tapered at approximately 9.6° for both 12 inch and 24 inch base vertical bed biofilters.

Media in the vertical biofilter developed frost on the outside surface at ambient temperatures of -20D F. The frost effect on the media may be reduced by using an insulated air duct system.

A more even distribution of moisture can be obtained by placing the soaker hoses horizontally on the top of the media rather than vertically through the filters.

**Acknowledgements**

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**Lay Interpretation**

A vertical biofilter may be a good option for reducing odor and gas emission when not enough space is available to install a horizontal biofilter. The vertical biofilter is cylindrical with the walls containing the media and the cylinder center biofilter inlet connected to the barn exhaust fan. The inner wall of the biofilter media is tapered (i.e. thicker at the top and narrower at the bottom), thereby compensating for media settling. This design achieves a more uniform airflow across the media surface. A 9.6 degree taper provided the most uniform airflow after biofilter media settling for two filter thicknesses of 12 and 24 inches that were tested.

The recommended wetting technique to keep the media at proper moisture is to lay a soaker hose on top of the vertical biofilter and let the water seep down through the media. Soaker hoses suspended vertically did not provide for uniform media moisture through the system.

A vertical biofilter will continue to reduce odor and hydrogen sulfide emissions during cold weather (-20º F) provided the air entering the biofilter is warm (50º F).

Questions about this report can be sent to:

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