Design and Management of Biofilters for Odor Reduction of Livestock Facilities

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Biofilter basics

Biofiltration is an odor reducing technology that can be used to treat the exhaust air from mechanically ventilated livestock barns or covered manure storage facilities. Biofilters contain moist and porous media with a large surface area where microorganisms can grow. The biofilter media treats contaminated air both physically and biologically. When the exhaust air is directed to pass through the biofilter media, the contaminants in air are adsorbed and broken down by microorganisms in addition to physical filtration. Fans are usually required to push the exhaust air through the biofilter media. Generally, biofilters cost less than most other odor treatment technologies and do not involve chemical handling, but they need regular maintenance to perform effectively. A well designed and maintained biofilter can reduce more than 80 percent of odor, hydrogen sulfide (H_2S), and ammonia (NH_3) in the contaminated air.

Biofilter media

Biofilter media must provide a nutrient-rich environment for microbial growth and maintain a high porosity for easy airflow. Peat, loam soil, and compost usually contain sufficient nutrients and microorganisms, and have good moisture holding capacity, while wood chips and straw have better porosity. The mixture of wood chips and compost (ratio of 70 to 30 by weight) has been proven to be an effective biofilter media in agriculture. Wood chips provide structural support and void space, and compost provides a source of aerobic microorganisms. Using mixtures with more compost than wood chips would result in unwanted higher exhaust air pressure drops but only slightly higher efficiencies.

The media porosity depends on media material, moisture content, and compaction of the media. Age of the media also affects porosity because media decomposition and settling reduce the pore space over time. Media porosity of 40 percent to 60 percent is recommended. If porosity is not measured, 40 percent voids can be used to estimate the worst-case pressure drop. Wood chips over 75mm screen size have been recommended for reducing exhaust air pressure drops. On-farm biofilters can use mixtures with more than 70 percent wood chips or use wood chips alone when the exhaust air contains enough microorganisms and nutrients. Additional nutrient supply or microorganism seeding can be done using compost and activated sludge if needed. Other possible biofilter media include wood bark, coconut fiber, feather, granular-activated carbon, perlite, lava rock, polystyrene beads, and zeolites.

New biofilters may experience a two- to six-week low efficiency conditioning period, which allows the microorganisms to adapt to the contaminated air. Biofilter media will degrade and make airflow through the media more difficult over time. It will need to be replaced when the required minimum airflow rate can no longer be achieved. Using mixed media with a minimum portion of easy-to-biodegrade materials can increase the life of the biofilter. Most biofilter media will last for at least three years and likely five years or longer. The used media can be disposed like other waste biomass such as compost.

Horizontal bed versus vertical bed

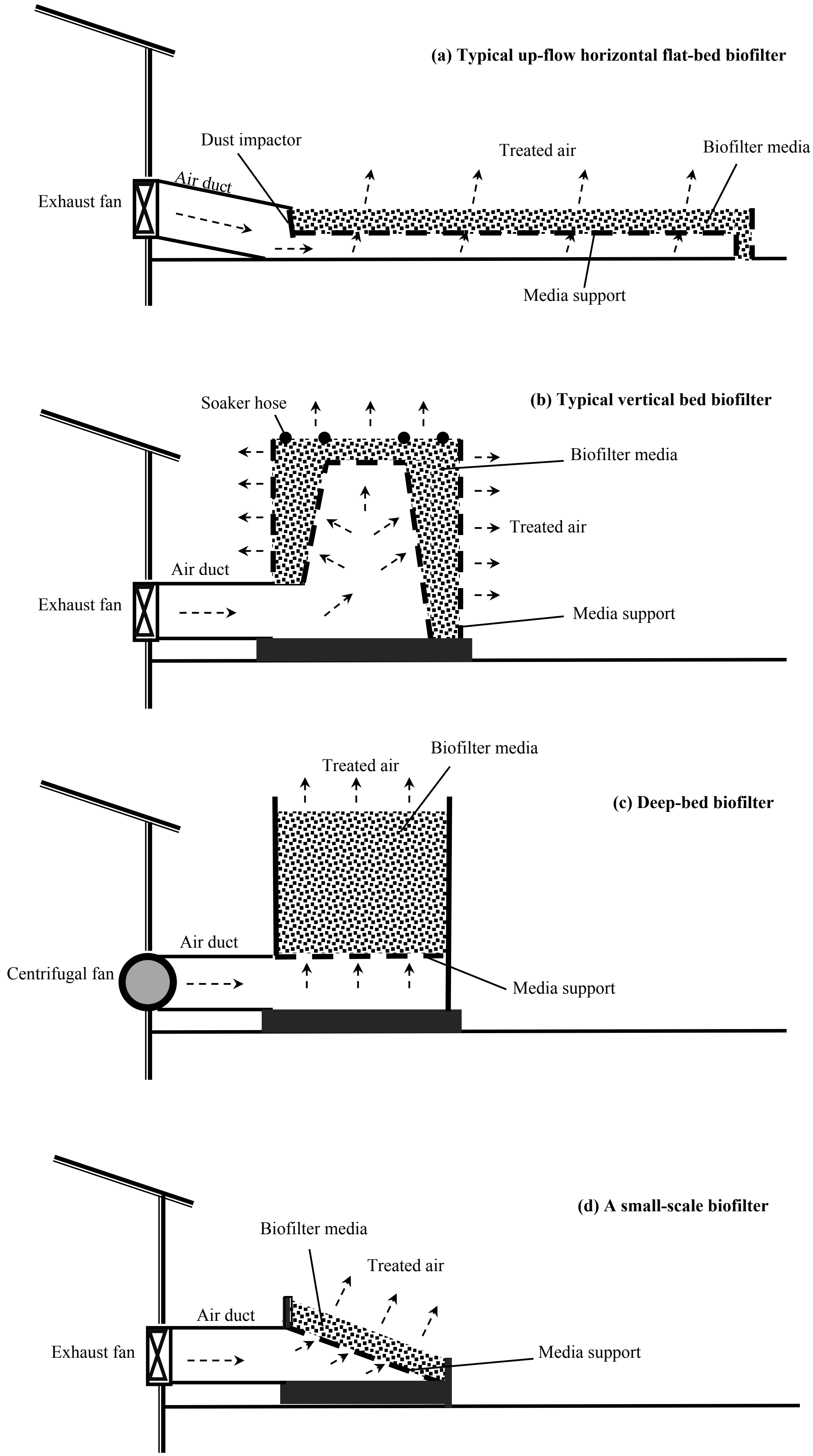
Most agricultural biofilters are horizontal bed biofilters (with vertical airflow), which can be constructed at a relatively low cost but will need a large ground area (Figure 1). The exhaust air is distributed evenly under the horizontal bed biofilter and flows up through the media. Some horizontal bed biofilters use down-flow design for easier water supply, because when air flows down, the media dries from the top and an overhead sprinkling system can add water directly on the top. The up-flow design is generally cheaper than the down-flow design in terms of construction costs.

Vertical bed biofilters need less ground area than a horizontal biofilter for treating the same airflow but are more expensive to build and maintain. They provide an alternative to reduce the required footprint. In a vertical bed biofilter, the media is placed between vertical support structures, and the exhaust air can pass through the media horizontally to the side as well as through the top. The media in vertical bed biofilters tends to settle over time and more compaction occurs at the bottom. This could result in uneven airflow through the media (more airflow through the top than the bottom). Methods for preventing this effect include tapering the media thickness (using thicker media at increased height), or using a multiple stage design. A taper angle of 9.6 degrees has been recommended for vertical bed biofilters (Figure 1).

Design of biofilters

The exhaust air passing through the biofilter should contact the biofilter media for an amount of time that allows the

Figure 1. Schematics of various biofilters



contaminants in air to be effectively reduced. Empty bed residence time (EBRT), or contact time, has been identified as the most important design parameter for biofilters. EBRT is defined as the time it takes for the air to flow through the empty bed filter, which can be calculated from dividing the empty bed filter volume by the airflow rate. For treating a certain airflow, longer EBRT requires a larger biofilter. A three- to five-second EBRT is generally sufficient for adequate odor reduction from livestock barns, while air from covered manure storages may require a 10-second EBRT. Reductions of NH_3 and H_2S are more sensitive to EBRT as compared to reduction of odor. A well-maintained biofilter is able to reduce odor, NH_3, and H_2S by 80 percent when EBRT is around five seconds. Biofilters with EBRT less than 1 second exist and are able to achieve 20 to 40 percent reduction.

Biofilters used to treat ventilating air exhausted from a livestock building can be sized to match the maximum airflow rate needed for the building, which is typically the warm weather rate. Higher construction and operating costs will occur if biofilters are designed for high airflows. In many cases, biofilters are designed to treat only a portion of the exhaust air (cold to cool weather rate) from the building. Biofilters used to treat air from covered manure storage units usually handle less airflow but a higher concentration of odorous gases in the air. A typical airflow rate is 0.01 cubic feet per minute (CFM) per square foot of manure surface area. Once the airflow rate is figured for the biofilter and the desired EBRT have been determined, the required volume of the biofilter bed can be calculated.

When biofilters are added to livestock buildings, the existing ventilation fans may need to be replaced if they are not powerful enough to handle the additional pressure drop caused by the biofilters. Agricultural ventilation fans generally are designed to operate at less than 62 pascal (0.25 inches of water) pressure drop. Pressure drops of less than 62 pascal have been suggested for biofilters to maintain reasonable fan ventilation efficiency. If the pressure drop through the biofilter can be kept to less than 40 pascal (0.16 inches of water), replacing the existing exhaust fans may not be necessary.

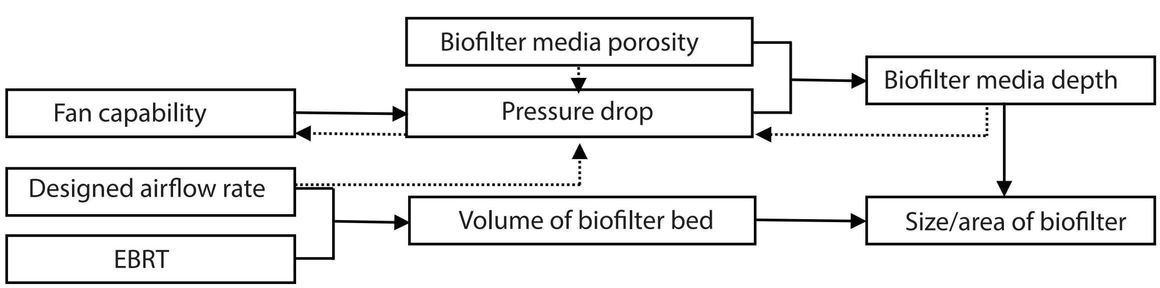
The pressure drop of biofilters depends on both media selection and media depth. Pressure drop increases linearly with increasing media depth. Many biofilters have media depth in the range of 10 to 18 inches (25 to 45 cm) in order to maintain acceptable pressure drop and odor reduction efficiency. Media depths greater than 18 inches usually result in excessive pressure drops. Media depths less than10 inches will dry out more quickly and have a greater potential for air channeling. Sometimes deep-bed biofilters (more than 3 feet deep) are used to treat small airflows when centrifugal fans are used and pressure drop is not a major concern. A flowchart for design of biofilters is shown in Figure 2.

Table 1 demonstrates the design process of a biofilter for a 1,000 head finishing swine facility that will treat all the exhaust air with a maximum warm weather ventilation rate of 120 CFM per pig space. One-foot biofilter media depth and 5 seconds EBRT are used. As demonstrated in Table 1, the pressure drop of biofilters is sensitive to the porosity of the biofilter media, which is a measure of percent voids (open pore space) in the media. When porosity decreases from 50 percent to 40 percent, the pressure drop is seven times higher.

Table 1. Example of a biofilter for a 1000 head finishing swine facility

Designed airflow rate (Q) = 120 CFM per pig×1000 pigs = 120,000 CFM
Desired EBRT = 5 seconds
Volume of biofilter bed (V_m) = Q*EBRT=120,000 ×5/60 = 10,000 ft^3
Biofilter media depth (D_m) = 1 foot
Biofilter media area (A_m) = V_m/D_m = 10,000/1 = 10,000 ft^2
Unit Airflow Rate (UAR) = Q/A_m = 120,000/10,000 = 12 CFM/ft^2
Unit Pressure Drop (UPD) = $8.82\times10^{11}\times(\text{media porosity})^{-8.6}\times UAR^{1.27}$
When media porosity = 50%, Biofilter pressure drop = UPD×D_m = $8.82\times10^{11}\times(50)^{-8.6}\times12^{1.27}\times1=$ 0.05 inches of water
When media porosity = 40%, Biofilter pressure drop = UPD×D_m = $8.82\times10^{11}\times(40)^{-8.6}\times12^{1.27}\times1=$ 0.35 inches of water

Figure 2. Flowchart for design of biofilters



Management of biofilters

Performance of biofilters depends on microbial activity, which is influenced by moisture, temperature, pH, and nutrient availability. Key operation parameters of biofilters that need to be managed are summarized in Table 2.

Table 2. Key operation parameters of biofilters

Moisture Content	• Optimum moisture content for biofilters is 50 percent, with a range of 40 to 65 percent. Inadequate moisture may deactivate microorganisms and cause dry areas that promote air channeling. Too much moisture may restrict airflow and oxygen supply for microorganisms. Also, NH_3 reduction is sensitive to moisture content. • In winter, the media moisture content is usually sufficient because of the warm moist exhaust air from livestock barns, and additional water supply may not be needed. • During mild and warm weather or whenever the temperature is above freezing, a watering system is often needed in order to maintain moisture level.
Temperature	• Optimum temperatures for biofilters range from 20°C to 50°C. • In winter, low temperatures will reduce microbial activity, but biofilters handle much less airflow because typically winter ventilating rates are only 1/10 of the summer levels. • In winter, biofilters for manure storage may freeze and stop working temporarily, while biofilters for treating exhaust air from livestock barns may be able to maintain working conditions as long as the temperature of the exhaust air promotes biofilter operation.
pH	• The pH of biofilter media needs to be maintained near neutral to maximize microbial activity. • Soil has the best pH buffering capacity, followed by compost and wood chips. Peats are naturally acidic and have little buffering capacity. • Degradation of high concentrations of some volatile organic compounds may result in acidic conditions and reduce microbial activity in biofilters.

Maintaining optimum moisture content is critical to efficient operation of biofilters. More than 90 percent of biofilter problems are attributed to media drying. Automated biofilter watering systems using lawn sprinklers and soaker hoses have been successful, while economical on-line moisture sensors that can be used in biofilters are being researched. Currently, biofilter moisture is typically monitored by look and feel rather than measurement. In a common up-flow biofilter, the media dries from the bottom. It may be necessary to dig down into the media to check moisture content. Certain job training may be needed for biofilter moisture management.

Media degradation and dust buildup in the media will increase pressure drop over time and may result in poor building ventilation. A manometer can be used to check the pressure drop across the biofilter periodically. A significant increase from the design pressure drop may indicate media plugging and the need to recondition or replace the media. Biofilter may fail if dust in the air fills the pore spaces faster than the microorganisms can break it down. When treating air with high dust loading, pre-filtering dust may be needed to improve the longevity of the biofilter.

To achieve uniform air treatment, maintaining uniform media depth and porosity throughout the biofilter is critical. Air will follow the path of least resistance, which is often where the media has the least depth or largest porosity. Air channeling reduces biofilter effectiveness. Efforts should be made to seal all duct and plenum joints as well as the edges of the biofilter media, and to check potential untreated air leaks or air channeling periodically.

Weed growth on the biofilter can cause air channeling and limit oxygen exchange. Mice and rats may burrow through the warm media during cold weather. Weed and rodent control may be needed to protect the biofilter.

Site selection of biofilters

Biofilters used to treat air from livestock facilities are often uncovered and exposed to weather conditions because open-bed biofilters cost less than closed types, and open-bed types help reduce pressure drops. An open-bed biofilter should be built on a sloped, well-drained area. Reducing chances of excessive water in the biofilter will increase system life. The biofilter should be far enough from the building to avoid rain or snowmelt running off the roof onto the biofilter media. Excessive water from storm events or a watering system failure can cause moisture to saturate the media and temporarily reduce the barn ventilating rate.

Costs of biofilters

Construction costs of biofilters may include fans, media, watering system, ductwork, and labor. Typical horizontal bed biofilters for treating exhaust air from livestock facilities may cost from \$60 to \$250 per 1,000 CFM airflow treated, which can be translated to \$7.20 to \$30 per finishing pig space, or \$28 to \$118 per dairy cow space (assuming warm weather airflow rate is 120 CFM per finishing pig space and 470 CFM per dairy cow space). Construction costs of vertical bed biofilters are usually 50 percent higher than horizontal bed biofilters.

Operation/maintenance costs of biofilters mainly include the additional electrical cost for fans to overcome the pressure drop of a biofilter, and the cost of replacing the media every three to five years. Assuming pressure drop of the biofilter is 0.25 inches of water and 79 watts are needed for 1,000 CFM airflow, monthly electrical cost for the biofilter fans in summer is estimated to be $4.50 per 1,000 CFM treated, which can be translated to $0.50 per finishing pig space, or $2 per dairy cow space. In winter the electrical cost is much less since usually only 1/10 of summer airflow needs to be treated and the pressure drop is lower.

Biofiltration technology has been proposed to be the most cost-effective method for treating exhaust air from livestock facilities as compared to other odor treatment technologies such as wet scrubber or oil spraying. Operation costs of biofilters may be further reduced by using partial biofiltration at certain times of the year.

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MF3387 November 2017