University of Minnesota Extension Service

# Biosystems and Agricultural Engineering Update

Department of Biosystems and Agricultural Engineering
**College of Agricultural, Food and Environmental Sciences**

**Revised March 2004** **BAEU-18**

# Biofilter Design Information

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Odor emissions from livestock and poultry facilities are a source of contention in many areas of Minnesota and across the United States. Under certain conditions odor emissions have been known to affect neighbors and communities at distances of a mile or more from the odor source. One odor control technology that has been shown to be both economical and effective is a biofilter. Biofiltration can reduce odor and hydrogen sulfide emissions from livestock and poultry facilities by as much as 95% and ammonia by 65%. This method of odor control has been used in industry for many years and was recently adapted for use in livestock and poultry systems. Biofilters are most easily adapted to mechanically ventilated building or on the pit fans of naturally ventilated buildings. Biofilters can also treat air vented from covered manure storage covers.

## Biofilter Design

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 is converted by the microbes to carbon dioxide and water. Key factors influencing biofilter performance are 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. Design issues addressed in this publication 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.

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## Biofilter Configurations and Elements

Biofilters can be configured as either open or closed beds. Open bed biofilters are the most prevalent configuration used today. Open bed biofilters are typically 10 to 18 inches deep and are much 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 or more) to reduce the space needed to achieve the required treatment, and are more expensive. Figure 1 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 available to the microorganisms.

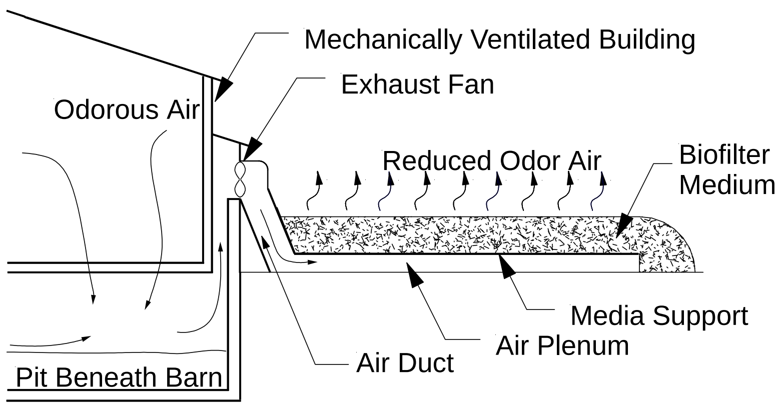


Figure 1. Schematic of a typical open bed biofilter.

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 the biodegradable gases into carbon dioxide, water, mineral salts, and biomass (i.e., microorganisms). The cleaned exhaust air then leaves the biofilter.

## Biofilter Design

Biofilter designs are based on the volumetric flow rate of air to be treated, specific air contaminants and concentrations, media characteristics, biofilter size (area) constraints, moisture control, maintenance, and cost. These parameters all play a role in either the efficient cleaning of airstreams or in the economical operation of the biofilter.

## 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. Proper ventilation design procedures can be found in MWPS-32, *Ventilation Systems for Livestock Housing*. Some building design ventilation rates are shown in Table 1.

**Table 1. Typical building ventilation rates (MWPS-32).**

| Facility Type | Ventilation requirements cubic feet per minute (cfm) Per animal space | | |
|---|---|---|---|
| | Cold Weather | Mild Weather | Warm Weather |
| Nursery | 3 | 15 | 35 |
| Finishing | 10 | 35 | 120 |
| Gestation | 12 | 40 | 150 |
| Farrowing | 20 | 80 | 500 |
| Broiler/Layer (5 lb) | 0.5 | 2.5 | 5 |
| Turkey (40 lb) | 3.2 | 14 | 32 |
| Dairy (1400 lb) | 50 | 170 | 470 |

Biofilters treating air from a manure storage unit may treat a lesser volume of air but air with a higher concentration of odorous gases. Typical airflow rates from a covered manure storage are 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. (More about fan selection later in this chapter.)

## 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 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 available in Minnesota. 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 | Good sources |
| Soil (heavy loam) | Poor | Good | Good | Good | of microorganisms |
| Compost (yard waste) | Average | Good | Good | Good | |
| Wood chips | Good | Average | Average | Average | Good additions |
| Straw | Good | Average | Poor | Poor | for porosity |

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 30:70 to 50:50 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.

The life of this media is at least three years and likely five years or longer. During this time the media decomposes and becomes more dense 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. 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 0.04 and 0.10 inches of water ($H_2O$).

For a biofilter, the relationship between air flow rate and static pressure depends on the type of media and media depth. Figure 2 shows this relation between Unit Airflow Rate (UAR) (the amount of airflow per square foot of biofilter surface) 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 that as the airflow rate increases the pressure drop through the media increases (i.e. as airflow increases it takes more pressure to push the air through the media). 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. 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.

Equation (1) is the relationship between void space (percent voids), Unit Airflow Rate (UAR) and Unit Pressure Drop (UPD) used for design. Percent voids is measured using the technique outlined below.

$$UPD = 8.82 * 10^{11} * (\text{percent voids})^{-8.6} * UAR^{1.27} \quad (1)$$

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.

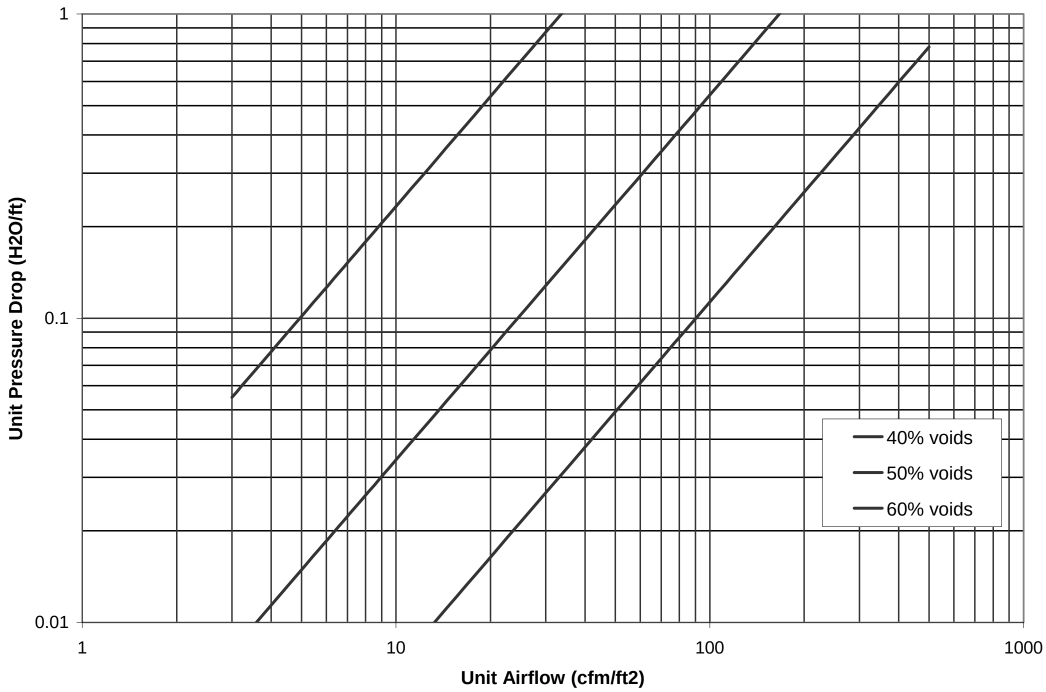


Figure 2. Media unit pressure drop and unit flow rate relations for various biofilter media.

## Estimating percent voids in biofilter media

1) Start with two identical five gallon buckets.
2) Fill one of the buckets one-third full with media. Drop the pail 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 pail 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 pail from a height of six inches on to a concrete floor.
5) Fill the bucket once again to the top edge of the pail.
6) Take the second bucket and fill it 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.
8) Record both the total depth inside the second bucket, and the distance between the level of the remaining water and the top of the bucket.
9) Calculate the percent voids by dividing the 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*. University of Minnesota Extension publication # BU-3296-GO. 2000

**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. 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). 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. Table 3 lists Empty Bed Contact Times to reduce odor and hydrogen sulfide emissions by 90%. These residence time requirements are not dependent on specific media—provided an approximately 40:60 mix ratio. These recommended contact times are based on average gas concentrations from typical facilities.

**Table 3. Recommended minimum empty bed contact times for various livestock systems.**

| 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 |

# Sizing a Biofilter

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

With a given airflow rate and selected EBCT, the biofilter media volume can be determined using the following:

$$V_m = Q * EBCT / 60 \text{ s/min} \qquad (2)$$

where: $V_m$ = Media volume ($ft^3$)

$Q$ = Airflow rate ($ft^3/min$)

EBCT = Empty Bed Contact Time (s)

If biofilter space (area) is not limiting, a media depth can be selected and used to find the space needed.

$$A_m = V_m/D_m \qquad (3)$$

where: $A_m$ = 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.

$$UAR = Q/A_m \qquad (4)$$

where: UAR = Unit Airflow Rate ($ft^3/ft^2$ s)

Use the UAR and Figure 7.2 (or Equation 5) to determine the Unit Pressure Drop (UPD) for the selected media.

$$UPD = 8.82 * 10^{11} * (\text{percent voids})^{-8.6} * UAR^{1.27} \quad (5)$$

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

$$\text{Total pressure drop} = UPD * D_m \quad (6)$$

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 $A_m$ , UAR, and UPD.

If biofilter space is limited, the area can be selected as the first design criteria. The allowable area along with the calculated volume of material is used to calculate the depth.

$$D_m = V_m/A_m \quad (7)$$

## Worked Example (Part 1)

*Determine the dimensions and pressure drop of a biofilter for a 5000 head swine nursery facility with a hot weather ventilation rate of 35 cfm per pig (Table 7.3). Assume a 14 inch ($D_m$=1.17 ft) biofilter bed depth of compost and woodchips. NO "percent voids" measurement was determined.*

• From Table 7.5 use a 5 second EBCT.

$Q = 35\ ft^3/min/pig * 5000\ pigs = 175,000\ ft^3/min$

• Using Equation 2

$V_m = Q*EBCT / 60 = 175,000\ ft^3/min * 5\ sec / 60 sec/min = 14,580\ ft^3$

• Using Equation 3

$A_m = V_m/D_m = 14,580\ ft^3 / 1.17\ ft = 12,460\ ft^2$

• Using Equation 4

$UAR = Q/A_m = 175,000\ ft^3/min / 12460\ ft^2 = 14\ ft^3/min\ per\ ft^2$

• Using Equation 5 or Figure 7.13 and a UAR of 14

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

At 60% = $UPD = 8.82*10^{11} * 5.1038 * 10^{-16} * 28.5 = 0.013$

At 50% = $UPD = 8.82*10^{11} * 2.448 * 10^{-15} * 28.5 = 0.061$

At 40% = $UPD = 8.82*10^{11} * 1.668 * 10^{-14} * 28.5 = 0.419$

The unit pressure drop (UPD) ranges from 0.013 to 0.419 inches per foot of media, depending on the percent void space.

**• If porosity is not measured (% voids determined) use 40% voids. This will give the worst case pressure drop.**

• The total pressure drop (eq. 6) through the media is 0.419 x 1.17 ft

= 0.49 inches of $H_2O$

## Relationship between EBCT and Pressure Drop

During hot weather the ventilation rate of the building increases and the odor concentration decreases. This lower odor concentration requires less contact time (EBCT) for cleanup. This suggests that if summer ventilation rates are used for sizing a biofilter, then the design EBCT can be less than the values shown in Table 3. Reducing the design EBCT results in a smaller media volume and increased pressure drops through the media, given the same media depth, because of the increased air velocity. To decrease this pressure drop, the media depth can be decreased. If this is not possible, the biofilter area must be increased thus increasing the EBCT. Increasing the EBCT means a better filter efficiency, a lower pressure drop, more biofilter media, and a larger biofilter area. Building a larger biofilter may be justified due to the less powerful fans needed and the reduced operating cost of these fans. Figure 3 graphically represents the relationship between EBCT, area of media, and Total Pressure Drop.

**Worked Example, Continued (Part 2)**

Note the following changes in biofilter size and pressure drop if the EBCT in the previously worked example is increased by a factor of 1.5 or increases from 5 to 7.5 seconds. Hot weather ventilation rate remains at 175,000 cfm.

- Using Equation 2

$V_m$ =Q*EBCT / 60
= 175,000 $ft^3$/min * 7.5 sec / 60 sec/min
= 21,875 $ft^3$

- Using Equation 3

$A_m = V_m/D_m$
= 21,875 $ft^3$ /1.17 ft
= 18,690 $ft^2$

- Using Equation 4

UAR = $Q/A_m$
= 175,000 $ft^3$/min / 18,690 $ft^2$
= 9.4 $ft^3$/min per $ft^2$

- Using Equation 5, a UAR of 9.4, and assuming 40% voids

$UPD= 8.82 * 10^{11} * (40)^{-8.6} * 9.4^{1.27}$
gives a unit pressure drop (UPD) of 0.21 inches per foot of media.

- The total pressure drop (eq. 6) through the media is 0.21 x 1.17 ft

= 0.25 inches of $H_2O$

This increase in EBCT (from 5 seconds to 7.5 seconds) resulted in a biofilter that is 1.5 times larger and a pressure drop that is nearly half of the original 0.49 inches of pressure drop.

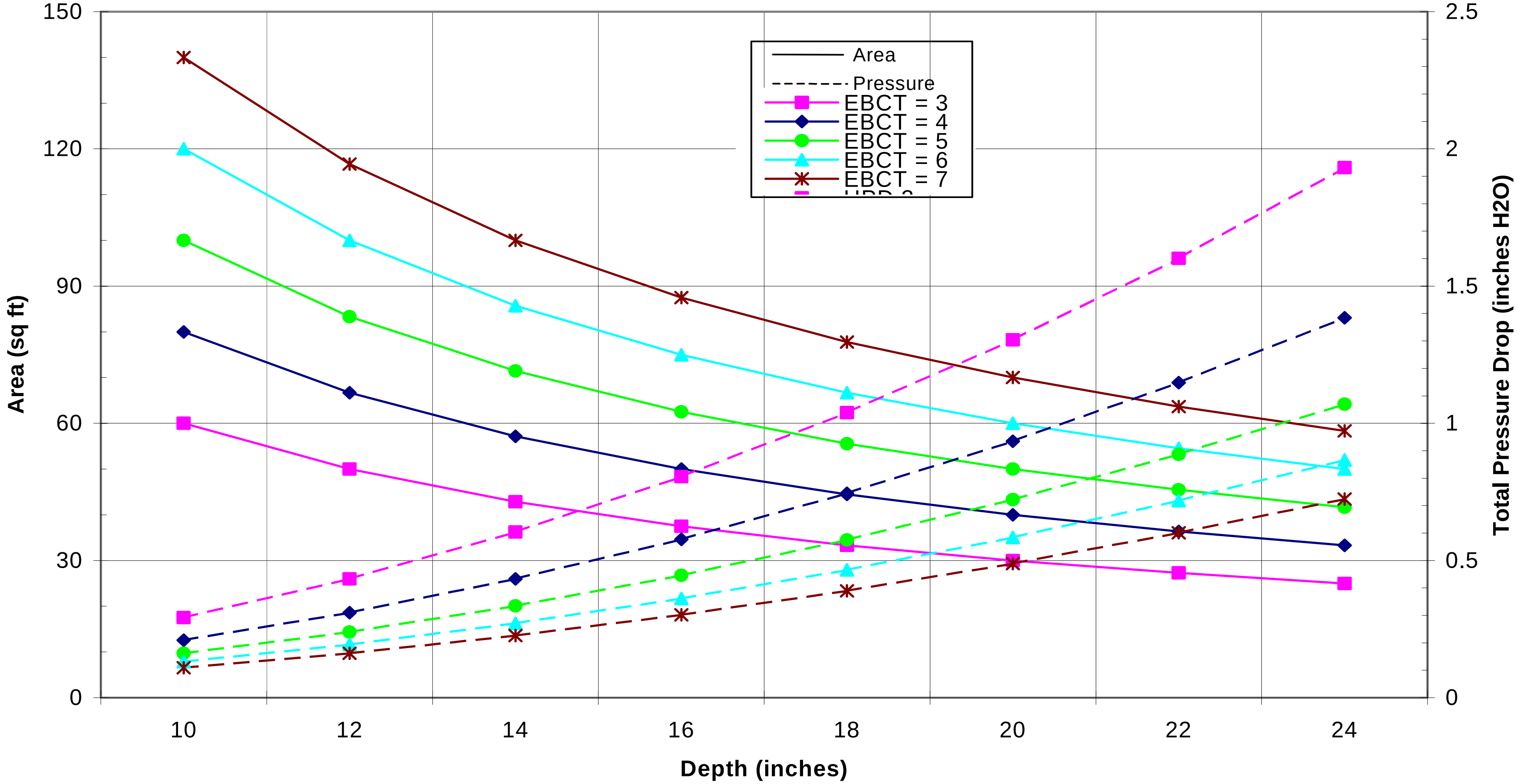


Figure 3. Media depth vs area of filter required and total pressure drop for a typical media.

## Fan Selection

Fan selection requires knowledge of both design airflow rate and pressure drop. Typical agricultural ventilating fans are selected for the design airflow rate and a pressure drop of 0.125 inches (1/8") 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 different fan 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.

Use rated fans with known performance characteristics. Figures 4 and 5 are two typical examples of standard agricultural fan curves. Centrifugal fans are capable of providing higher pressures but less CFM at similar power requirements. Unfortunately, most centrifugal fans are not designed for use in livestock facilities and will corrode quickly. Select fans to provide the airflow and pressure drop needed using fan manufacturer supplied information. The fan rating information should come from a recognized independent testing laboratory.

**Table 4. Static Pressure, Airflow, and power requirements for MXT48, 2 hp fan.**

| Static Pressure | Airflow (cfm) | RPM | Volts | Amps | Watts | cfm/Watt |
|---|---|---|---|---|---|---|
| 0.00 | 31281 | 678 | 230.4 | 8.13 | 1530 | 20.4 |
| 0.05 | 29900 | 676 | 230.4 | 8.4 | 1600 | 18.7 |
| 0.10 | 28365 | 674 | 230.4 | 8.68 | 1660 | 17.1 |
| 0.15 | 26740 | 673 | 230.1 | 8.95 | 1721 | 15.5 |
| 0.20 | 25009 | 671 | 230.2 | 9.16 | 1775 | 14.1 |
| 0.25 | 23041 | 669 | 229.7 | 9.36 | 1822 | 12.6 |
| 0.30 | 20406 | 667 | 229.6 | 9.56 | 18270 | 10.9 |

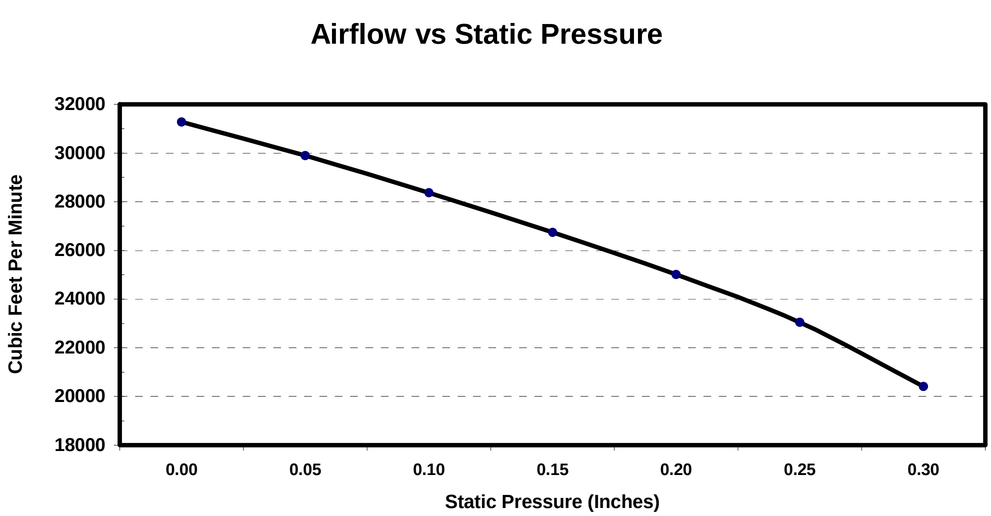


Figure 4. MXT48. 48-inch 2 hp fan

**Table 5. Static Pressure, Airflow, and power requirements for MXT24, 1.5 hp.**

| Static Pressure | Airflow (cfm) | RPM | Volts | Amps | Watts | cfm/Watt |
|---|---|---|---|---|---|---|
| 0.00 | 10884 | 1757 | 230.0 | 5.35 | 1178 | 9.2 |
| 0.05 | 10638 | 1755 | 230.0 | 5.47 | 1201 | 8.9 |
| 0.10 | 10387 | 1754 | 230.0 | 5.58 | 1229 | 8.5 |
| 0.15 | 10152 | 1753 | 230.0 | 5.75 | 1263 | 8.0 |
| 0.20 | 9864 | 1751 | 230.0 | 5.87 | 1294 | 7.6 |
| 0.25 | 9641 | 1749 | 230.0 | 5.97 | 1321 | 7.3 |
| 0.30 | 9439 | 1748 | 230.0 | 6.09 | 1339 | 7.0 |
| 0.35 | 9194 | 1746 | 230.0 | 6.19 | 1370 | 6.7 |
| 0.40 | 8941 | 1745 | 230.0 | 6.32 | 1398 | 6.4 |
| 0.45 | 8695 | 1743 | 230.0 | 6.43 | 1412 | 6.2 |
| 0.50 | 8428 | 1741 | 230.0 | 6.53 | 1446 | 5.8 |
| 0.55 | 8151 | 1739 | 230.0 | 6.63 | 1465 | 5.6 |
| 0.60 | 7865 | 1738 | 230.0 | 6.72 | 1487 | 5.3 |
| 0.65 | 7536 | 1736 | 230.0 | 6.76 | 1496 | 5.0 |
| 0.70 | 7158 | 1735 | 230.0 | 6.78 | 1498 | 4.8 |
| 0.75 | 6723 | 1736 | 230.0 | 6.75 | 1497 | 4.5 |
| 0.80 | 5901 | 1738 | 230.0 | 6.53 | 1446 | 4.1 |

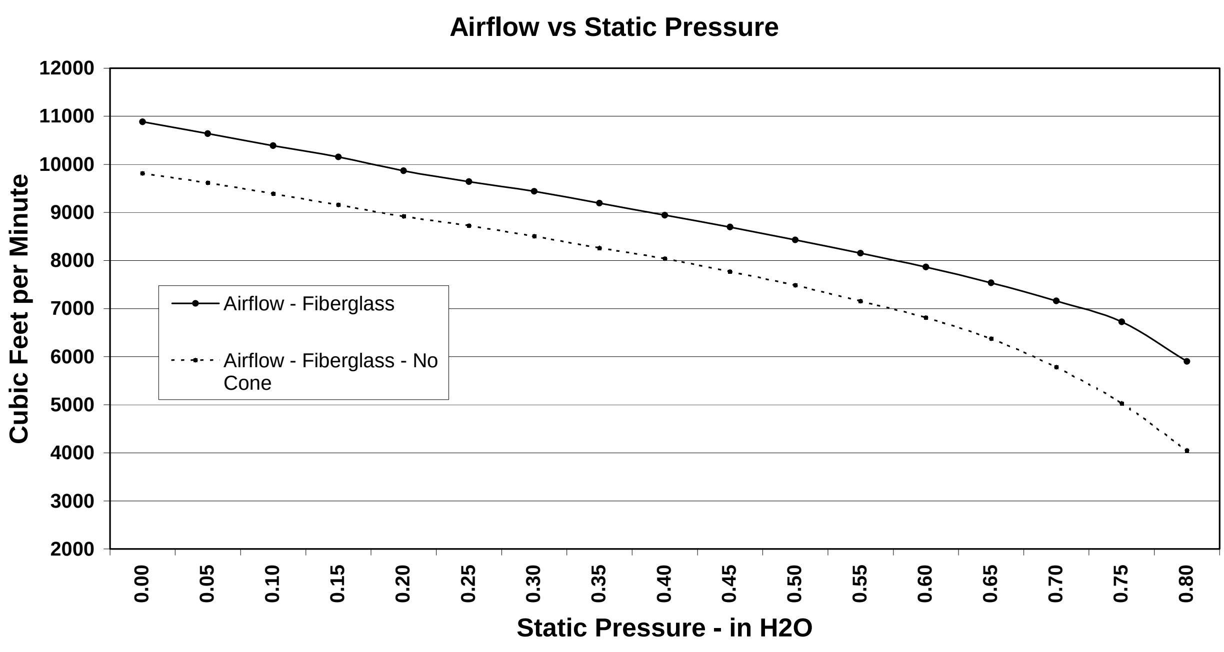


Figure 5. MXT24. 24-inch 1.5 hp fan

Fan information will also include information on electrical power consumption. Typically the fan efficiency (cfm/watt) decreases as the static pressure increases. Also, larger fans are more efficient than smaller fans.

Fan selection must also consider the range of ventilation rates needed to meet the ventilation requirements. Fans must be sized to meet the minimum ventilation requirements and then staged to meet the additional ventilation requirements as temperatures increase throughout the year. This typically means a series of fans – some small and some large integrated with a temperature controller.

Shutters are 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 concurrent back drafting through the fans.

Dust accumulation on fans, guards, and shutters can significantly reduce fan performance. Therefore, ducting design must provide access for fan maintenance and inspection. Also, select 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. Inadequate moisture can allow the media to dry out, deactivating the microbes, and creating cracks and channeling of air which results in a reduction of filter efficiency. Too much moisture 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 to 65% wet basis (w.b.) for compost biofilters with an optimum moisture content of 50% (w.b.).

During the summer months, the warmer temperatures and increased airflow causes the media to dry out. Moisture can be supplied by sprinkling water directly onto the bed. Water addition can be automated with a timer and a lawn sprinkler system. This sprinkling should be uniform throughout the bed. Dry areas will promote air channeling and reduce odor reduction efficiency. During the winter months and cooler temperatures, moisture transfer to the media from the exhaust air prevents drying, therefore no water addition is needed. In periods of rainy weather, no additional water is needed.

Excessive water from storm events or a watering system failure can cause moisture to seep out of the media. This water, known as leachate, can contain high concentrations of nitrate. Fortunately, the biofilter media is capable of absorbing most large rainfall events so the potential for any leachate is relatively small. Recent research at the University of Minnesota captured the leachate from a biofilter after simulated rainfall events of 6, 9 and 12 inches in 24 hours. In this study, leachate was not detected until the 9 inch rainfall event. This leachate was high in organic matter and nitrate. Fortunately this large of rainfall event rarely if ever occur in Minnesota. This research, however, does suggest that large quantities of roof runoff falling on the biofilter may create a leaching hazard. Therefore, the biofilter should be placed away from the roof or gutters should be installed to intercept this runoff. Design guidelines suggest a clay, concrete, or plastic liner under the biofilter bed to collect the leachate. This is not currently required in Minnesota. More testing and analysis are needed to determine the likelihood and pollution potential of biofilter leachate.

## Temperature

Microorganisms tolerate a range of temperatures. They are most active between 70 and 90º F. 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 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 covered manure storage. Naturally ventilated buildings typically cannot make use of a biofilter. However, curtain-sided buildings actually use some mechanical ventilation and 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. Unfortunately, the total odor reduction achieved using a biofilter in this situation is quite 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 are 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 limited. In essence, 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). Therefore, the warmer the ambient temperature the higher percentage of ventilation air is unfiltered and thus the lower the odor reduction for the total building.

One means of increasing the odor reduction efficiency for these naturally ventilated buildings is to increase the amount of airflow through the biofilter by increasing the number or size of the fans (increasing the percentage of time the building is mechanically ventilated). One such study has been conducted on a 1000 head finishing barn. On the west half of the barn (500 head room) a biofilter was installed on the pit fans. These pit fans ventilated approximately 8% of the design ventilation rate for warm weather. On the east half of the barn the pit fans were replaced with fans designed to ventilate 26% of the warm weather ventilation rate. These fans were operated throughout the year. From the data it is clear that the odor reduction is quite variable and dependent primarily on the ambient temperatures. Good odor reduction was observed during colder months and poor odor reduction during warmer months. More work is needed 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, most of the rain or snow that falls on an open bed biofilter is absorbed by the organic material. 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 6). 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. Therefore, ducts and plenum should be designed to keep the air velocity between 600 and 1000 feet per minute. To calculate this velocity, divide 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.

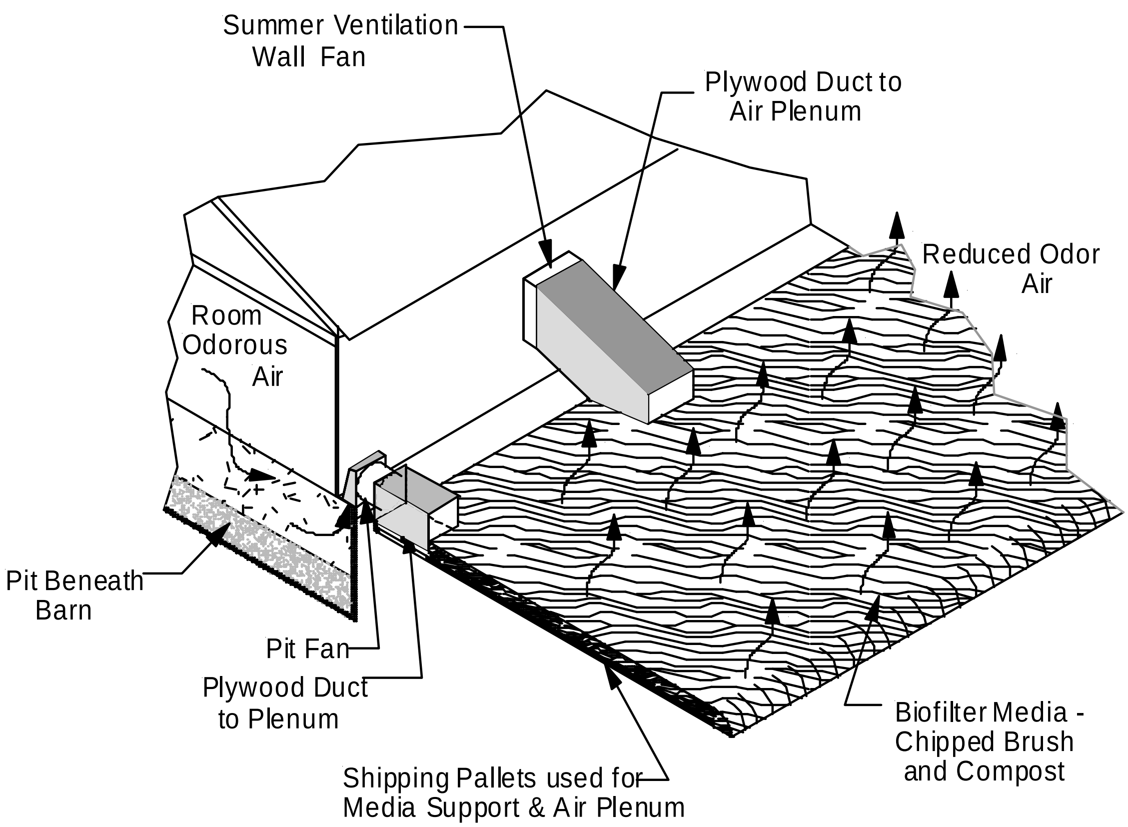


Figure 6. Biofilter construction.

The plenums for most biofilters in Minnesota 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 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 using a TMR wagon (Total Mixed Ration wagon used in the dairy industry) before the next row of pallets is laid down. This 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 for air to move from the plenum to the biofilter. This same criteria of maintaining air velocities between 600 and 1000 ft/min should be used.

### Organic Media

As discussed previously, the biofilter media is made up of a mixture of compost and wood chips at a weight ratio of 50:50 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 distribute the weight and 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 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 breathing this dust.

## Biofilter Costs

Costs to install a biofilter include the cost of the materials—fans, media, ductwork and plenum— and labor to construct. Typically this cost for new construction on mechanically ventilated buildings will be between $150 and $250 per 1000 cfm. Annual operation/maintenance of the biofilter is estimated to be $5-$15 per 1000 cfm. This cost includes the increase in electrical costs to push the air through the biofilter and the cost of replacing the media after 5 years. Both capital costs and operation and maintenance costs are quite variable.

High cost situations are those where biofilters are retrofited on naturally ventilated buildings *to filter air from pit fans or from additionally installed fans for mild weather ventilation*. These costs include the additional costs of the fans (not just the cost of increased fan size) and the added cost of electricity to operate these newly added fans.

## Maintenance

There are four areas of maintenance needed on biofilters—moisture content, weed control, rodent control and assessing pressure drop. None of these management issues takes significant amounts of time but all are important 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 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 to much water. If however, only the top few inches are damp then the amount of water needs to be increased. During summer months the lawn sprinkler might run for one or two hours per day. Often watering is done at night 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 will require limited if any modifications. Costs of professional rodent control is approximately $400 per year for a typical animal production operation.

### 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. Poor building ventilation 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.

## Worked Example, Continued (Part 3)

Select a fan or series of fans for the swine nursery example. From Part 1, the pressure drop was 0.49 inches and the total flow rate was 175,000 cfm. (Note that this facility has 5 rooms of 1000 pigs per room.) Also, estimate the range of capital and annual operation/maintenance cost for the biofilter.

• Since each room needs separate ventilation, fan capacity for each room is 55,000 cfm. A pressure rating of at least 0.49 inches for the biofilter *plus* 0.15 inches for the building is required.

• From Tables 4-5:
Since the MXT48 does not provide enough static pressure, MXT24 fans are required.

At a pressure of 0.64 inches, 5 of the MXT24 fans are required per room.

• A low estimate for capital cost for the biofilter is
175,000 cfm * $100/1000 cfm = $17,500

• A high estimate for capital cost for the biofilter is
175,000 cfm * $250/1000 cfm = $43,750

Annual operation/maintenance
• cost is 175,000 cfm * $10/1000 cfm = $1750 per year

## Health and Safety Concerns

There is little research information 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 a laboratory study researchers found that relatively large numbers of spores 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 missions during construction, maintenance, and removal may pose a potential health risk. Dust control and personal protection (dust filter masks) may be useful to minimize exposure.

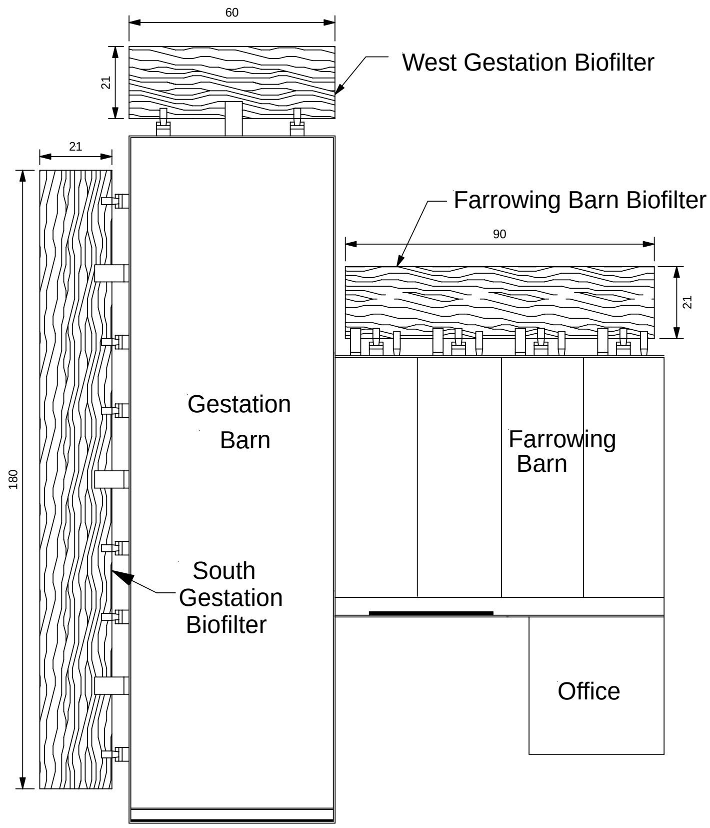


Figure 7. Site layout.

## Biofilter Design Cases

Biofilter designs for two cases are described here to illustrate the design procedure. One is for a swine gestation/farrowing facility. The second biofilter treats exhaust air from a manure collection pit on a freestall dairy using a deep bed biofilter.

### Swine Gestation/Farrowing Facility Case

In the swine case three biofilters treat all of the ventilating air exhausted from a 700-sow gestation / farrowing building. Figure 7 shows the building layout. The manure system consists of a pull plug system in the farrowing barn that empties into a deep pit beneath the gestation barn. The gestation barn has a slatted floor. The minimum and mild weather ventilation air is exhausted through the pits and hot weather ventilation is exhausted through wall fans. The ventilating system data is summarized in Table 6. The rates used exceed those recommended by MWPS-32, mainly for the winter rates. The design procedure used to size this first biofilter is slightly different than the procedure outlined earlier and illustrates some of the decisions that a design engineer may make. The engineer designing these biofilters decided that biofilter size obtained using the maximum ventilating rate and a 5 s EBCT was excessively large. The final design was obtained after several iterations and is summarized in Table 7. The smaller EBCT times were deemed to be acceptable because the maximum ventilating rate installed was slightly greater than that recommended by MWPS-32 and because that maximum rate was expected to be needed only a few hours each year. It was recognized that the lower EBCT time leads to a larger UPD, expected $\Delta P$, and reduced ventilating rate at the time most needed.

**Table 6. Seasonal ventilating rates (CFM).**

| | Winter | Spring & Fall | Summer |
|---|---|---|---|
| Gestation barn | | | |
| South biofilter | 11,900 | 26,300 | 74,300 |
| West biofilter | 3,970 | 8,760 | 24,800 |
| Total Gestation | 15,870 | 35,060 | 99,100 |
| Farrowing barn | 6,760 | 17,400 | 51,400 |

**Table 7. Biofilter design information for a 700-sow gestation/farrowing building.**

| | Gestation biofilters | Farrowing biofilter |
|---|---|---|
| Total airflow ($ft^3$/min) Maximum summer | 99,100 | 51,400 |
| Residence time (s) | 2.8 | 2.4 |
| Media volume ($ft^3$) | 4,640 | 2,050 |
| Media depth (ft) | 0.92 | 1.1 |
| Media area ($ft^2$) | 5,040 | 1,890 |
| Unit airflow ($ft^3$/min per $ft^2$) | 20 | 27 |
| Unit pressure drop (inch $H_2O$/ft) | 0.4 | 0.6 |
| Expected media pressure drop (inch $H_2O$) | 0.37 | 0.66 |

Biofilters were built on the south and west sides of the gestation barn and on the west side of the farrowing barn (Figure 7). The biofilter on the south side of the gestation barn is 180 ft long by 21 ft wide and the one on the west side is 60 ft by 21 ft. The media on both is 11 in. (0.28 m) deep. The biofilter on the west side of the farrowing barn is 90 ft long by 21 ft wide. The media is 13 in. deep.

Limited fan performance information was available for fan selection. Table 8 gives data for the fans used.

**Table 8. Fan performance data (CFM)**

| | Diameter (in.) | Motor HP | Static pressure (in. $H_2O$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** |
| Gestation Barn | | | | | | | |
| | 20 | 0.33 | 4260 | 3970 | 3620 | 3150 | 2460 |
| | 20 | 0.5 | 5170 | 4960 | 4790 | 4560 | 4390 |
| | 48 | 2 | 22,000 | | 19,000 | | 16,000 |
| Farrowing Barn | | | | | | | |
| | 12 | | 1779 | 1691 | 1588 | 1452 | 521 |
| | 16 | | 2920 | 2790 | 2650 | 2940 | 2300 |
| | 30 | 1 | 10,000 | | 8500 | | |

Figure 6 illustrates the construction and mode of operation of the biofilter on the swine facility. The minimum and mild weather ventilation air is exhausted from the building through the pit beneath the floor. Fans located on pit extensions outside the building move the air through a duct to an air plenum beneath the media. Additional summer ventilation air is exhausted through wall fans that were ducted into the plenum.

Wooden shipping pallets were used as the support structure for the media. They also provide the approximately 3.5 in. high plenum for the exhaust air to reach all areas of the media. The first row of pallets adjacent to the barn was raised 6 in. to allow for air distribution parallel to the barn before entering the pallets which were aligned perpendicular to the barn. A plastic net with 0.5 x 0.5 in. grid was placed over the pallets to prevent media from dropping through the pallet openings and plugging the air plenum.

The distribution duct running adjacent to the barn were not sized to limit the air velocity. The cross sectional area is approximately 3.2 $ft^2$ (4 ft • 9.5 in./12 = 3.2 $ft^2$). Since air can flow both directions from the fan, the total duct area to the fans is approximately 6.3 $ft^2$. At 1000 fpm, the duct can handle 6300 CFM, which is greater than the output of the winter and spring/fall fans. The summer fans on the gestation barn have a greater flow rate which suggests that pressure losses due to high duct velocities could be significant.

The media was a mixture of 50% yard waste compost and 50% brush chips by weight. Initial percent voids was not measured. Both the compost and brush chips were locally available and relatively inexpensive. The biofilter was built by laying down a row of pallets, covering them with the plastic netting, preparing media in a feed mixer wagon, and placing it on one row of pallets. Another row of pallets was laid down, covered with netting, and then covered with the media. This procedure was repeated for all six rows of pallets. An additional pass of the mixer wagon was made to cover the end of the last pallet row. Plastic sheets are recommended along the outside edge of the biofilter constructed this way to reduce untreated air leakage from the edges.

Garden hoses with lawn sprinklers were laid on top of the biofilter to add moisture during mild and warm weather. At the present time, a timer that turns the sprinkles on for one hour every night controls the sprinklers. Sprinkling is done at night to avoid wind and to minimize evaporation.

For this swine facility, all the ventilation fans exhaust through the biofilter. The number of fans that operate at one time depends on the ambient air temperature. Data was collected to evaluate the flow rate / pressure drop relation for the completed biofilter. The measured pressure drop across the media increased from 0.02 in. $H_2O$ at a ventilation rate of 3200 CFM to 0.24 in. $H_2O$ at a ventilation rate of 35,000 CFM. The pressure drop would be expected to increase more as the ventilation rate increases towards the maximum.

Biofilter performance has been monitored quarterly since it was put into operation in Fall 1997. Average odor reduction for the past two years has been 90%. The odor emissions have remained low except for three slight increases during April and September 1998 and October 1999. These three reduced odor efficiencies occurred when the media moisture content was less than 30% measured on a wet basis. This illustrates the need for moisture control. Average hydrogen sulfide reduction for the same two-year period is 85%. Hydrogen sulfide reduction showed similar losses in performance due to media desiccation. Ammonia reduction for the swine facility biofilter averaged 55%.

**Deep Bed Dairy Biofilter**

The second biofilter, constructed in May 1999, treats emissions from a manure holding pit at a 2000 cow dairy. Manure is scraped into the holding pit from two freestall dairy barns and transferred daily to an earthen storage basin. Hydrogen sulfide emissions from a pit fan exhausting from the holding pit were sufficient to have the site be potentially out of compliance with Minnesota's hydrogen sulfide ambient air standard. The biofilter design is summarized in Table 9.

Figure 8 illustrates the deep bed biofilter built. The centrifugal fan draws air from the manure holding pit through a housing over a hole into the pit and blows the air into the plenum below the media. Table 10 gives fan performance date for the fan used. The design flow rate is 5500 CFM (2.6 $m^3/s$). The biofilter constructed was 9 ft (2.75 m) by 17.25 ft (5.25 m). Concrete walls were used on three sides. One end, opposite the fan, has wood planks. The planks are removable and allow access to the biofilter for maintenance and media replacement in the future.

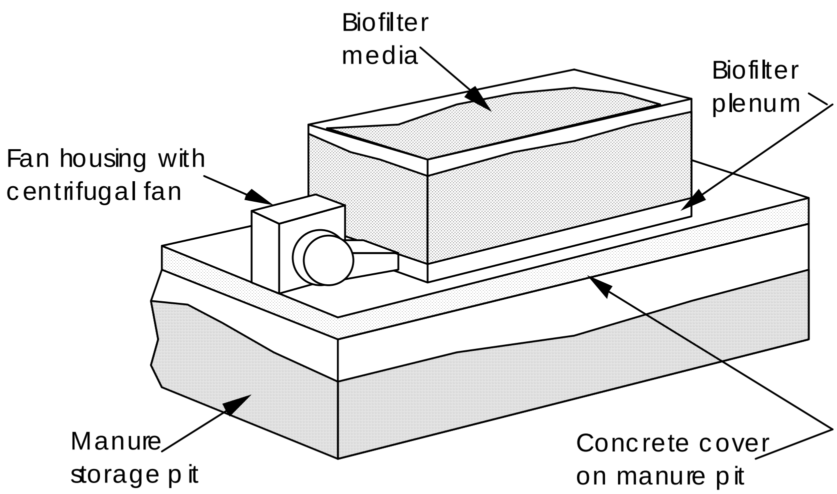


Figure 8. Deep bed filter.

**Table 9. Biofilter design information for a deep bed biofilter.**

| | Deep bed biofilter |
|---|---|
| Total airflow ($ft^3$/min) | 5,500 |
| Residence time (s) | 5 |
| Media volume ($ft^3$) | 460 |
| Media depth (ft) | 2.7 |
| Media area ($ft^2$) | 170 |
| Unit airflow ($ft^3$/min per $ft^2$) | 32 |
| Unit pressure drop (inch H2O/ft) | 0.5 |
| Expected pressure drop (inch H2O) | 1.3 |

**Table 10. Fan performance data (CFM).**

| Diameter | | Static pressure (in. $H_2O$) | | | |
|---|---|---|---|---|---|
| (in.) | Motor HP | 0.5 | 0.75 | 1.0 | 1.25 |
| 20 | 2 | 7235 | 5940 | 5290 | N/A |

Plastic coated steel, used for flooring in pig barns, was used for the porous support for the biofilter media. The support was laid on top of wood members (2 in. x 10 in.) to form a 10 in. high plenum. The plenum cross sectional area is approximately 6.9 $ft^2$ (9 ft • 9.25 in./12 = 6.9 $ft^2$). This produces an average face velocity of approximately 800 fpm, which is within recommended design limits of 800 to 1000 fpm.

The locally available media was yard waste compost and wood chips (chipped oak). The predicted pressure drop through the unpacked biofilter was 0.95 in. of $H_2O$ (235 Pa). The measured pressure drop for the dairy facility across the biofilter was 0.9 in. $H_2O$ (225 Pa) after one month of operation. A sprinkler system was added for moisture addition during mild and hot weather. After 10 months of operation the static pressures had increased to 1.2 in. $H_2O$.

The biofilter on the dairy facility was constructed in May 1999 and began with a 25% odor and hydrogen sulfide removal rate. After a two-month conditioning period, the removal rate increased to 94% for odor and 88% for hydrogen sulfide. Ammonia removal rate has averaged 60%. Longer term performance has varied from 57 to 95% odor reduction, 75 to 100% hydrogen sulfide reduction, and 60 to 100% ammonia reduction. On site observations suggest that performance depends on media moisture content with poor performance occurring from dry media.

## Case Summary

These cases illustrate biofilter design procedures for treating air from animal facilities. Biofilter performance has been good as long as the media moisture content is sufficient. Continued maintenance is necessary. Updated designs will continue to be developed as experience increases and unanswered questions are addressed.

## Biofilter Design Exercise 1

Design a biofilter to treat the pit fan exhaust from a swine finishing barn. Assume that the pit fans exhaust is at least 5000 CFM and up to 10,000 CFM. Assume that there are no space limitations. List assumptions made. Determine the media area, depth, and expected media total pressure drop. Identify one or more fans to use. Size a distribution duct. Summarize your results in the following table.

| **Parameter** | **Units** | Results |
|---|---|---|
| Ventilating rate, Q (As per building requirement) | CFM | |
| EBCT (Designer selects) | s | |
| Media volume, $V_m$ (Q*EBCT / 60) | $ft^3$ | |
| Media depth, $D_m$ (Designer selects) | | |
| Biofilter media area, $A_m$ ($A_m = V_m/D_m$) | ft | |
| Unit Airflow Rate, UAR (UAR = $Q/A_m$) | CFM / $ft^2$ | |
| Unit Pressure Drop, UPD UPD= $8.82 * 10^{11} * (\% \text{ Void})^{-8.6} * UAR^{1.27}$ | in. $H_2O$ / ft | |
| Biofilter Pressure Drop, $\Delta P$ ($\Delta P$ =UPD x Depth) | in. $H_2O$ | |
| Total Pressure Drop, $\Delta P_{biofilter} + \Delta P_{building}$ | in $H_2O$ | |
| Minimum Duct area (Duct area = Q/1000) | $ft^2$ | |
| Potential fans (Selected from Fan Curves) | | |

## Biofilter Design Exercise 2

Design a biofilter to treat the exhaust from a covered settling basin. Assume that the exhaust airflow rate is 4000 CFM. Assume that space for the biofilter media area is limited to a space 15 ft by 20 ft. List assumptions made. Determine the media depth and expected media total pressure drop. Identify one or more fans to use. Size a distribution duct. Summarize your results in the following table.

| **Parameter** | **Units** | **Results** |
|---|---|---|
| Ventilating rate, Q (As per building requirement) | CFM | |
| EBCT (Designer selects) | s | |
| Media volume, $V_m$ (Q*EBCT / 60) | $ft^3$ | |
| Media depth, $D_m$ (Designer selects) | | |
| Biofilter media area, $A_m$ ($A_m = V_m/D_m$) | ft | |
| Unit Airflow Rate, UAR (UAR = $Q/A_m$) | CFM / $ft^2$ | |
| Unit Pressure Drop, UPD UPD= $8.82 * 10^{11} * (\% \text{ Void})^{-8.6} * UAR^{1.27}$ | in. $H_2O$ / ft | |
| Biofilter Pressure Drop, $\Delta P$ ($\Delta P$ =UPD x Depth) | in. $H_2O$ | |
| Total Pressure Drop, $\Delta P_{biofilter} + \Delta P_{building}$ | in $H_2O$ | |
| Minimum Duct area (Duct area = Q/1000) | $ft^2$ | |
| Potential fans (Selected from Fan Curves) | | |

## REFERENCES

Janni, K. A., W. J. Maie, T. H. Kuehn, B. B. Bridges, D. Vesley and M. A. Nellis. 1996. Evaluation of Biofiltration of Air, an Innovative Air Pollution Control Technology.

MWPS-32. 1990. *Mechanical Ventilating Systems for Livestock Housing*. Ames, IA: MidWest Plan Service.

Nicolai, R. E. and K. A. Janni. 1997. Development of a Low Cost Biofilter on Swine Production Facilities. ASAE Paper No. 97-4040. St. Joseph, MI: ASAE.

Noren, O. 1985. Design and use of Biofilters for Livestock Buildings. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming.* eds. V.C. Nielsen, J. H. Voorburg, and P. L'Hermite, pp. 234 - 237. New York: Elsevier Applied Science Publishers.

Zeisig, H. D. and T. U. Munchen. 1987. Experiences with the use of Biofilters to Remove Odours from Piggeries and Hen Houses. In: *Volatile Emissions from Livestock Farming and Sewage Operations.* eds. V.C. Nielsen, J. H. Voorburg, and P. L'Hermite, pp. 209 - 216. New York: Elsevier Applied Science Publishers.