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Biofilters in animal agriculture

Lide Chen and Howard Neibling

What is a Biofilter?

Biofilters are living systems that rely on microbial populations to degrade polluting compounds. As contaminated air passes through biofilter media, two basic removal mechanisms occur simultaneously: absorption/adsorption and biological oxidation or biodegradation. The success of biofilters used for controlling odors and gases is based on both these processes. Odorous gases, aerosols, and particulates passing through a biofilter are adsorbed on the surfaces of the biofilter medium particles and/or absorbed into their moist surface layer, or "biofilm." Bacteria then degrade them to carbon dioxide (CO_2), water (H_2O), inorganic salts, and biomass during the biodegradation process.

Why Biofilter?

With the intensification of animal production in the United States, the reduction of odor, gas, and particulate matter (PM) emissions from concentrated animal feeding operations is a significant challenge for livestock producers. Most odors and gas emissions from these operations are by-products of anaerobic decomposition and transformation of the organic matter in manure by microorganisms. These by-products are a complex mixture of over 100 volatile compounds, of which 30 have a detection threshold of 0.001 mg/m^3 or less and hence are most likely to be associated with an odor nuisance. Any successful odor emission reduction technology must be able to accommodate the complexity of odor-producing compounds.

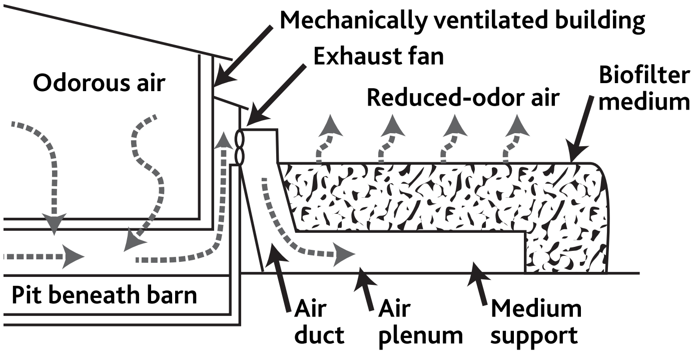

Figure 1. Vertical gas flow flat-bed biofilter on mechanically ventilated livestock building (adapted from Schmidt et al. 2004).

As a promising odor and gas treatment technology, biofilters are gaining acceptance in agriculture. Initially, biofilters filled with soil were used for controlling air pollution in wastewater plants and chemical manufacturing facilities. Biofilters were first applied to livestock facilities in West Germany in approximately 1966–67 to reduce odor emissions from a hog production facility.

Most of the biofilter research and application of biofiltration technology since the 1980s has occurred in a few European countries, including Germany and the Netherlands. In the United States, the feasibility of treating pit gases from a swine farrowing barn with biofilters was first investigated in 1997. Since then, biofilters have gained more attention for their potential applications in U.S. agriculture.

Where Are Biofilters Used?

Biofilters are used to treat air from mechanically ventilated buildings that use fans to control airflow. The ventilating fans allow contaminated air to be collected and directed to a biofilter. In some cases, biofilters treat 100% of the exhausted ventilation air. In other cases, biofilters treat only a portion of the ventilation air. Biofilters also can treat air from a covered manure storage unit or enclosed treatment facility. Manure gases trapped under the cover can be blown through a biofilter for treatment.

Biofilter Elements

Though there are different biofilter types, a typical biofilter includes the following elements (figure 1):

- A mechanically ventilated space with biodegradable gas emissions
- A duct connecting the ventilated space to the biofilter and an air plenum that distributes the air to be treated evenly through the biofilter medium
- A porous structure to support the medium
- A porous biofilter medium that serves as a surface for microbes to live on, a source of some nutrients, and a structure where moisture can be applied, retained, and available to the microbes
- A fan to move the odorous exhaust air from the building or manure storage through the duct, plenum, and biofilter medium
- A water supply system to keep the biofilter medium wet

Biofilter Type

Biofilters can be classified in several ways, depending on their layout. Biofilters can be either open bed or closed bed. The medium in open-bed biofilters is uncovered and exposed to weather conditions, including rain, snow, and temperature extremes (figures 2 and 3). Closed-bed biofilters are mostly enclosed, with a small exhaust open for venting of

Figure 2. Open-bed biofilter with a PVC pipe water supply system and a bypass louver. Photo courtesy of Dr. Steven Hoff, Iowa State University.

Figure 3. Open-bed, slant-cell biofilter with a sprinkler water supply system. Photo from odorcell.com. Used by permission.

Figure 4. Outside view of a closed-bed biofilter. Photo by Lide Chen.

Figure 5. Inside view of a closed-bed biofilter. Photo by Lide Chen.

Figure 6. Horizontal biofilter. Photo by Lide Chen.

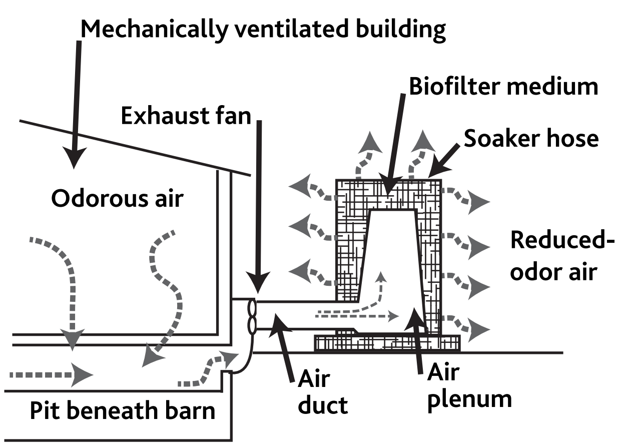

Figure 7. Vertical biofilter schematic (adapted from Nicolai and Thaler 2007)

Figure 8. Vertical biofilters. Photo by Lide Chen.

treated air (figures 4 and 5). Open-bed biofilters are the most common type used to treat air from animal facilities.

Biofilters also can be classified as horizontal (figure 6) or vertical (figures 7 and 8). Horizontal biofilters have larger footprints than vertical biofilters. Vertical biofilters come in circular and rectangular designs. The medium in a vertical biofilter is placed between two vertical support structures and across the top. The air passes either horizontally through the vertical supports or through the top. Vertical biofilters use less surface area than horizontal biofilters for treating the same airflow but are more expensive to build and maintain.

Vertical biofilters must compensate for settling of the medium over time. As the medium settles, more compaction occurs at the bottom. This reduces the airflow through the bottom portion of the structure more than through the top. One method for overcoming uneven airflow is to taper the support and the thickness of the medium, with the medium at the top of the vertical support thicker than at the bottom. Initially, tapering allows greater airflow through the bottom, but, over time, the medium becomes compacted and airflow becomes uniform throughout the vertical supports.

Important Factors Affecting Biofilter Performance

Biofilter medium

Selecting the proper biofilter medium is an important step toward developing a successful biofilter. The medium must provide a suitable environment for microbial growth and maintain high porosity to allow air to flow easily. Desirable properties include (1) suitable environment for microorganisms to thrive, including enough nutrients and moisture, neutral pH, and unlimited carbon supply; (2) large surface area to maximize attachment area, sorption capacity, and number of reaction sites per unit of medium volume;

(3) high moisture-holding capacity to keep absorption ability high and microorganisms active; (4) stable compaction properties to resist compaction and channeling; (5) high percentage (50% to 80%) of moderate- to large-sized voids to allow air to flow through easily; and (5) slow decomposition for biofilter longevity.

The most widely used media are organic materials such as compost, peat, wood chips, bark mulch, and mixtures of them. Proven mixtures for animal agriculture biofilters range from approximately all wood chips to a 30:70 ratio by weight of compost and wood chips or wood shreds. Wood chips provide structural support and void space, while compost provides a nutrient-rich environment and an initial source of aerobic microorganisms. Mixtures with more compost (less wood chips) and other fine particles will result in higher pressure drops. Other possible filter media include coconut fiber, granular activated carbon, perlite, lava rock, and polystyrene beads.

Both odorous compounds and biofilter media are degraded by the same microorganisms. Over time, degradation of the medium, dust accumulation, microorganism buildup, and medium settling cause biofilters to become clogged, making airflow more difficult. Eventually the fans are unable to force the ventilation air through the biofilter, resulting in biofilter failure.

The longevity of biofilters mainly relies on medium type, microbial activity, and exhaust air dustiness. Remixing of the medium can extend longevity, with a drawback of increased labor costs. No long-term studies on the length of media life in agricultural biofilters have been reported, but it is estimated that most biofilter media will remain effective with an acceptable pressure drop for 3 to 5 years or more. Some researchers suggest that no more than a 3-year life should be expected.

Biofilter medium moisture content

Biofilter moisture control is essential for effective treatment. Biofilter failures have been attributed to drying of the medium in over 90% of cases. Inadequate moisture can reduce filter efficiency by lowering its absorption capacity, deactivating the microbes, and creating cracks that allow air channeling, which reduces empty bed residence time (EBRT). EBRT is defined as the time it takes for air to pass through a volume the same size as the medium's (medium volume/airflow rate).

Too much moisture can plug some of the pores in the medium; cause high pressure drops; generate high-volume, low-pH leachate; and limit oxygen flow in saturated areas in the medium. All of this creates anaerobic zones in the biofilter. These anaerobic zones may generate odor and produce nitrous oxide, an important greenhouse gas. Installing a clay, concrete, or plastic liner under the biofilter bed to collect the leachate is suggested.

Typically, biofilters require moisture to be added whenever the temperature is above freezing. A range of 40% to 65% (weight basis) is believed suitable for media commonly used in agriculture, such as compost-based and wood chip-alone media.

Lawn sprinklers can easily be adapted to wet biofilters. Soaker hoses laid horizontally are another option to add moisture uniformly. The sprinkler and soaker hose systems can be controlled with timers to operate at the duration and frequency needed to maintain the needed moisture content.

When ambient temperatures are below freezing, moisture need not be added. During colder weather, the warm, moist air from a livestock or poultry barn supplies the biofilter with necessary moisture. Any snow that falls on the biofilter will be melted by the warm exhaust air and supply additional moisture.

Contact time

Contact time indicates the amount of time that the air is in contact with the biofilter medium. Empty bed resistance time (EBRT) is often used to represent the contact time. The real contact time is shorter than EBRT because the pore space in the medium is not 100%. Theoretically, pollutants in the gas phase first need to be transferred to the liquid phase, where they can be degraded by the microorganisms living in the biofilter. Therefore, a sufficient EBRT is necessary to allow the transfer and degradation of pollutants to occur, which makes EBRT a critical design and operating parameter. Longer EBRTs have better treatment effects but require a larger biofilter for the same amount of air to be treated.

Different pollutants have different characteristics that affect the absorbing and adsorbing times and degradation processes, and thus they need different EBRTs to be completely degraded. A reasonable EBRT is closely related to medium moisture content and pollution loading. Systems with higher moisture contents and lower pollutant loadings need a shorter EBRT. Based on the literature, 3 to 5 seconds is sufficient for most livestock facilities, but air from covered manure storage usually requires 10 seconds or longer.

Concerns for Installation and Operation of Biofilters

Removal efficiency

Removal efficiency (RE) is defined as follows:

RE = 100 × [(inlet concentration
– outlet concentration)/inlet concentration].

It reflects a biofilter's ability to mitigate odor, gases, and volatile organic compounds (VOCs). At ideal conditions, the RE can be 100%. At a typical 5-second EBRT and 55% medium moisture content, a mixture of compost and wood chips can achieve an average RE of 78% for odor, 78% for H_2S (a colorless gas with the foul odor of rotten eggs), and 81% for NH_3 (a colorless gas with a pungent smell).

Removal efficiency depends on EBRT, medium type, medium moisture content, animal species, temperature, and initial concentrations. Maintaining proper conditions, especially a proper range of moisture content and EBRT, is critical for a desirable RE.

Biofilter operating pressure

Pressure drop is one of the main considerations for successful operation of full-scale biofilters. In order to keep reasonable fan ventilation efficiency, agricultural ventilation fans should be run at a pressure drop less than 62 Pa (0.25 inch water column). If the pressure drop through the biofilter can be kept to a few tens of pascals (Pa), existing fans in a livestock building may be used when installing and operating a biofilter.

The pressure drop is closely related to medium type, medium depth, and airflow rate through the medium. There is a linear relationship between unit pressure drop and unit airflow rate for a mixture of compost and wood chips. The pressure drop caused by biofilters influences the existing ventilation systems in agricultural facilities and results in higher fan operation costs. The pressure drops through on-farm biofilters are best at no more than 50 Pa.

Construction and operation costs

Any technology used to mitigate odors will be an added expense for animal production. Biofilters have been proven to be the most cost-effective method for treating ventilation exhaust air. Different types of biofilters vary in their costs. Costs may be reduced by introducing strategies such as partial biofiltration.

Costs generally can be split into two parts: construction and operation/maintenance. One study showed construction costs of about $0.22 per piglet or $0.062 per cfm (cubic feet per minute) of treated air when a biofilter filled with a 50:50 by weight mixture of yard waste compost and brush wood chips was installed on a swine gestation barn. Operation costs were estimated at $275 per year for an effective rodent control program and $125 per year for sprinkling water on the biofilter medium and using higher-power ventilation fans.

Another study estimated that installation costs for new construction on mechanically ventilated buildings will be between $150 and $250 per 1000 cfm air treated. Annual operation/maintenance costs of a biofilter were estimated to be $5 to $15 per 1000 cfm air treated. These costs include the increased electrical costs to push the air through the biofilter and the cost of replacing the medium after 5 years.

Our own recent study showed that the installation cost for a new, closed-bed biofilter with a 50:50 by weight mixture of wood chips and shredded bark on mechanically ventilated swine nursery barns was approximately $800 per 1000 cfm air treated. It is worth pointing out that both capital and operation/maintenance costs are highly variable.

For more cost-effective biofilter use, partial biofiltration is an option. Partial biofiltration combines biofiltration with natural atmospheric dilution. During calm and stable weather conditions, the exhaust air from livestock buildings is forced through the biofilter. Under unstable weather conditions, natural atmospheric mixing is used, thus bypassing biofilter operation. In this way, the operation costs will be reduced while still mitigating odors during potentially high-impact periods.

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About the Authors:

Lide Chen, Extension Waste Management Engineer, University of Idaho Twin Falls Research and Extension Center; **Howard Neibling**, Extension Water Management Engineer, University of Idaho Kimberly Research and Extension Center.

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