11-2011

Air Quality Education in Animal Agriculture: Biofilters for Odor and Air Pollution Mitigation in Animal Agriculture

Kevin A. Janni
University of Minnesota–Twin Cities

Richard E. Nicolai
South Dakota State University

Steven J. Hoff
Iowa State University, hoffer@iastate.edu

Rose M. Stenglein
University of Minnesota

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Biofilters for Odor and Air Pollution Mitigation in Animal Agriculture

AIR QUALITY EDUCATION IN ANIMAL AGRICULTURE

Mitigation Strategies: Biofilters
November 2011

Kevin A. Janni, Professor, Department of Bioproducts and Biosystems Engineering, University of Minnesota
kjanni@umn.edu
Richard K. Nicolai, Associate Professor, Department of Agricultural and Biological Engineering, South Dakota State University
Steven Hoff, Professor, Department of Ag and Biosystems Engineering, Iowa State University
Rose M. Stenglein, Junior Scientist, Department of Bioproducts and Biosystems Engineering, University of Minnesota

This publication discusses biofilters use and design and performance factors.

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Biofilters are a proven and effective method for reducing odor and other gaseous emissions from mechanically ventilated animal facilities and manure storage units. Biofilters work by absorbing noxious gases into a biofilm where microorganisms break down the gases into carbon dioxide, water, and salts and use the energy and nutrients to grow and reproduce. Well-designed and managed biofilters can reduce odors and hydrogen sulfide (H_2S) by as much as 95 percent and ammonia (NH_3) by 80 percent. Biofilters have been used by nonagricultural industries for many years and on animal facilities for over 12 years in North America.

Biofilters are actively being researched; additional information about pollution reduction efficiencies, biofilter media, configurations, and maintenance will be available in coming years. Additional potential benefits may include reducing airborne transmission of viruses and reducing greenhouse gas emissions.

What Is a Biofilter?

Biofilters used to treat air from livestock barns include biofilter media, ductwork, distribution plenum, and fans. *Figure 1* shows a flat-bed biofilter treating air from a livestock barn with a belowground manure pit. The biofilter media supports a moist, biologically active biofilm in which gases in the air are absorbed and broken down before the air leaves the biofilter. Ductwork connects the livestock barn or other air source and fan to the plenum where the air is distributed evenly to the media. Fans are required to draw air from the barn and push it through the ductwork and biofilter media.

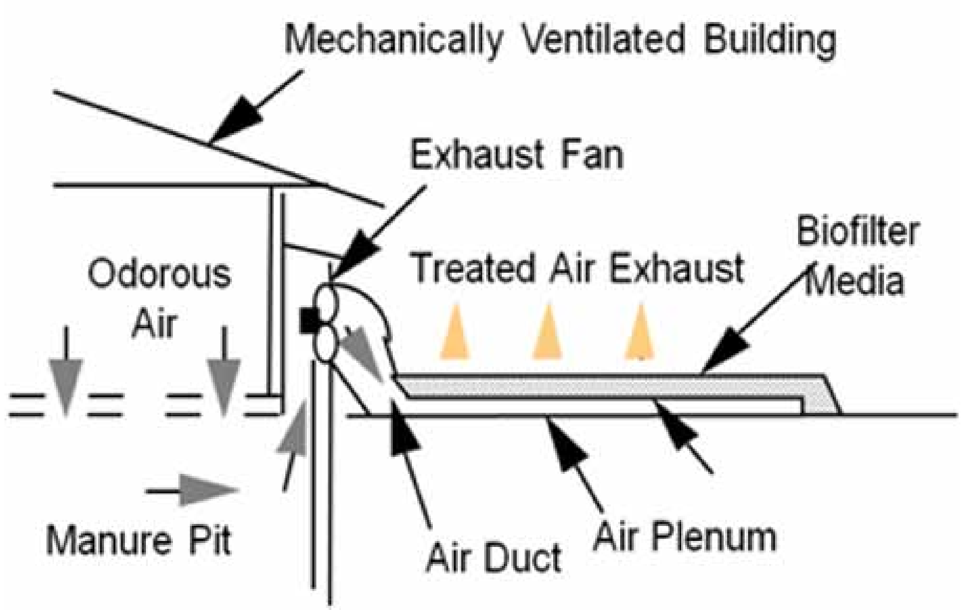

Figure 1. Typical flat-bed biofilter on mechanically ventilated livestock building.

Biofilters are actively being researched. Additional information about pollution reduction, configurations, and maintenance will be available in the future.

Biofilter media treats contaminated air both physically and biologically. Physical treatment occurs when contaminants (such as odorous gases, aerosols, and small particles) are trapped on the media surface and/or absorbed into the moist biofilm. Biological treatment occurs when microbes in the biofilm degrade contaminants into carbon dioxide (CO_2), water (H_2O), mineral salts, volatile organic compounds (VOCs), and microbial biomass. The microbial action is what differentiates a biofilter from a simple filter or wet scrubber.

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 percent of the exhausted ventilation air. In many other cases, biofilters treat a portion of the exhaust ventilation air. Manure pit fan exhaust can be treated with a biofilter.

Biofilters also can be used to treat air from a covered manure storage unit or enclosed treatment facility. Manure gases that are trapped under the cover can be blown through a biofilter for treatment.

Biofilters cannot treat air that exhausts from naturally ventilated barns through open sidewalls or ridges because the air cannot be collected and directed to a biofilter. Biofilters can be used to treat air from pit fans on naturally ventilated barns. These pit fans take air from the underground manure storage pit under the naturally ventilated buildings. In cold weather these pit fans may move 100 percent of the exhaust air, which can be treated with a biofilter. During warm weather, pit fans may move only 10 percent of the exhaust air. One way to treat more air during warm weather is to increase the pit fan capacity to 40 percent of the maximum hot weather ventilation. The increase pit fan capacity will assure that most pit gases will be treated by the biofilter before the sidewall curtains open.

Biofilters also can be used to treat a critical minimum amount of ventilation air from animal facilities when stable atmospheric conditions reduce odor dispersion. Stable atmospheres are more common during the evening and early morning hours when there is very little air mixing in the lowest few hundred feet of the atmosphere. Biofiltration of mechanically ventilated air during these stable periods reduces emissions when odor plumes can travel long distances close to the ground. Biofilters used in this manner are expected to reduce odor nuisance complaints, while costing less to operate than systems that biofilter all exhaust air all the time.

Biofilter Types

Biofilters are classified in several ways, depending on the layout. Biofilters can be either open- or closed-bed. The media in open-bed biofilters is uncovered and exposed to weather conditions, including rain, snow, and temperature extremes. Closed-bed biofilters are mostly enclosed with a small exhaust port for venting of the cleaned air. Open-bed biofilters are the most common type used to treat air from animal facilities. Some open-bed biofilters can have roofs over the biofilter to provide some weather protection.

Biofilters also can be classified as horizontal or vertical (*Figure 2*). Horizontal biofilters have larger footprints than vertical biofilters. Contaminated air is distributed evenly under the horizontal biofilter and flows up through the media. Many open-flat-bed horizontal biofilters have media 10 to 18 inches deep. These biofilters are relatively inexpensive to build and easy to maintain.

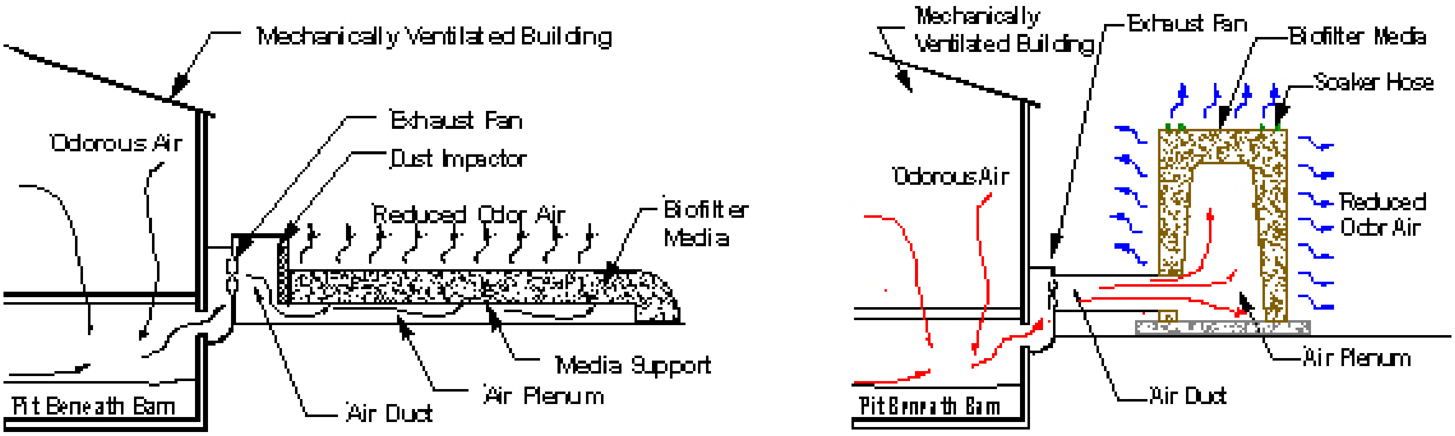

Figure 2. Horizontal flat-bed biofilter (left) and vertical biofilter (right)

Some horizontal biofilters have been built with media depths between 3 and 7 feet. These deep-bed biofilters usually treat smaller airflows and require a smaller footprint than comparable shallower biofilters, but they require more powerful fans, which are more expensive.

Vertical biofilters are being developed to reduce the footprint required. There are different vertical biofilter designs. (See circular and rectangular vertical biofilters pictured in Figure 3A and 3B respectively.) The media 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 a horizontal biofilter for treating the same airflow but are more expensive to build and maintain.

Vertical biofilters must compensate for media settling over time in between the vertical supports. As the media settles, more compaction occurs at the bottom. This reduces airflow through the bottom portion more than through the top. One method for overcoming the uneven airflow through the media between the vertical supports has been to taper the support and the media thickness. The media at the top of the vertical support is thicker than the bottom (*Figure 2*). Initially, tapering allows greater airflow through the bottom but, over time, the media becomes compacted and airflow becomes uniform throughout the vertical supports.

Biofilter Elements

Open-bed horizontal biofilters are the most common in animal agriculture and, as shown in *Figure 1*, include the following elements:

- A mechanically ventilated space with biodegradable gas emissions.
- A fan to move the odorous exhaust air from the building or manure storage through the duct, plenum, and biofilter media.
- Ducting connecting the ventilated space and an air plenum that distributes the air to be treated evenly beneath the biofilter media.
- A porous structure to support the media above the air plenum.
- Porous biofilter media that serves as a surface for microorganisms to live on, a source of some nutrients, and a structure where moisture can be applied, retained, and be available to the microorganisms.

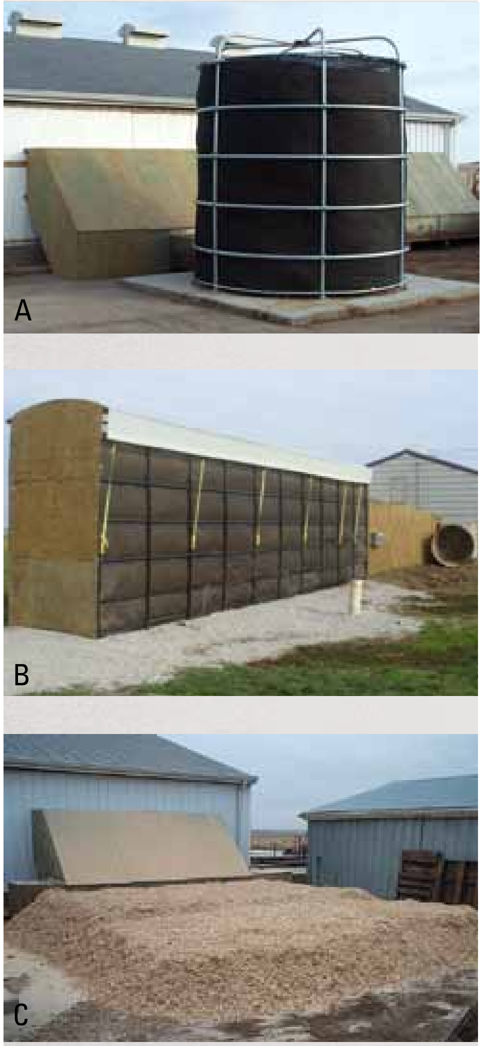

Figure 3. (A) Circular vertical biofilter; (B) rectangular vertical biofilter; and (C) flat-bed biofilter

Table 1. Empty bed contact time (EBCT); listed in seconds required to treat air from different types of livestock and poultry facilities.

Livestock System	EBCT (s)	References
Swine barn with deep pit manure storage	5	Zeisig, 1987; Nicolai and Janni, 1999
Poultry barns with dry litter	3	Zeisig, 1987
Covered manure storage units	10	Zeisig, 1987
Dairy heifer barn with deep pit manure storage	5	Nicolai and Janni, 1999

Biofilters are used to treat air from mechanically ventilated buildings that use fans to control airflow.

Design and Performance Factors

Contact Time and Airflow

Contact time indicates the amount of time that the air is in contact with the biofilter media. Empty bed contact time (EBCT) is defined as the time it takes for the air to flow through a volume the same size as the media. Longer contact times give the biofilter more time to treat gases but also require a larger biofilter. Three to five seconds is sufficient contact time for most livestock facilities but air from covered manure storages usually requires 10 seconds of contact time. (*Table 1*).

When treating air from mechanically ventilated buildings, the airflow rates are determined by the season and the type of livestock housed in the building, specifically the number, species, and size. Higher airflow rates are required during warm weather. Biofilter design should use the highest airflow rate intended for biofiltration. Exhaust fans need to be powerful enough to create a vacuum in the building to draw fresh air in from outside while pushing exhaust air out and through the biofilter. When biofilters are added to mechanically ventilated livestock and poultry barns, the existing fans may not be powerful enough to push air through the biofilter and may need to be replaced.

When treating air from covered manure storage units, the recommended minimum airflow rate is 0.01 cubic feet per minute per square foot of manure surface area.

Once the desired contact time and maximum airflow rate have been determined, they are used to find the volume of biofilter media needed. A typical open-bed horizontal biofilter with media 1 foot deep may require 50 to 85 square feet per 100 cubic feet per minute of airflow. A deep-bed biofilter with media 3 feet deep may require 15 to 30 square feet per 100 cubic feet per minute of airflow.

Moisture Content

Biofilter media moisture control is essential for effective treatment. Inadequate moisture can reduce filter efficiency by allowing the media to dry out, deactivating the microbes and creating cracks that allow air channeling. Too much moisture can plug some of the pores in the media, cause channeling, restrict airflow through the media and the barn, and limit oxygen flow in saturated areas in the media, which creates anaerobic zones in the biofilm. These anaerobic zones may produce nitrous oxide, an important greenhouse gas. Some excess moisture is generally not a problem because the extra moisture could either drain through the media or evaporate due to the airflow through the media.

Typically, biofilters require moisture be added whenever the temperature is above freezing. Lawn sprinklers can easily be used to wet horizontal open-bed biofilters. Soaker hoses laid horizontally along the top of vertical biofilters, especially each vertical section, have been used successfully to add moisture uniformly to the media. 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. The recommended moisture content for biofilters ranges from 30 to 70 percent in the top ¾ of the media with an optimum moisture content of 50 percent. In the field biofilter moisture is usually monitored by look and feel rather than measurement. To check media moisture content, dig into the media. Dampness should be felt ½ to ¾ of the way through the media depth. If dampness is felt throughout the depth of the media, the watering system is providing too much water. If, however, only the top few inches are damp, more water needs to be added. Often, watering is done at night to reduce evaporation losses. Research is under way to develop a moisture sensor and automated watering system.

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 sufficient moisture. Any snow that falls on the biofilter will be melted by the warm exhaust air and will supply additional moisture.

Excessive water from storm events or a watering system failure can cause moisture to saturate the media and seep out the bottom. The water seeping out, known as leachate, can contain high concentrations of organic matter and nitrate. Most biofilter media are capable of absorbing most large rainfall events so the potential for leachate is relatively small. Design guidelines suggest a clay, concrete, or plastic liner be installed under the biofilter bed to collect the leachate. More testing and analysis are needed to determine the effects of excess moisture.

Excessive water from storm events or over watering can restrict airflow through the media and increase the pressure drop across the media. This can reduce the barn ventilating rate to less than the designed rate. As the media dries, the pressure drop will decrease and the airflow rate will be restored.

Biofilters can be either open- or closed-bed. Open-bed biofilters are the most common type used to treat air from animal facilities.

Temperature

Microorganisms tolerate a range of temperatures. They are most active between 70 and 90°F. In winter the cooler temperatures will reduce the microbial activity, but at the same time, there is less airflow because winter ventilating rates are approximately 1/10 the summer levels. Most biofilters maintain portions of the biofilter media above freezing even in winter due to continuous flow of warm air from livestock or poultry buildings. However, biofilters on manure storages or on unheated buildings will freeze in cold weather, temporarily stopping biofilter treatment. As the biofilter heats up in the spring, microorganisms become active again and biofilter effectiveness is restored. Heating a biofilter to avoid freezing is usually not cost effective in animal agriculture.

Siting

The biofilter bed should be located close to the exhaust fans to limit the duct length but far enough from the building to avoid rain or snowmelt running off the roof onto the biofilter media. It is also important to construct a biofilter in an area where water will not pond. Keeping this area dry will increase system life. Typically, most of the rain or snow that falls on an open-bed biofilter is absorbed by the porous media. However, during periods of high rainfall or if the sprinkling system fails, water potentially could leach out of the biofilter media. Therefore, the biofilter bed should be built on a sloped, well-drained area so excess water can move away from the biofilter.

Media

Media selection is critical in biofilter design. Media must provide a suitable environment for microbial growth and maintain a high porosity to allow air to flow easily. Critical properties of media material include (1) porosity, (2) moisture holding capacity, (3) nutrient content, and (4) slow decomposition. *Table 2* lists the characteristics for various biofilter media. Mixtures of these materials have the advantage of combining these characteristics.

Table 2. Biofilter media characteristics.

Material	Porosity	Moisture Capacity	Nutrient Capacity	Useful Life	Comments
Peat	Average	Good	Good	Good	
Soil (heavy loam)	Poor	Good	Good	Good	Good Microorganism Sources
Compost (yard waste)	Average	Good	Good	Good	
Wood Chips	Good	Average	Average	Average	Good Additions
Straw	Good	Average	Poor	Poor	for Porosity

Biofilter media moisture control is essential for effective treatment.

Biofilter media needs to include plenty of voids, 50-80 percent, to allow air to flow through easily. Many biofilters used in animal agriculture use a media that is a mixture of wood chips and compost. Wood chips provide structural support and void space, and compost provides a nutrient-rich environment and an initial source of aerobic microorganisms. Recent research has demonstrated that media comprised primarily of wood chips coated in manure slurry or another microorganism source is also effective and requires less frequent replacement. Other possible filter media include wood bark, coconut fiber, peat, granular-activated carbon, perlite, lava rock, and polystyrene beads.

A proven organic media mixture for animal agriculture biofilters ranges from approximately all wood chips to 30:70 ratio by weight of compost and wood chips or wood shreds. Some early biofilters used a 50:50 wood chip compost ratio but their porosity tended to be less than desired. Media mixtures with more compost (less wood chips) and other fine particles will result in higher pressure drops but only slightly higher efficiencies.

Over time wood chip degradation, dust accumulation, microorganism buildup, and media settling cause biofilters to become clogged, making airflow through the media more difficult. Eventually the fans are unable to force the required ventilation air through the biofilter and ventilating rates decrease, resulting in poor building ventilation. Both biofilter media and exhaust air dustiness affect the length of time before the media needs to be replaced. Typically wood chip media needs to be replaced every 3 to 10 years.

Currently there are no requirements for disposal of biofilter media. Some of the media can be mixed with more wood chips and reused in the biofilter. The remaining media could be handled similarly to compost and land applied to cropland at agronomic rates. If the biofilter media is very dry, it is likely that significant amounts of dust will be generated during loading and land application. Care should be taken to avoid breathing this dust.

Microorganism Seeding

Biofilter treatment efficiency depends on the microbial breakdown of volatile compounds in the air. Microorganism type and number in the biofilter impact performance. Natural media materials such as peat, loam soil, and compost usually contain sufficient microorganisms to seed a biofilter treating air from a livestock building or manure storage. Biofilters also can be seeded with aerated manure. A three- to six-week conditioning period allows the microorganisms to adapt to the compounds in the air. During this conditioning time, the biofilter efficiency is limited.

Construction

During biofilter construction, efforts should be made to minimize media compaction. All ducting work should be completed before the media is placed. No machinery or foot traffic should be allowed on the media to prevent media compaction, which reduces airflow. Access lanes could be constructed to allow for fan or duct maintenance. If there is a need to walk across the media, it is best to lay down planks or plywood to distribute the weight and limit compaction.

To achieve uniform air treatment, it is critical to maintain uniform media depth across an open flat-bed biofilter. Air will follow the path of least resistance, which is often the thinnest area of the media. Any channeling of air reduces the biofilter effectiveness. Untreated air can escape from around the edges of the biofilter media or at the ductwork and plenum intersection. Efforts should be made to seal all duct and plenum joints with appropriate caulking or plastic sheeting to minimize untreated air leaks.

Weeds

Weed growth on the biofilter surface can reduce efficiency by causing air channeling and limiting oxygen exchange. Roots can plug biofilter pores. Weeds on a biofilter also reduce the aesthetic appearance of the livestock site. A systemic herbicide or some other means should be used to manage weeds growing in biofilter media.

Rodents

A good rodent control program is essential to protect biofilters. Fortunately, most livestock and poultry operations currently have a good rodent control program, which can be adequate around biofilters. Mice and rats burrow through the warm media during the cold winter months, causing channeling and poor air filtration. Rabbits, woodchucks, and badgers have been suspected of burrowing through and nesting in biofilters. Incorporating a biofilter into existing rodent control programs is simple and inexpensive.

Health and Safety Concerns

There has been very little research on potential health and safety concerns related to biofilters. The reliance on natural microorganisms found in compost, soil, or peat suggests that individuals sensitive to these organisms may need to wear a face mask to minimize exposure to airborne microorganisms and mold spores. Respiratory protection is recommended during construction, maintenance, and media removal.

Biofilter Costs

Capital and installation costs, and operation and maintenance costs are quite variable. Capital costs to install a biofilter include the cost of the materials — fans, media, ductwork, and plenum. Installation costs may include labor and equipment rented to build the biofilter. Typically, cost for a new horizontal biofilter on mechanically ventilated buildings will be between $150 and $250 per 1,000 cfm. A vertical biofilter is approximately 1.5 times the cost of a horizontal biofilter.

Annual operation/maintenance of the biofilter is estimated to be $5-$10 per 1,000 cfm. This includes the increase in electrical costs for fans to push the air through the biofilter and the cost of replacing the media after five years.

Respiratory protection is recommended during construction, maintenance, and media removal.

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Reviewers

Phil Westerman, North Carolina State University
Rhonda Miller, Utah State University
Rick Stowell, University of Nebraska–Lincoln

USDA United States Department of Agriculture National Institute of Food and Agriculture

The Air Quality Education in Animal Agriculture project was supported by National Research Initiative Competitive Grant 2007-55112-17856 from the USDA National Institute of Food and Agriculture.

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