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ECS White Paper 2020-4: Biofilter Theory, Design, and Operation

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Biofilters are a common method of scrubbing process emissions and odors from composting and other biological and chemical processes such as from waste water treatment plants. This paper provides a brief background on how biofilters work and outlines key elements in their design and operation that determine their efficiency.

1. Overview: Biofilters

Biofiltration is a proven, cost-effective method of scrubbing odorous and volatile organic compound (VOC) rich air exhausted during industrial processes such as composting. Odor complaints and VOC levels above those permitted by local air quality standards can shut down a composting operation. A well maintained biofilter can reduce the odor and VOC concentration by well over 90%. The following sections include ECS' recommendations for constructing, operating, and maintaining a biofilter.

2. Design Theory

Figure 1: Compost particle biofilm Figure 1, below, depicts the watery biofilm on the surface of a compost particle. Biofilter media (usually coarse wood chips) can also be wetted and therefore have a biofilm. As is the case in the composting process, the biochemical conditions in the biofilm on the media are critically important to the biofilter's performance, or scrubbing efficiency.

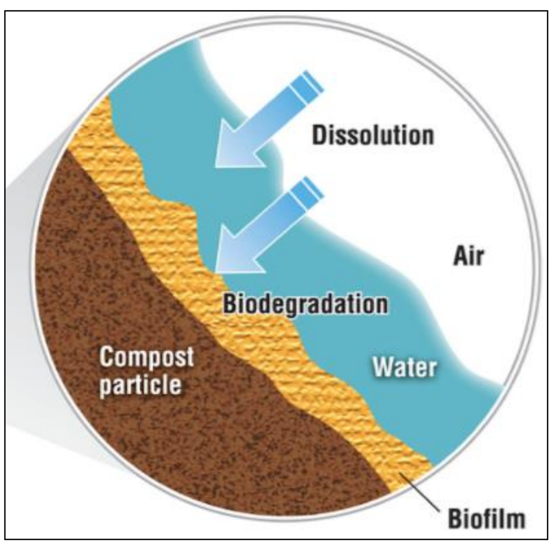

Figure 1: Compost particle biofilm

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A biofilter absorbs volatile compounds from the exhaust air stream into the biofilm layer. The biofilm, rich with aerobic bacteria and other microorganisms (aerobes), bio-oxidizes (consumes) the absorbed compounds, releasing energy and/or essential nutrients, such as nitrogen in ammonia (NH_3), which are necessary for cellular maintenance and division. The following conditions in the media determine the efficiency of the aerobes:

- Amount of surface area
- Relatively uniform airflow distribution
- Contact time of the air in the media
- Levels and consistency of moisture, temperatures, and pH

When these conditions are maintained within a reasonable range, biofilters efficiently oxidize a broad spectrum of volatile chemicals present in low part-per-million concentrations. The rule-of-thumb for scrubbing efficiency stipulates that the average biofilter will provide at least one log (factor of 10) reduction of most bio-oxidizable compounds (or alternatively, enact a 90% reduction in odor and VOCs).

Biofilters have shown good resilience to varying environmental and process conditions. Even with one or more of the media conditions out of the target range, they still s generally provide 70 – 85% reduction in VOCs and odors, depending on the degree and duration of the non-target conditions.

3. Design Specifications

The specifications for biofilter design depend on the types and concentrations of the compounds to be scrubbed in the exhaust air, the climate, and the site's sensitivity to either odor generation or regulated VOC and NH_3 emissions. Table 1 lists a typical range of biofilter design specifications.

Specification	Typical Range of Values
Empty-Bed Residence Time	15 - 60 seconds
Media Temperature	40° - 120°F
Media pH	5 - 9
Active Media Depth	36" – 72"
Media Moisture Content	> 50%
Initial Pressure Drop Thru Fresh Media	< 0.2" wc/foot of depth
Max Pressure Drop Thru Aged Media	< 0.8" wc/foot of depth
Dry Media Density (assuming wood)	< 600 lb/yd^3
Main Media Screen Size	2"+
Base Layer Screen Size	4"+
Base Layer Depth	12" – 24"

Table 1: Biofilter design specifications

ECS recommends replacing biofilter media when the maximum pressure drop through the biofilter media exceeds 0.8 in W.C. of static pressure per foot of depth at full design airflow.

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4. Biofilter Media Preparation & Placement

When building the biofilter, the media choice and preparation is key to all performance metrics including: scrubbing efficiency, fan power consumption, and media longevity. A bed of relatively coarse, stable media with a base layer of coarser media will provide more uniform flow, higher surface area, lower friction loss, and a longer lifetime than a bed of finer degradable media. Good quality media should last from two to four years and this lifetime can often be extended by adding an additional one to two feet of media over the top of the bed.

When preparing the media, add only a very small amount (1-2% by volume) of more degradable fines, such as compost, to otherwise coarse, clean, freshly shredded wood. The primary reason for adding compost to the media is to shorten the biological conditioning period by allowing the biofilm of the media to be thoroughly colonized by microbes. Colonization typically takes four to eight weeks to reach peak performance.

ECS recommends the following media preparation procedure:

1. Obtain root/stump wood (best) or trunk wood. Hardwood is best for longevity, fir is acceptable, avoid cedar or soft deciduous woods like cottonwood or hybrid poplar (fast growing pulp trees).
2. If possibly, process wood in a shear shredder with semi-coarse grates (6 – 8”).
3. Screen enough of the shredded wood to make a base layer using a 4”+ screen. Do not wet this material or add any compost to it. Keep the base layer material sperate from the rest of the prepared media.
4. Add the fines back to the shredded wood pile, along with 1 – 2% (by volume) stable compost fines. Mix with a wheel loader bucket.
5. Run the material over a 2” screen, setting the fines aside.
6. Heavily wet the overs as they exit the screen and allow them to sit 4+ hours so that the water can soak in.

The media should be placed in sections that are small enough to allow the base layer to be laid down, then the wetted media layer to be added over the top without driving on the base layer. If placing material with a conveyor, or an extended reach machine, large sections can be constructed at one time. If placing material with an smaller excavator or wheel loader, the reach of the machine will limit the width of the section that can be built at one time. Once the base layer is placed, carefully place wetted media on top up to the initial design depth. Compression limits the useful life of the media; Never drive on top of the media with a machine. If a uniform top surface is desired, hand raking is almost always required.

5. Operations

Maintaining the correct moisture content in the filter media is an important operational factor for a biofilter. The compost site operator should maintain the media between 40 and 60 percent moisture (see the following section for maintenance recommendations). Media that becomes too dry will suppress microbiological activity, reduce absorption, and will not fully bio-oxidize odorous gases. Assuming the media is porous, it is quite difficult to err on the higher end of moisture content (>65%) as the media will drain well and not hold the water. However, if the media has significantly degraded, it may absorb more than 65% moisture. The potential for the media to channel or crack also increases with age. This allows

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air to move faster through drier passages causing further localized drying and shrinkage of the media, reducing overall performance. Once this occurs, the operator should add additional media. The operator should change the media when it begins to visibly degrade, densify, and crack.

The exhaust air from a composting process is generally saturated (100% relative humidity, or RH). This is not true for building exhaust air. An airstream with 100% RH will constantly deliver moisture to the majority of the media as it cools when passing through the bed. If a significant volume of building exhaust air is to be included, then an in-line humification system should be considered. Even when fed with moist exhaust air, the upper layer of the media will often appear dry due to evaporation to ambient air. This generally does not strongly impact the overall performance. Adding irrigation to the surface or within the media can improve performance, especially in dry hot environments. This can be done by either placing tight-spaced soaker hoses at the top of the pile or using surface sprinklers. Irrigation can have the added benefit of washing out soluble nitrates that can build-up in the media (especially while composting biosolids).

Temperature of the biofilter media is another important operational factor. The ideal media temperature ranges between >10° F and 110°F. Biofilter efficiency slowly declines up to 120 - 130°F and thereafter falls off more quickly. The media itself will also degrade more quickly at temperatures above 130°F (a settled bed may lose a foot of depth in a matter of months if temperatures above 135°F are maintained). Short term excursions up to 130°F are generally acceptable so long as monthly average media temperatures are $\leq$ 115°F. The compost aeration and control system should monitor, log, and control the temperatures of exhaust air and biofilter media. Ideally, the system will automatically control the exhaust air temperature to an operator chosen setpoint by adjusting the volume of added ambient air. If performance is critical, psychrometric (the thermodynamics of mixing air) and heat transfer calculations should be carried out to ascertain if additional humidification is required to prevent dilution air from over-drying the biofilter media.

The pH of the media can also impact both the scrubbing effectiveness and the nature of the odor emitted. Measuring the pH of media can be tricky since the pH is, by definition, an aqueous phase phenomenon. The loading rate, chemical spectrum, and the pH of the air stream and the irrigation water over time are typically the primary drivers of pH. As the pH changes, the biofilter scrubs different compounds with different efficiencies (acidic media better scrubs NH3 and mildly alkaline media best treats organic acids). ECS has measured the pH effect of VOC scrubbing efficiency of two identical biofilters at the same site. One biofilter had an apparent pH of 5.5 and an efficiency of 90% (factor of 10), and the second biofilter had a pH of 5.0 and a scrubbing efficiency of 80%. A few weeks later the second biofilter's pH had risen to 5.7 and the scrubbing efficiency increased back above 90%. While pH is important, little can be done to change the pH of a biofilter in operation. Sustained low pH most likely indicates an inadequately managed composting process that is producing the low pH droplets that are depositing in the biofilter.

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Figure 2: Biofilter with Above Grade Pipe and Coarse Media

Figure 3: Biofilter with a Suspended Perforated Floor

6. Maintenance

Even though biofilters are quite resilient to varying inlet and environmental conditions, there are several parameters a compost site operator should periodically monitor.

Moisture

The operator should take grab samples from at least 12” deep in the media once every two weeks to test for moisture content. If the media appears to be over-drying, increase humidification (if present) or irrigation.

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Temperature

The operator should monitor the biofilter media temperature weekly (this temperature will be displayed on the operator's graphical user interface (GUI) screen in the automated control and monitoring software). The operator can vary make-up and exhaust damper control setpoints, as well as the relative settings of the supply and exhaust blowers, to control the temperature of this exhaust air. These settings are typically adjusted seasonally.

pH

The operator should monitor the biofilter media pH monthly. Monitor the pH more frequently if it is out of the target range. Assuming the pH of the water will bring the media within the target range, increase irrigation rates.

Pressure Drop/Media Densification

The operator should record the static pressure drop through the biofilter at a standardized operating condition (compost aeration process supplier should specify system setting during start-up that identify such a condition). Pressure drops should be measured with the biofilter floor bare, then with new media, then once every six months to track densification in the media.

General Inspection

The useful life of the biofilter media depends on the material used and the operating conditions. Different types of coarse ground wood have varying resistance to breaking down. Also, higher temperatures tend to degrade biofilters more quickly. Generally, one should expect the media to last one to three years. Spent biofilter media is characterized by:

- Cracking and channeling
- Breakthrough of contaminants (odors)
- Increased head loss (compaction and increased density)
- Shifts in media pH

Once the media has degraded, it should be changed. The operator can screen old media can be screened and reuse the coarse overs (2"+). Otherwise, it can be added into the compost mix as an amendment or used as well-matured compost.

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