factsheet
Pork Information Gateway

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Biofilters for Odor Control at Swine Facilities

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Biofiltration can reduce odor and hydrogen sulfide emissions from livestock facilities by as much as 95% and ammonia by 65% (Nicolai & Janni, 2000) This method of odor control has been shown to be both economical and effective in swine raising systems. Biofilters are most easily adapted to mechanically ventilated buildings or on the pit fans of naturally ventilated buildings. Biofilters can also treat air vented from under manure storage covers.


Figure 1. Open bed biofilter

A biofilter is simply a layer of organic material, typically a mixture of compost and wood chips or wood shreds that support a microbial population. Odorous air is forced through this material and converted by the microbes to carbon dioxide and water. Key factors, influencing biofilter performance, include the amount of time the odorous air spends in the biofilter (contact time) and the moisture content of the filter material. The biofilter reliance on microorganisms requires an appreciation of ecological concepts, which must be considered in biofilter design. Concepts addressed in this publication were developed at the Biosystems and Agricultural Engineering Dept., University of Minnesota (BAEU-18) by Nicolai, et al. 2004. Factors include the sizing of the biofilter bed, selecting fans to push the air through the biofilter, choosing biofilter media, moisture control, operation and management, and cost of construction and operation.

Biofilter Configuration and Elements

Biofilters can be configured as either open or closed beds (figure 1). Open bed biofilters are the most prevalent configuration used today. Open bed biofilters are typically 10-18 inches deep and are larger than closed bed biofilters. Open bed biofilters are typically built outdoors on the ground and are exposed to a variety of 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. Closed bed biofilters usually treat smaller airflows, typically have deeper media (2-3 feet) to reduce the space needed to achieve the required treatment, and are more expensive. Figure 2 illustrates elements of an open-bed biofilter. They are:

- A mechanically ventilated space with biodegradable gaseous emissions;
- An air handling system to move the odorous exhaust air from the building or manure storage through the biofilter;
- An air plenum to distribute the exhaust air evenly beneath the biofilter media,
- A 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 made available to the microorganisms.

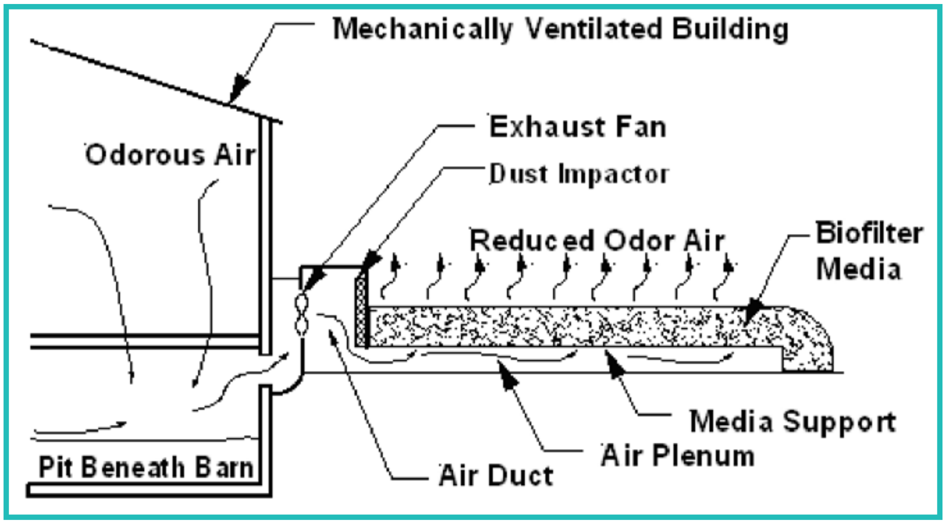

Figure 2. Schematic of a typical open-faced biofilter

The odorous air is exhausted by a fan from the building and uniformly distributed through the biofilter media. Microorganisms attached to the organic media create a biofilm. In the biofilm, the microorganisms oxidize or converts the biodegradable gases into carbon dioxide, water, mineral salts that remain in the media, and biomass (i.e., microorganisms). The cleaned exhaust air then leaves the biofilter.

Biofilter Design

Biofilter designs for swine facilities are based on the volumetric flow rate of air to be treated, media characteristics, biofilter size (area) constraints, air retention time, moisture control, maintenance, and cost. Efficient cleaning of airstreams and economical operation of the biofilter depend on careful consideration of all factors.

Airflow Rate Biofilters used to treat ventilating air exhausted from a livestock building should be sized to treat the maximum ventilation rate, which is typically the warm weather rate of the building. This ventilation rate is dependent on the type, size, and number of animals in the building. Industry recommended ventilation design procedures can be found in MWPS-32, Ventilation Systems for Livestock Housing. Biofilters treating air from a manure storage unit may treat a lesser volume of air having a higher concentration of odorous gases compared to building ventilation air. A typical airflow rate from covered manure storages is 0.01 cfm per square foot of surface area. For this use, fans should be selected to ensure a negative pressure under the cover of between 0.5 and 1.0 inch of water (See section on fan selection).

Media Characteristics Media selection is critical in biofilter design. For a biofilter to operate efficiently, the media must provide a suitable environment for microbial growth while maintaining 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 of the substrate itself. Table 1 lists the characteristics for various biofilter media available. Mixtures of these materials have the advantage of combining these characteristics.

Because biofilter treatment efficiency depends on the microbial breakdown of volatile organic compounds, the number and type of microorganisms present in the biofilter is important. Natural media materials such as peat, loam soil, and compost normally contain sufficient microorganisms for a biofilter treating air from a livestock building or manure storage. However, a short conditioning period (two to three weeks) may be necessary to allow the microorganisms to adapt to the odorous gases in the exhaust air. During this conditioning time the biofilter efficiency is limited.

A proven organic media mixture for animal agriculture biofilters ranges from approximately 20:80 to 30:70 ratio by weight of compost and wood chips or wood shreds. The wood provides the porosity and structure while the compost provides microorganisms, nutrients, and moisture holding capacity. Media mixtures with more compost (less wood chips) will result in higher pressure drops but only slightly higher efficiencies.

Figure 3. 60% Void Media

The life of this media is at least three years and more likely five to ten years. During this time the media decomposes and compacts which reduces the porosity (air space in the media) and increases the pressure needed to move the air through the biofilter media. As the airflow rate through the biofilter increases, the force needed to push the air through the media increases. This force is measured as the static pressure difference from the inlet side of the biofilter to the atmosphere.

For a biofilter, the relationship between airflow rate and static pressure depends on the type of media and media depth. Figure 4 shows this relation between Unit Airflow Rate (UAR) (the amount of airflow per square foot of biofilter surface area) and Unit Pressure Drop (UPD) (the static pressure drop per foot of biofilter media depth) for a variety of materials tested in the lab. The lines shown are for media with different percent voids. The percent voids is a measure of the amount of open pore space in the media. Note as airflow increases it takes more pressure to push the air through the media (i.e. as the airflow rate increases the pressure drop through the media increases). Also, as porosity increases the pressure drop decreases. This porosity is both a function of the original media, compaction of the media, and media moisture content. Porosity can also be affected by the age of the media.

Material	Porosity	Moisture capacity	Nutrient capacity	Useful life	Comments
Peat	Average	Good	Good	Good	Good sources of micro-organisms
Soil (heavy loam)	Poor	Good	Good	Good	
Compost (yard waste)	Average	Good	Good	Good	
Wood chips (3 in.)	Good	Average	Average	Good	Good additions for porosity
Bean Straw	Good	Average	Average	Poor	
Corn Stalks	Good	Average	Average	Poor	

Table 1. Biofilter media characteristics.

If the media porosity is less than 50% the static pressure drop across the biofilter media exceeds the capability of most agricultural ventilation fan. The porosity may be increased by adding slightly larger woodchips to the media mixture. Also over time the media decomposes and settles which reduces the pore space. Also, any activity that causes compaction, such as walking on the media, will reduce pore space. Care must be taken to maintain adequate porosity to maintain designed airflow.

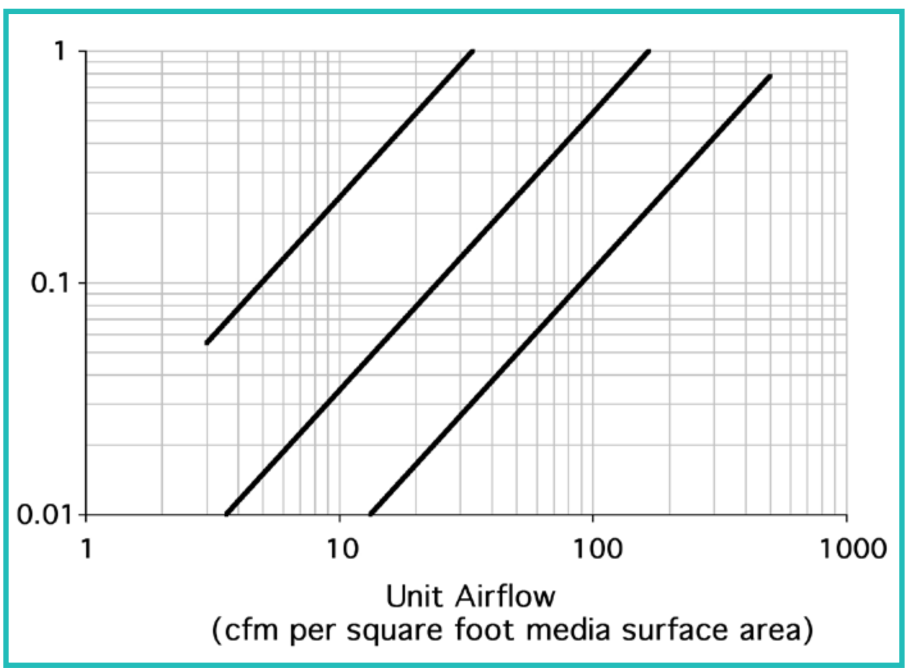

Figure 4. Media unit pressure drop and unit flow rate relations for various biofilter media.

For livestock systems, biofilter media depth is typically 10 to 18 inches. Media depths greater than 18 inches result in excessive pressure drops and greater potential for compaction. Media depths less than 10 inches will dry out more quickly and have a greater potential for air channeling.

The procedure for estimating percent voids in biofilter media (bucket test).

1. Start with two identical straight-sided five-gallon buckets.
2. Fill one bucket one-third full with media. Drop the bucket ten times from a height of six inches onto a concrete floor.
3. Add media to fill the same bucket two-thirds full and drop the bucket ten times from a height of six inches on to a concrete floor.
4. Fill the bucket to the top with media and once again drop the bucket ten times from a height of six inches onto a concrete floor.
5. Fill the bucket once again to the top edge of the bucket.
6. Fill the second bucket to the top with clean water.
7. Slowly pour water from the second bucket into the first bucket containing media until the water reaches the top of the media-filled bucket (figure 5).
8. Record the total depth of the second bucket, and the distance between the level of the remaining water and the top of the bucket (figure 6).
9. Calculate the percent voids by dividing the water level drop in the second bucket (i.e. distance from the water line to the top of the bucket) by the total bucket depth and multiply by 100.

Method is modified from Composting and Mulching: A Guide to Managing Organic Yard Waste. U of M Ext #BU-3296-GO.

Figure 5. Step 7 adding water

Figure 6. Step 8 measuring water removed

Air Retention or Empty Bed Contact Time

Retention time indicates the amount of time that the air is in contact with the biofilter media. Longer retention times give the biofilter a longer time to treat the odorous gases. Optimum retention time depends on the specific gas (or gases) being treated and the concentration of the gas (gases). For design purposes, the residence time is expressed as the empty bed contact time (EBCT) (Figure 7). EBCT is determined by dividing the volume of the media (ft^3) by the airflow rate (ft^3/s). Note that the actual contact time is much less than the EBCT because the media fills much of the biofilter bed volume so the air flows through the pores in less time. EBCT is used in the calculations since the actual contact time is difficult to measure. Empty Bed Contact Times to reduce odor and hydrogen sulfide emissions by 90% for swine has been shown to be about 5 seconds. This residence time requirement is not dependent on specific media —provided an approximately 20:80 mix ratio is used. These recommended contact times are based on average gas concentrations from typical facilities.

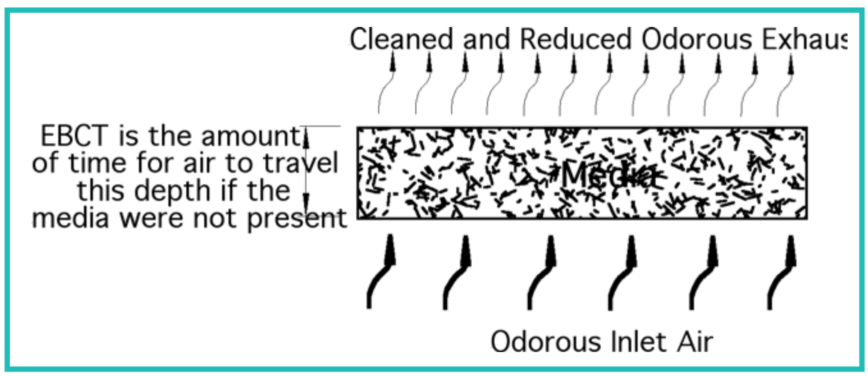

Figure 7. Residence time is expressed as Empty Bed Contact Time (EBCT)

Sizing a biofilter

To determine the biofilter surface area or footprint requires selection of the volumetric flow rate, the Empty Bed Contact Time (EBCT), and the preferred media depth.

With a given airflow rate that is to be treated and recommended EBCT (5 seconds for swine), the biofilter media volume can be determined using the following:

$$V_m = Q * EBCT / 60 \quad (1)$$

where: V_m = Media volume (ft^3)
Q = Airflow rate (ft^3/min)
EBCT = Empty Bed Contact Time (s)

By selecting a media depth, the media area or footprint needed can be determined.

$$Am = V_m/D_m \quad (2)$$

A_m = Biofilter media area (ft^2), and
D_m = Media depth (ft).

Next, calculate the Unit Airflow Rate (UAR) using the media area and airflow rate.

$$UAR = Q/A_m \quad (3)$$

UAR = Unit Airflow Rate (ft^3 air/ft^2 of media surface area /s)

Use the UAR and Figure 2 (or Equation 4) to determine the Unit Pressure Drop (UPD) for the selected media.

$$UPD=8.82 * 10^{11} * (\text{percent voids})^{-8.6} * UAR^{1.27} \quad (4)$$

UPD = Unit Pressure Drop (inches of H_2O column per foot of media depth)

Multiply the UPD by the media depth, Dm to determine the total pressure drop for the biofilter.

$$\text{Total pressure drop (inches of } H_2O \text{ column)} = UPD * D_m \quad (5)$$

The expected total pressure drop can be used with the building airflow rate to select the exhaust fan(s). If the total pressure drop is greater than desired, the depth selected and used in Equation 2 can be reduced to calculate new values of Am, UAR, and UPD.

If biofilter space is limited or if the footprint available for the biofilter is not sufficient, the area can be ajusted by determining a new depth. The allowable area and the calculated volume of material are used to calculate the depth.

$$D_m = V_m/A_m \quad (6)$$

Worked Example

Determine the dimensions and pressure drop of a biofilter for a 5000 swine nursery facility with a hot weather ventilation rate of 35cfm per pig (MWPS-32). Assume a 14-inch (Dm=1.17ft) biofilter bed depth of compost and woodchips. No "percent voids" measurement was determined.

- Use a 5 second EBCT from Nicolai, et al. 2004: Q = 35 ft^3/min/pig * 5000 pigs = 175, 000 ft^3/min
- Using Equation 1: V_m=Q*EBCT / 60 = 175,000 ft^3/min * 5 sec / 60sec/min = 14,580 ft^3
- Using Equation 2: $A_m = V_m/D_m$ = 14,580 ft^3 / 1.17 ft = 12,460 ft^2
- Using Equation 3: UAR = Q/A_m = 175,000 ft^3/min / 12460 ft^2 = 14 ft^3/min per ft^2
- Using Equation 4 or Figure 4 and a UAR of 14: UPD= 8.82 * 10^{11} * (percent voids)$^{-8.6}$ * $UAR^{1.27}$
  At 60% the UPD = 8.82*10^{11} * 5.1038 * 10^{-16} * 28.5 = 0.013
  At 50% the UPD = 8.82*10^{11} * 2.448 * 10^{-15} * 28.5 = 0.061
  At 40% the UPD = 8.82*10^{11} * 1.668 * 10^{-14} * 28.5 = 0.419
  The unit pressure drop (UPD) ranges from 0.013 to 0.419 inches per foot of media, depending on the percent void space. The 0.4 pressure drop is out of range of most agricultural ventilation fans, thus requiring selecting a more pores media.
- If porosity is not measured (% voids determined) use 40% voids. This will give the worst-case pressure drop.
- Using Equation 5 the total pressure drop through the media is 0.419 x 1.17 ft = 0.49 inches of water.

Fan Selection

Fan selection requires knowledge of both design airflow rate and pressure drop. When a biofilter is added to a ventilation system the force needed to push the air through the media increases. This force is measured as the static pressure difference from the inlet side of the biofilter to the atmosphere. This static pressure can also be thought of as the resistance to air flow through the biofilter material. Resistance to air flow is fundamental to all ventilation systems and is typically reported in inches of water. Static pressure (pressure drop) between the inside and outside of a mechanically ventilated livestock building without a biofilter ranges between 0.02 (winter conditions) and 0.10 (summer conditions) inches of water (H_2O).

Typical agricultural ventilating fans are selected for the design airflow rate and a pressure drop of 0.12 inches of H_2O to account for the pressure drop through the building. As discussed earlier, the pressure drop through a biofilter can range from 0.1 to 1.0 inches of water. This means that installation of a biofilter requires ventilation fans with the ability to move air through both the building and the biofilter-the sum of the two pressure drops. For existing facilities, either the existing fans can be replaced with fans that have higher pressure characteristics or additional fans, in series with the existing fans, can be added to provide the pressure necessary to push the air through the biofilter.

Fan selection must also consider the range of ventilation rates needed to meet the barn ventilation requirements. Fans must be sized to meet the minimum ventilation requirements of the animals and then staged to meet the additional ventilation requirements as ambient temperatures increase. This typically means a set of fans - some small and some larger all controlled with an integrated temperature controller. Use rated agricultural ventilation fans with known performance characteristics. Select fans to provide the airflow and pressure drop needed, using rating information from a recognized independent testing laboratory (http://www.bess.uiuc.edu).

Shutters may be needed on fans if more than one fan supplies a biofilter and one or more of the fans can cycle on and off. Shutters will prevent back drafting through fans that are not running. Another option is to use only one fan to supply each isolated biofilter section. In this case, each section of biofilter must be sized according to the flow rate of the individual supply fan. Care in construction is needed to avoid air leakage between biofilter sections and subsequent back drafting through the fans.

Dust accumulation on fans, guards, and shutters can significantly reduce fan performance. Therefore, ducts must be designed to provide access for fan maintenance and inspection. Also, select only fans and motors that can operate in a corrosive environment. Fiberglass, stainless steel, and PVC materials are preferred over galvanized or carbon steel.

Moisture control

Biofilter media moisture control is essential for odor reduction through a biofilter. If the media dries out, the microbes are deactived, and cracks and channeling of air results in a reduction of filter efficiency. Too much water can plug some of the pores in the media, causing channeling and limiting oxygen flow in saturated areas of the filter, thereby creating anaerobic zones in the biofilm. Excess moisture is generally not a problem because the additional moisture drains through the media or evaporates due to the constant airflow through the biofilter. Recommended moisture contents for biofilters range from 40-65% wet basis (w.b.) with an optimum moisture content of 50% (w.b.).

During the summer months, the warmer temperatures and increased airflow cause the media to dry out. Moisture can be supplied by sprinkling water directly onto the top of the biofilter. Water addition can be easily automated with a timer and a lawn sprinkler system. This sprinkling should be uniform as possible across the top surface of the media. Dry areas will promote air channeling and limit odor reduction efficiency. During the winter months (cooler temperatures) moisture transfer to the media from the room exhaust air prevents drying; therefore no water addition is needed. In periods of rainy weather, no additional water is needed. If the media dries out, recovery begins shortly after water is applied and can be complete in one week.

Temperature

Microorganisms that are useful in biofilters tolerate a range of temperatures and are most active between 70-90ºF. In winter the cooler temperatures will reduce the microbial activity but at the same time there is less airflow because of winter ventilation rates in the buildings. Most building exhaust air biofilters maintain temperatures well above freezing even in winter due to continuous flow of warm air from the building. However, biofilters on manure storages or on unheated buildings will freeze in cold weather, temporarily reducing the efficiency of the biofilter. As the biofilter heats up in the spring, the microorganisms become active again and the effectiveness of the biofilter is restored.

Design of Biofilters on Naturally Ventilated Buildings

Biofilters are only effective when there is a captured air stream. This air stream is typically the fan exhaust from mechanically ventilated buildings or the exhaust from a non-porous covered manure storage. The air emissions through the side wall of a naturally ventilated building typically cannot make use of a biofilter. However, some naturally ventilated buildings use mechanical ventilation in combination with natural ventilation. The mechanical portion of the ventilation is the exhaust fans on the pit or possibly sidewall fans that operate to provide minimum ventilation in the winter. For these types of facilities it is possible to install biofilters on these exhaust fans. The total odor reduction achieved using a biofilter in this situation will be variable. During the cool months when most of the ventilation air passes through the exhaust fans, and subsequently the biofilter, the odor reduction is similar to mechanically ventilated buildings-approximately 80-95%. However, during the summer months the primary means of providing air exchanges in the barn is through the natural ventilation system (curtains and/or ridge vents). During these times, the odor reduction provided by installing a biofilter on the minimum ventilation system is less dependent on the percentage of total ventilation air treated. The amount of odor reduction achieved with the biofilter is directly related to the percentage of air moving through the biofilter (vs. the natural ventilation system). The warmer the ambient temperature the higher percentage of ventilation air is unfiltered and thus the lower the odor reduction for the total building. During the summer ventilation mode with the curtains lowered or opened, the exhaust air through the curtain is not controlled and is dependent upon the wind. Also, with very little or no pressure drop across the slatted floor, parts of the barn experience up-drafting due to buoyancy while in other areas air is moving down through the slats. Thus pit gases can rise to the pig environment zone and be exhausted uncontrolled through the open curtain.

To achieve pit gas odor reduction through biofiltration, up-drafting through the slatted floor must be eliminated or greatly reduced when the curtains are lowered. On a typical concrete slat finishing floor (14% opening) up-drafting begins when the pit ventilation falls below 40 cfm per pig.

One means of increasing the odor reduction efficiency for these naturally ventilated buildings is to increase the percent of airflow through the biofilter by increasing the number or size of the fans (converting the building to more mechanical ventilation).

More research is being done to establish the optimum design and management of biofilters on naturally ventilated buildings.

Biofilter Construction

Siting: The biofilter bed should be located close to the exhaust fans to limit the length of ducting but far enough from the building so that it does not intercept roof runoff. It is also important to construct the biofilter in an area where water will not pond near the ducting, plenum or fans. Keeping this area dry will increase the life of the system. Typically, the organic material absorbs most of the rain or snow that falls on an open bed biofilter. However, during periods of high rainfall or in the event of a sprinkling system failure, there is the potential for water to leach out of the organic material. Therefore, the biofilter bed should be built on a sloped, well-drained area so excess water can move away from the biofilter.

Ductwork and Plenum: Ductwork and plenum construction are critical components of a biofilter. Ducting must be constructed to move the air from the fans to the plenum of the biofilter (figure 8). Materials to construct both the ducting and plenum must be smooth and resistant to rotting or corrosion. These ducts must be sized in such a way to minimize pressure drop. A pressure drop will occur when there are sharp bends or flow restrictions. Pressure drop is also a function of the air velocity. As the air velocity increases the pressure needed to move the air increases. A suggested air velocity range for most ducts and plenums is between 600-1000 feet per minute. The velocity can be calculated by dividing the flow rate through the duct (cfm) by the cross sectional area of the duct (ft^2). This same calculation must be made in the plenum and where the air moves from the plenum to the biofilter material.

The plenums beneath the media for most low cost biofilters have been constructed out of wood pallets. With these systems the row of pallets next to the barn are raised to allow air distribution parallel to the barn before entering the pallets which are aligned perpendicular to the barn. Plastic mesh or screen (that has a maximum opening of 1 in and has at least 75% opening) is placed over the pallets to prevent the small biofilter particles from falling through the pallet slats. Each row of pallets is laid down, covered with netting, and then covered with media before the next row of pallets is laid down. This procedure reduces the potential for compaction as the media is being placed. Depending on the pallet construction and mesh or screen used, airflow from the plenum to the biofilter may be restricted causing excessive pressure drops.

Therefore, it is critical to verify that there is adequate open area under the pallets for air to move from the plenum to the biofilter. The same criteria of maintaining air velocities between 600 and 1000 ft/min should be used.

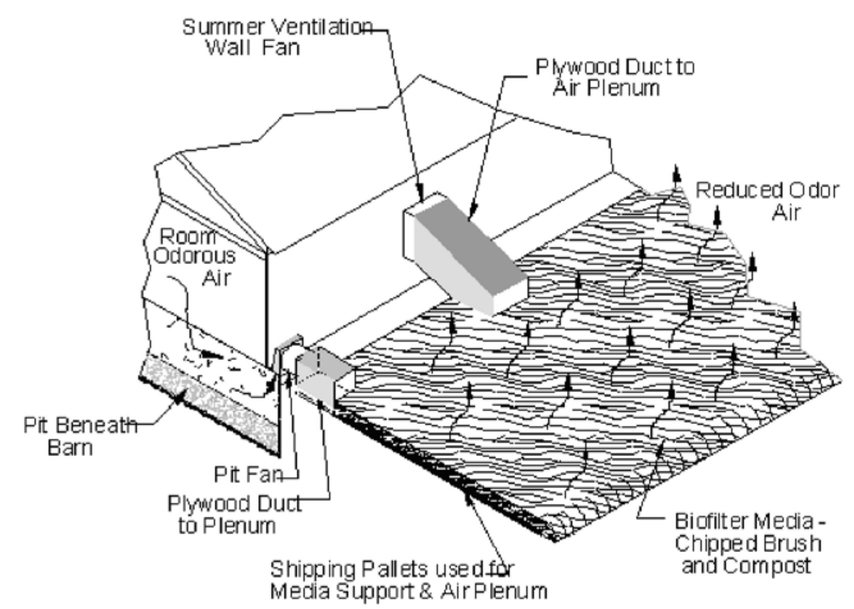

Figure 8. Biofilter construction

Organic Media: As discussed previously, the biofilter media is made up of a mixture of compost and wood chips at a weight ratio of 20:80 to 30:70. Mixing this material can be done on the ground with a front-end loader or with a TMR mixer. After mixing, the material is placed on the plenum and leveled. Because compaction of the biofilter media leads to increased pressure drops, it is important to minimize compaction during construction. All ducting work should be done before the media is placed and no machinery or foot traffic should be allowed on the media. 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 sheets of plywood to limit compaction.

It is critical to maintain an even layer of media throughout the 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. Odorous air may also escape from around the edges of the biofilter media or at the intersection of the ductwork and plenums. Therefore, efforts should be made to seal all duct and plenum joints with appropriate caulking or plastic sheeting.

Over time the media will decompose and need to be replaced (see Maintenance). Currently there are no regulatory 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 should be handled similar to compost and land applied to cropland at agronomic rates. If the biofilter media is very dry, there will be significant amounts of dust generated during loading and land application. Care should be taken to avoid inhaling this dust.

Maintenance

The four areas of maintenance needed for biofilters include: moisture content, weed control, rodent control and assessing pressure drop. None of these management issues takes significant amounts of time but each is important to be done regularly for proper biofilter operation.

Moisture Content: Biofilter moisture management requires some on the job training. Typically, no moisture measurements are needed. Rather, the feel and look of the filter material are adequate indicators of too much or too little water. During cold weather the media moisture content is fairly constant (from heated exhaust air) and remains at a moisture content of approximately 50%. However, in the summer a media watering system is needed. A standard lawn sprinkling system has been used in the past and is fairly effective. However, because the media dries from the bottom and is watered from the top, it is necessary to dig down into the media to check moisture content. Dampness should be felt one-half to three-quarters of the way down through the depth of the media. If dampness is felt throughout the depth of the media, then the watering system is providing too much water. However, if only the top few inches are damp then the amount of water needs to be increased. Often watering is done at night for one or two hours to reduce evaporation losses.

Weeds: Weed growth on the biofilter surface can reduce the treatment efficiency by causing air channeling and limiting oxygen exchange. Roots can contribute to plugging of 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 control weeds.

Rodents: A good rodent control program is essential with a biofilter. Mice and rats burrow through the warm media during the cold winter months causing channeling and poor treatment. Rabbits, woodchucks, and badgers have been suspected of burrowing through and nesting in biofilters. Fortunately, most livestock and poultry operations currently have a good rodent control program and these programs are not very expensive and can easily be expanded to incorporate any biofilters.

Assessment of Pressure Drop

Over time the degradation of the media material and dust buildup in the media and media settling will cause the pressure drop across the media to increase. As pressure drop increases the amount of air moved by the ventilation fans decreases. This decrease in flow will eventually result in poor building ventilation. The type of biofilter media and the dustiness of the exhaust air will both affect the length of time before the media plugs and the pressure drops become excessive. Unfortunately, no long-term studies have been conducted to determine just how long this will take, but it is estimated that most biofilters will last 3 to 5 years or more. Reduced air quality in the building at maximum ventilation rates will likely be the first sign of biofilter plugging. A manometer can be used to check the pressure drop across the biofilter. Depending on the design of the biofilter and ventilation fans, pressure drops over 50% of the design pressure drop indicate the need to replace the media. Note that the maximum pressure drop must be measured at maximum ventilation rates. Fans used with biofilter systems should be cleaned regularly to ensure fans can provide design airflow rates at design pressure drops.

Health and Safety Concerns

Little research information exists on the potential health implications of microbial emissions from biofilters. One study measured microbial emissions from biofiltration processes and concluded that the concentrations were only slightly more than ambient outdoor air. In another study (Krzymien, etal. 1999) researchers found that relatively large release of VOC's were released during the initial startup but that the numbers quickly diminished and stabilized. The dust and bioaerosols from biofilters are not expected to be a problem during normal operation. Dust and mold spore emissions during construction, maintenance, and removal may pose a potential worker health risk. Dust control and personal protection (dust filter masks) may be useful to minimize worker exposure during media construction, maintenance or removal activities.

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