*A SunCam online continuing education course*

→

# Biological Odor Control Systems

by

Mark Ludwigson, P.E.

Course Outline:

## Odor Control Options

Odor control involves removing or masking foul smells from odorous air. Common applications for engineered odor control systems include the following:

- Sewers and lift stations (see Figure 1 for an example),
- Wastewater treatment plants,
- Biosolids handling,
- Landfills,
- Compost facilities,
- Livestock, poultry, and fish processing,
- Pulp & paper manufacturing,
- Food processing,
- Breweries and beverage facilities,
- Pharmaceuticals,
- Coating processes, and
- Various industrial processes.

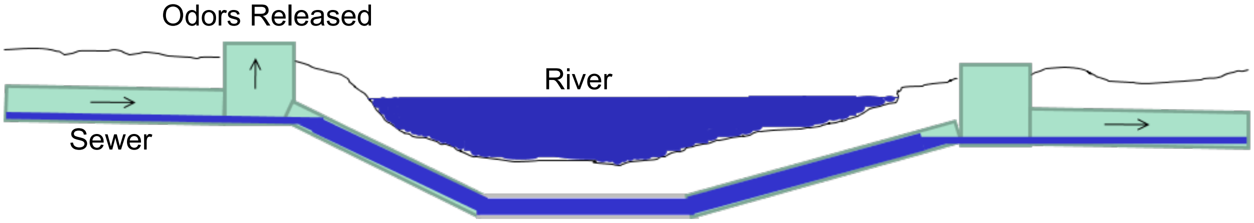


Figure 1: A gravity sewer river crossing in which sewer odors are released upstream of the crossing.

Odor compounds may include the following:

- Acetic Acid
- Acrylates
- Alcohols
- Aldehydes
- Ammonia
- Amines
- Butyric Acid
- Carboxylic Acids
- Chlorine
- Creosols
- Dimethyl disulfide
- Dimethyl sulfide
- Hydrogen Sulfide ($H_2S$)
- Ketones
- Mercaptans
- Phenols
- Sketoles
- Sulfur Dioxide ($SO_2$)
- Volatile fatty acids

| | |
|---|---|
| • Volatile organic compounds | (VOCs) (various) |

*Odor Control Alternatives*

Treatment options for odors fall into two categories: liquid phase and vapor phase:

1. Liquid phase treatment prevents odors from being released by altering the liquid from which the odors emerge (wastewater, sludge, leachate, etc.). Liquid phase treatment options include chemical injection for oxidation, precipitation, or pH adjustment.

2. Vapor phase treatment captures the gaseous odors and prevents them from being released through physical, chemical, or biological treatment. Vapor phase treatment options include:

   - Physical treatment:
     i. Thermal destruction
     ii. Wet absorption/packed tower scrubbers (see Figure 2)
     iii. Dry adsorption systems (see Figure 3)
     iv. Ionization systems (see Figure 4)
   - Chemical treatment:
     i. Chemical scrubbers also called chemical stripping (see Figure 2)
     ii. Chemical masking
   - Biological treatment:
     i. Biofilters (see Figure 5)
     ii. Biotrickling filters (see Figure 6)
     iii. Bioscrubbers (see Figure 7)

This course covers the three biological treatment options.

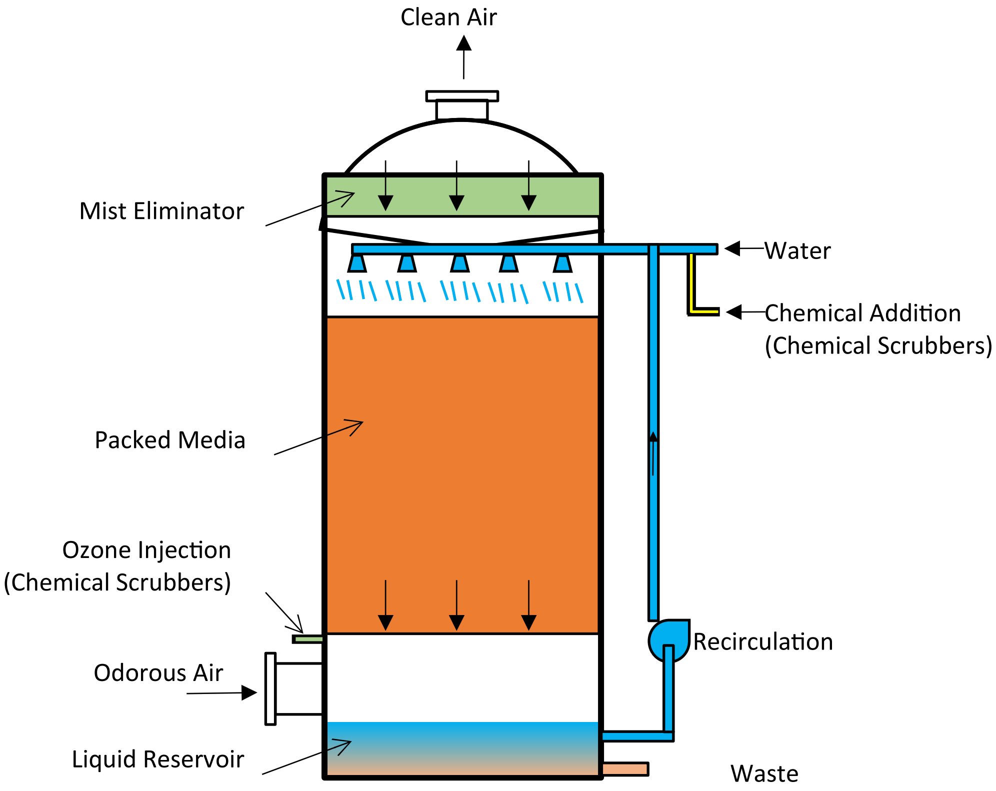


Figure 2: Example of a packed tower scrubber and a chemical scrubber. The difference is that chemical scrubbers include chemical/ozone addition.

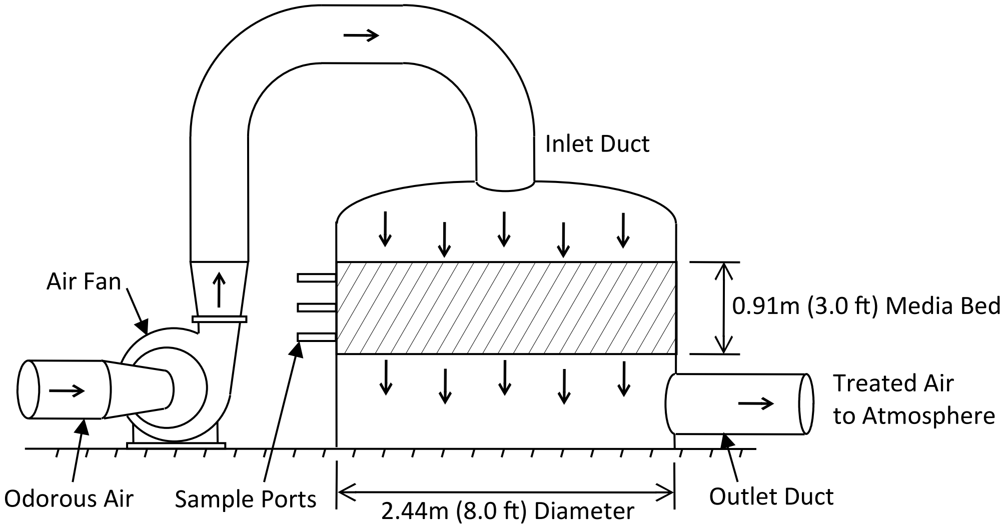


Figure 3: Schematic of an activated carbon odor control system.

Figure 4: Example of an ionization odor control system.
Inside the duct at the blue modules are a series of ion tubes.

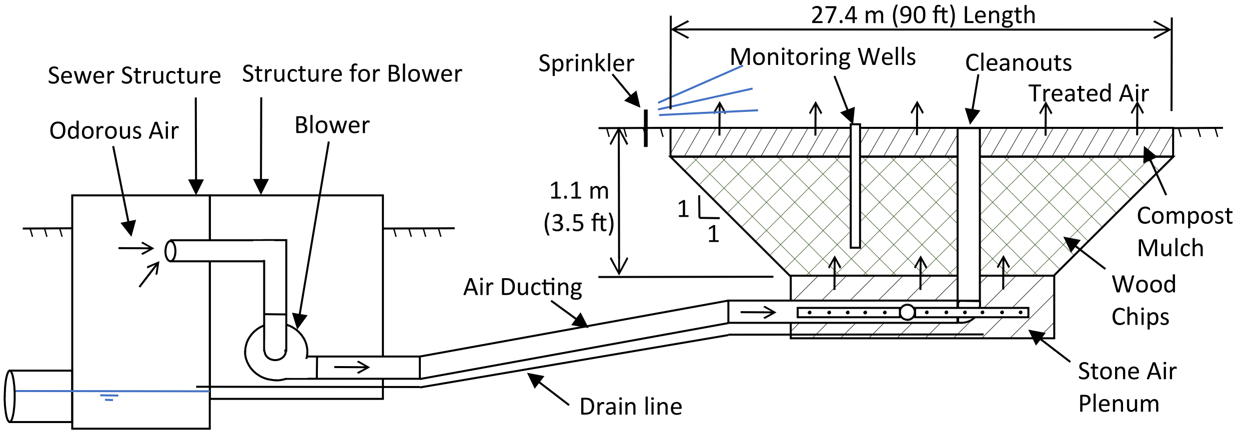


Figure 5: Example of a biofilter bed.

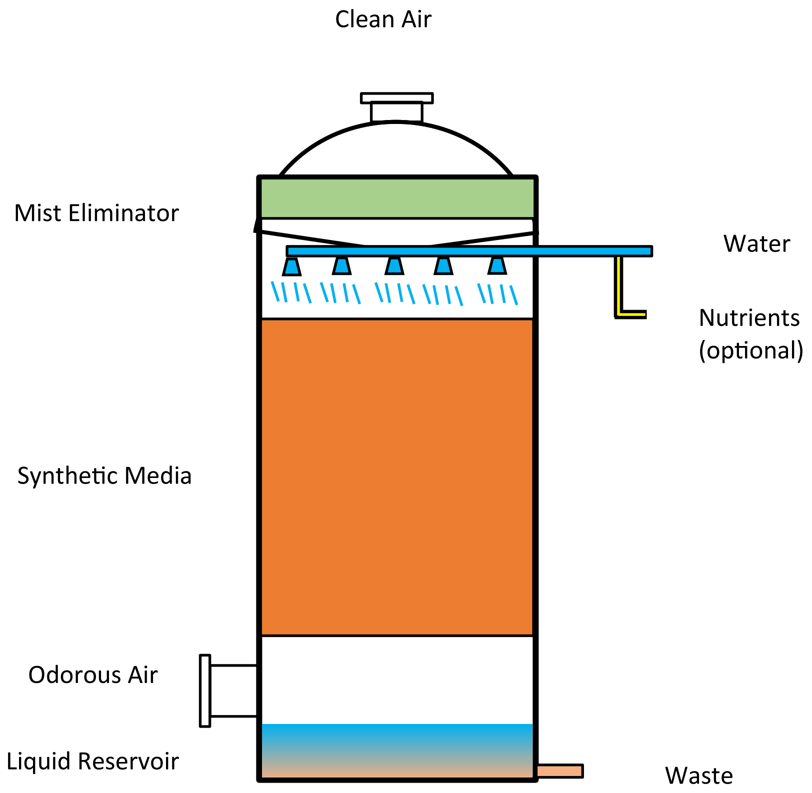


Figure 6: Schematic of a typical biotrickling filter.
Note that recirculation of water is typically not included.

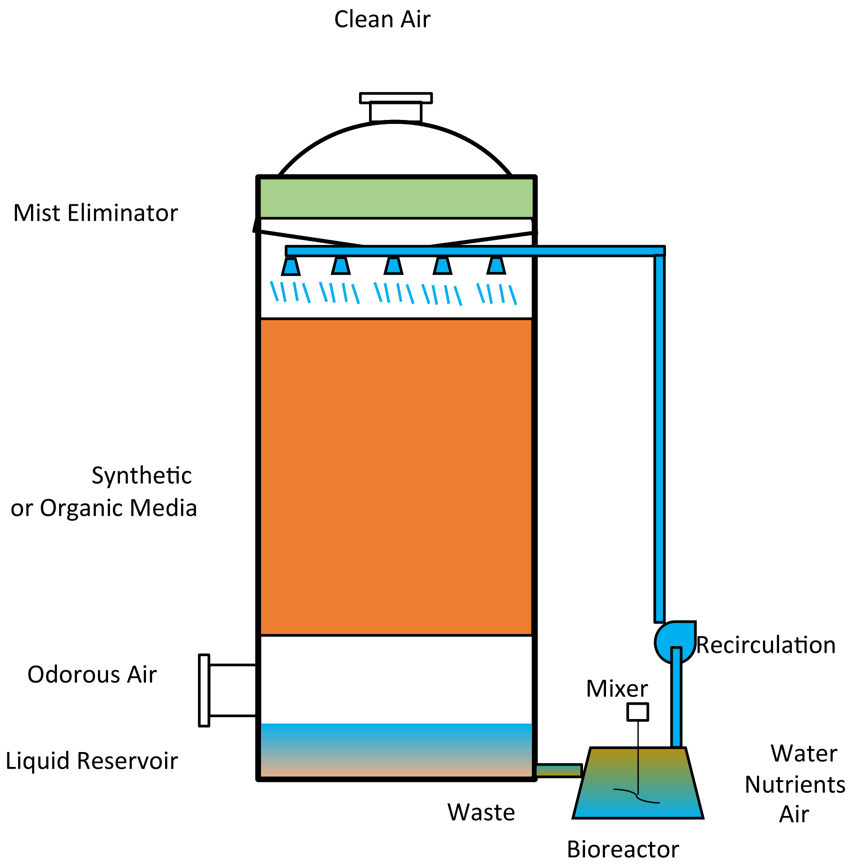


Figure 7: Schematic of a typical bioscrubber. A bioreactor with living organisms is maintained by adding nutrients (chemicals), air, and water. The mixture is a type of activated sludge and is sprayed on top of the media.

## Overview of Biological Treatment

Biological odor control systems are popular across many industries. They are a safe, sustainable, and cost-effective alternative for removing odors. Here is a summary of the three main types of biological odor control systems:

1. Biofilters consist of a large bed of organic media with bacteria living on the surface of the media. When odorous air moves up through the bed, the bacteria degrade the odorous compounds. Moisture is often maintained by either spraying water into the inlet air stream or irrigating the bed. See Figure 5.

2. Biotrickling filters consist of a vessel with synthetic media with bacteria living on the surface of the media. When odorous air moves up through the vessel, the bacteria degrade the odorous compounds. Irrigation water is added at the top to maintain moisture and to rinse away the metabolized compounds. See Figure 6.

3. Bioscrubbers consist of a vessel with synthetic or organic media. Water with a high concentration of bacteria is dispersed over the top of the media. When odorous air moves up through the vessel, the bacteria degrade the odorous compounds. The drain water is typically directed to a bioreactor which recycles some activated sludge back to the top of the bed, while the rest is sent to waste. See Figure 7.

The biochemical reactions are essentially the same for each type of biological odor control system. The normal odor removal mechanism consists of these main processes:

1. Odor compounds in the air are dissolved into any liquid water present in and around the media. This is a function of the odor compound solubility in water and Henry's law gas constant.
2. Biological degradation of the dissolved odor compounds occurs by bacteria living on the media. Biochemical reactions transform the odorous compounds into non-odorous compounds, also called metabolized compounds.
3. Metabolized compounds remain on the media and either build up or are rinsed away. The media requires periodic cleaning or replacement to avoid excessive buildup.

### *Hydrogen Sulfide Removal*

The most common odor compound is hydrogen sulfide, $H_2S$. In biological odor control systems, Thiobacillus bacteria are responsible for removing $H_2S$. These bacteria convert $H_2S$ to sulfuric acid in the presence of oxygen, thereby gaining energy for cellular growth and reproduction (metabolism). Thiobacillus is a genus of obligate chemoautotrophic bacteria, meaning they obtain energy by the oxidation of inorganic electron-donating molecules, such as $H_2S$.

Here is the common chemical reaction for $H_2S$ removal by Thiobacillus:

$$H_2S + 2O_2 \rightarrow H_2SO_4\,\text{(aqueous)} + \text{metabolic energy}$$

See Figure 8 for an image of Thiobacillus on organic media.

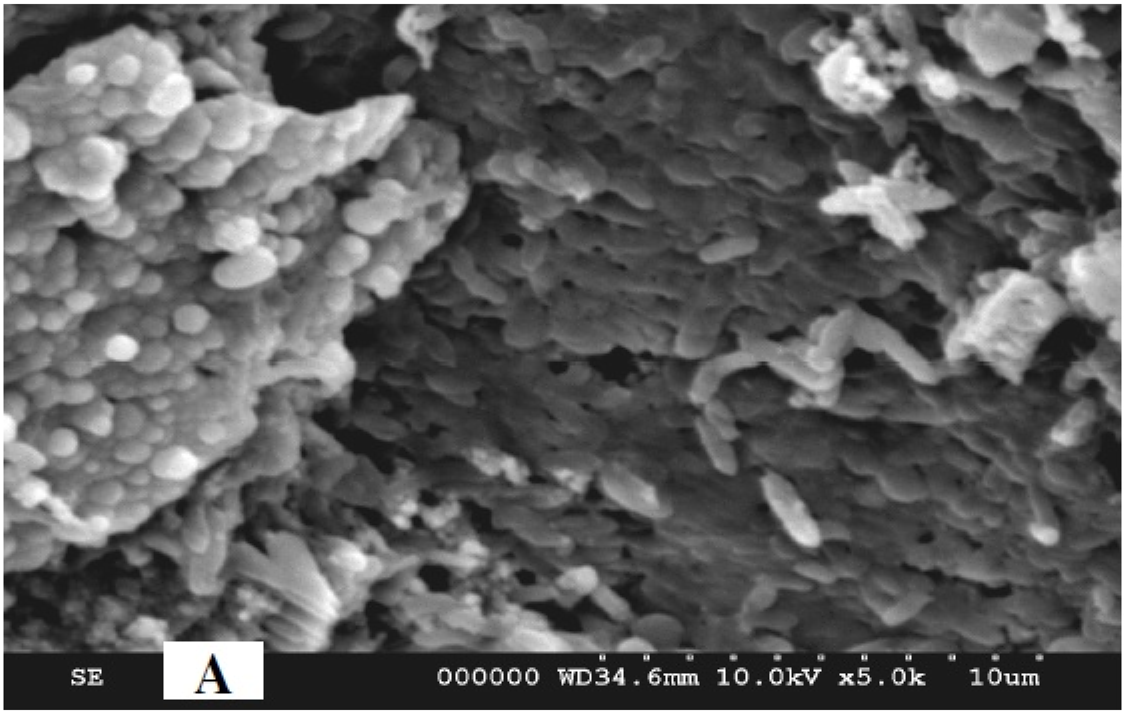


Figure 8: Scanning Electron Microscope image of organic media with Thiobacillus bacteria visible as the light rod-like structures.
Source: Ravichandra Potumarthi, Indian Institute of Chemical Technology

Thiobacillus is the same bacteria that cause corrosion inside sewer pipes and manholes due to the sulfuric acid ($H_2SO_4$) that the bacteria produce. There are several different species of Thiobacillus bacteria, each adapted to different environmental factors, such as temperature and pH. The pH is lower near the bottom of a media bed because the sulfuric acid drips downward. At this low pH, acidophilic species of bacteria will thrive. While at the top of the bed, at neutral pH, neutrophilic bacteria will thrive. See Figure 9.

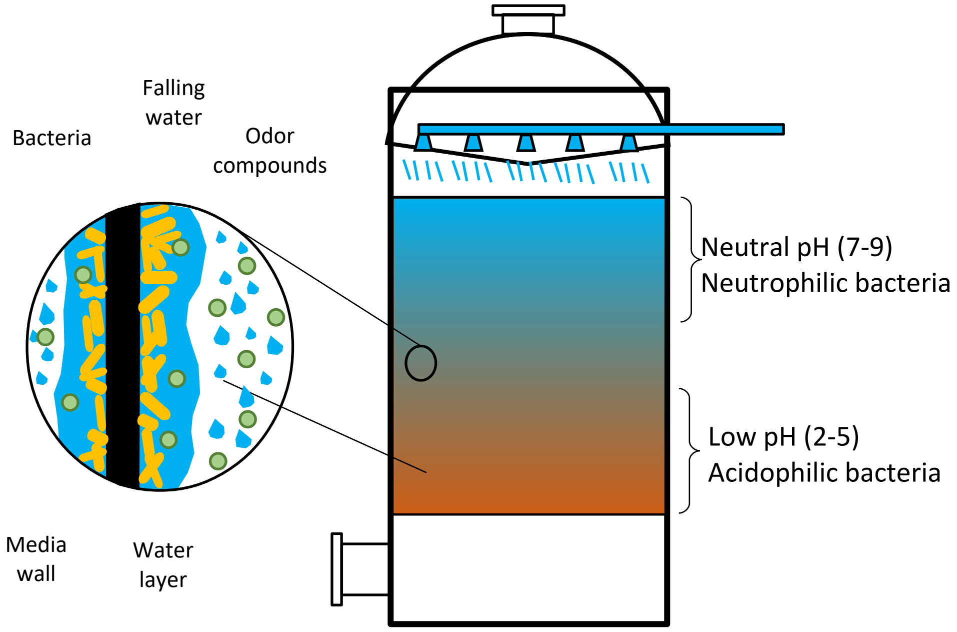


Figure 9: Biotrickling filter with pH zones and an enlargement depicting the dissolution of odor compounds into water at the surface of the media for bacteria to treat.

Thiobacillus is common in nature and is not harmful to humans from normal contact. The bacteria do not need to be introduced into the filter media as they will naturally be present and populate the media when odorous air is introduced. However, the media can be "seeded" with Thiobacillus at startup to quicken the time it takes for the bed to be populated for $H_2S$ removal.

*Organic Compound Removal*

Organic odor compounds are treated with heterotroph bacteria, which use organic carbon as food for metabolism and cell synthesis. Heterotrophs can consume mercaptans, dimethyl sulfide, dimethyl disulfide, and volatile organic compounds

(VOCs). Heterotroph bacteria are mostly neutrophilic, and so may not survive near the bottom of the bed.

## Biofilter Beds

Biofilter beds are also called soil beds or compost filters. They are a common, reliable, and economical method of odor control. Biofilter beds have been engineered for odor control since the 1950s and have become popular worldwide.

Biofilter beds function by forcing foul air through a large bed of organic media for treatment. In a typical arrangement, the air is moved by an air fan (or blower) to a network of perforated piping installed in a plenum of stones/rocks below the media bed. The air exits through the small perforation holes in the piping and rises through the media bed for treatment. See Figures 10 to 12 for an example.

Figure 10: Network of PVC piping with small holes on the bottom (perforated piping). After the pipe installation, stones are spread around the piping to form a solid plenum.

Figure 11: Wood chips being poured on top of the stone plenum to form the media bed.

Figure 12: Completed media bed that is flush with grade.
Decorative plants in islands of soil have been added for aesthetic value.

Biofilter beds are typically designed specifically for each application and constructed with local materials, rather than being purchased as pre-fabricated from a manufacturer. And the media bed is commonly below ground, as this is most economical and aesthetically pleasing. However pre-fabricated aboveground biofilters are available.

Typical biofilter components, as shown in Figure 5, include an air fan system, power supply, controls, pressure gauges, concrete slab or structure, air ducting, stone plenum, media bed, monitoring wells, irrigation system, and drain piping.

### *Media Selection*

The media must be able to perform the following functions:

- Retain moisture for the bacteria to live on the surface,
- Support the weight of the media above,
- Allow air to flow through gaps and holes, and
- Resist sulfuric acid for an acceptable amount of time.

Local wood chips are the most popular choice, although a variety of materials have proven successful, including coconut fibers, compost, nuts, and shells. See Figures 13 and 14 for examples. A mixture of compost and wood chips is also common. For the wood chips, it is best to use large chips, 2 to 6 inches in length, as the smaller chips break down too quickly. Also, hardwood chips are better than softwood chips for the same reason.

Figure 13: Wood chips (left) and coconut fiber (right).

Figure 14: Examples of compost material.

Iron sponge media is comprised of wood chips that have been impregnated with ferric oxide ($Fe_2O_3$) powder. The ferric oxide reacts with hydrogen sulfide to produce iron sulfide and water. This not only removes hydrogen sulfide but also provides liquid water to maintain a moist bed for bacteria to take up residence and remove other odors. However, the iron sponge media is costly. The design engineer can consider an upper layer of iron sponge media and the less expensive wood chips for the remainder of the bed.

*Moisture*

Biofilter media must be maintained in a moist condition to keep the bacteria active in removing odors. If the bed is too dry, odor treatment will be poor. If the bed is continuously too wet, the lifespan of the bed will decrease due to increased compaction of media which demands increased air pressure. It is recommended to design conservatively by providing sufficient or even slightly excessive moisture.

As a rule of thumb, a wood chip bed should be designed and monitored to maintain a minimum of 85% relative humidity. The high humidity level can be accomplished through the use of an in-line duct spray system or a surface spray system.

In wastewater applications, the odorous air is likely to be near saturated, which has 100% relative humidity. This can be confirmed by examining for condensation on surfaces exposed to the air, or by taking a humidity measurement. If the air is not saturated, the use of an in-duct spray system is recommended.

As the saturated air enters the biofilter bed, it will change temperature to match the bed. If the bed is cool, the odorous air will cool down, causing condensation of some water into the bed, and maintaining 100% relative humidity. But if the bed is warmer, the odorous air will warm up and no longer be saturated. In this situation, the relative humidity in the bed will depend on the temperature change, as shown in Figure 15. For example, air that is saturated with a temperature of 20°C has a water content of about 15g per kg of air.  If it is blown into a filter bed and warms to 30°C, the same water content of 15g per kg of air results in a relative humidity of about 50%.

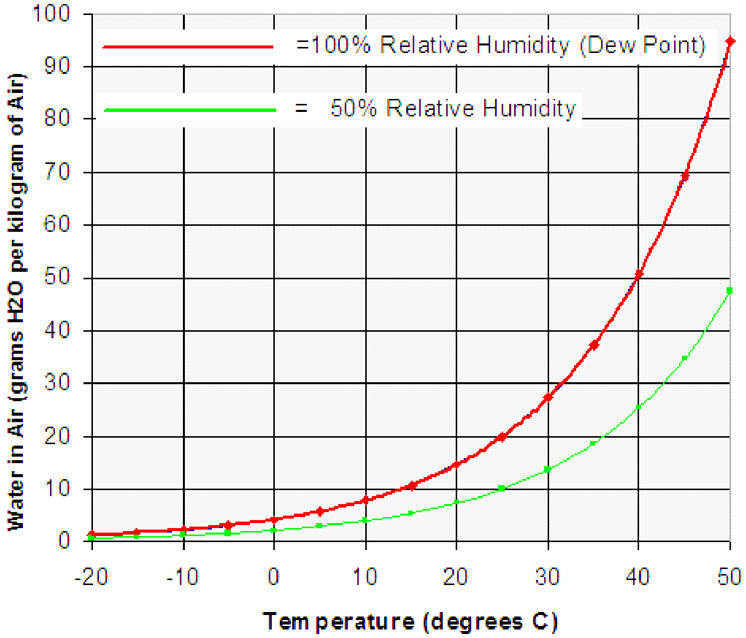


Figure 15: Plot of Water Content versus Temperature for Air at 100% and 50% relative humidity. The two points indicate the relative humidity change from 100% to 50% when the air temperature increases by 10 degrees C.

Poor odor removal due to moisture loss is most likely to occur during hot summer days when the air gets warmed inside the bed. Also, evaporation at the surface of the bed from sunlight is greatest in the summer months. To help maintain a moist environment in these conditions, outdoor beds are frequently designed with irrigations systems. The irrigation can be with a lawn-type sprinkler system or with perforated hoses running along the top of the bed.

*Bed Sizing*

The biofilter bed should be sized large enough so that the odor compounds have time to absorb into the water on the media particles. The time it takes for the odorous air to pass through the bed is called the contact time. Designing for a proper media contact time will ensure that odor compounds have time to dissolve into the moisture layer on the surface of the filter media for treatment by bacteria. For ease of calculations, the contact time is calculated as if the bed is empty of media. This is called the empty bed contact time (EBCT) or empty bed residence time (EBRT) and is calculated as the volume of the biofilter bed without media (empty) divided by the air flow rate.

EBCT = bed volume / flow rate

For removing hydrogen sulfide with organic media, the recommended minimum EBCT is 30 seconds. More complex odor compounds, such as volatile organic compounds (VOCs), can require an additional 30 to 75 seconds. These times already take into account the porosity for organic media, which is typically around 50%. An “apparent contact time” between the air and media can also be obtained by multiplying the EBCT by the porosity of the media; however, EBCT values are more typically used for design purposes and reported in various literature.

Note that for inorganic media, such as sand or crushed stone, a greater EBCT is required compared to organic media to remove the same amount of odor compounds. For example, a supplier of inorganic media made of lava rocks recommends a contact time of 72 seconds. Inorganic media does have the benefit of lasting longer.

Given the flow rate, the required bed volume can be found by multiplying the flow rate by the EBCT. An economical bed depth is 3 feet (roughly 1 meter). The surface area can be determined by dividing the required volume by the depth. The resulting formula is listed here:

Surface area = EBCT * flow rate / bed depth

Another approach is to design for a minimum surface loading rate. For a 3 feet (≈1 meter) deep bed, a common surface loading rate range is 3 to 5 cfm/ft$^2$ (1 to 1.7 m$^3$/min/

m$^2$). This loading rate is based on the removal of hydrogen sulfide at a concentration below 100 ppm.

If the odor concentration is anticipated to be greater than 100 ppm on a regular basis, consider the following options:

- Increase the EBCT by increasing the bed volume,
- Increase the flow rate to drop the concentration (while maintaining an EBCT above 30 seconds),
- Add iron sponge media as a top layer.

See Table 1 for a list of biofilter installations with loading rates (Filter Loading) and EBCT (Residence Time). Note how the loading rates are an average of 4.5 cfm/ft$^2$ and EBCT is an average of 50 seconds.

Table 1: Biofilter Installations with Key Characteristics

| **Facility**[a] | **Odor Source** | **Flow Rate CFM** | **Filter Loading CFM/ft$^2$** | **Area feet$^2$** | **Depth feet** | **Volume feet$^3$** | **Residence Time, Sec.** |
|---|---|---|---|---|---|---|---|
| CMCMUA, NJ | Compost | 2,400 | 4 | 600 | 4 | 2,400 | 60 |
| CCCSD, CA | WWTP | 3,500 | 5 | 700 | 4 | 2,800 | 48 |
| DMUA, IA | Compost | 210,000 | 5 | 42,000 | 4 | 168,000 | 48 |
| EHMSW, NY | Compost | 50,000 | 5 | 10,000 | 3 | 30,000 | 36 |
| EWWWTP, NY | WWPT | 15,000 | 2.67 | 5,620 | 4 | 22,480 | 90 |
| HRRSA, VA | Compost | 3,150 | 4 | 790 | 4 | 3,160 | 48 |
| HWQD, MA | Compost | 15,000 | 3.5 to 5 | 3,600 | 3 | 10,800 | 40-60 |
| RWSA, VA | Sewage | 2,825 | 5 | 565 | 4 | 2,260 | 48 |
| SBC, TN | Compost | 80,000 | 4.5 | 19,800 | 2.5 to 3 | 54,450 | 30-45 |
| UNISYN, HI | Food Waste | 2,500 | 4 | 625 | 3.5 | 2,188 | 42 |
| WLSSD, MN | WWPT | 50,000 | 4.2 | 11,800 | 4 | 47,200 | 57 |

Source: Using Bioreactors to Control Air Pollution, EPA-456/R-03-003

These design guidelines will help ensure an odor removal efficiency of at least 75%. Most biofilters report an $H_2S$ removal rate of around 90%, with a few reporting >95% removal.

*Piping*

It is common to size air pipes based on achieving an air velocity of around 2,000 fpm (ft/min). The goal of the air distribution piping is to dispense the odorous air as equally as possible throughout the biofilter bed. It is common to use 2” to 4” PVC pipes spaced every 2 feet and with holes at that same spacing. See Figure 16 for an example of an air distribution grid.

The holes, also called orifices, should have a diameter at least 10 times smaller than the pipe diameter to help ensure the orifice headloss is great enough to encourage equal flow out all the holes. See Figure 17 for an example with 4” diameter piping and 3/8” diameter holes, which is a hole to pipe ratio of 10.67. For large beds with large flows, hydraulic calculations or hydraulic modeling is recommended to confirm the air distribution throughout the bed. Often there needs to be fewer holes in the center of the bed where the air supply enters the bed, and more holes (or larger holes) at the extremities to ensure equal airflow distribution.

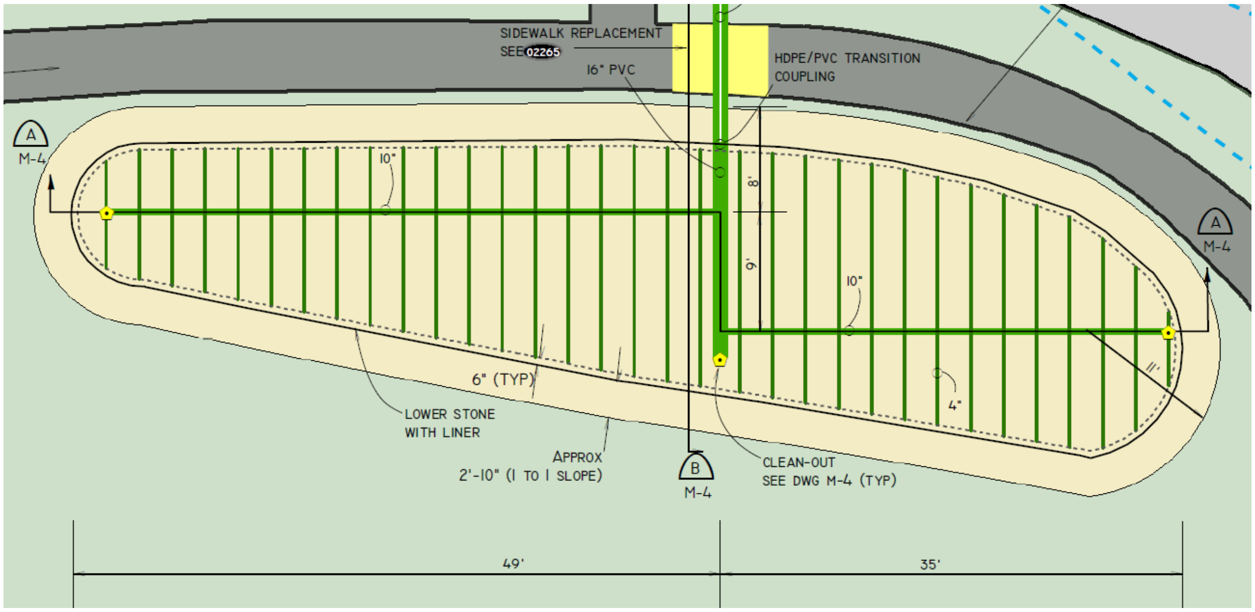


Figure 16: Plan view of a biofilter bed showing the air distribution piping in green.

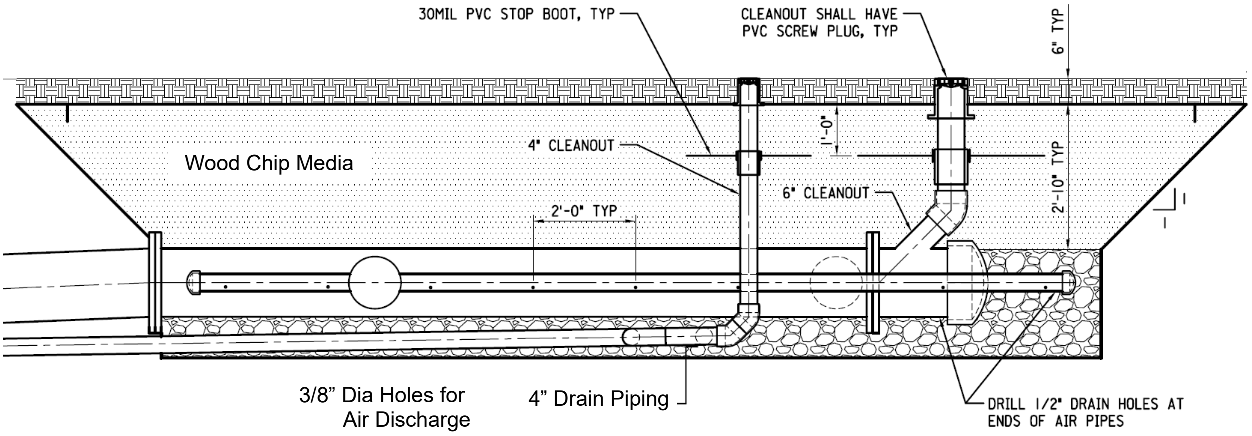


Figure 17: Section view of a biofilter bed showing the air and drain pipes.

*Blower*

The terms blower and "air fan" are often used interchangeably. Technically, an air fan operates at low pressure (a pressure ratio less than 1.11), a blower operates at medium pressure (a pressure ratio of 1.11 to 1.20), and a compressor operates at high pressure (a pressure ratio greater than 1.20). Depending on the biofilter design, either an air fan or blower will be required. See Figure 18 for an example.

Figure 18: Looking down on a blower that draws odorous air from the right and discharges the air at a higher pressure through the pipe at the top.

The blower, or air fan, should be designed to handle a large range of pressures since the media will compact over time causing the pressure to increase. Typical media headlosses range from 0.5 inches of water (0.12 kPa) when first placed into service to 10.0 inches of water (2.5 kPa) at the end of the bed life. See Figure 19 for an example system curve and fan curve used for blower selection. Often a single blower is insufficient to cover such a large range of pressures. Either multiple blowers are needed or the rotation speed is adjusted with a variable frequency drive (VFD).

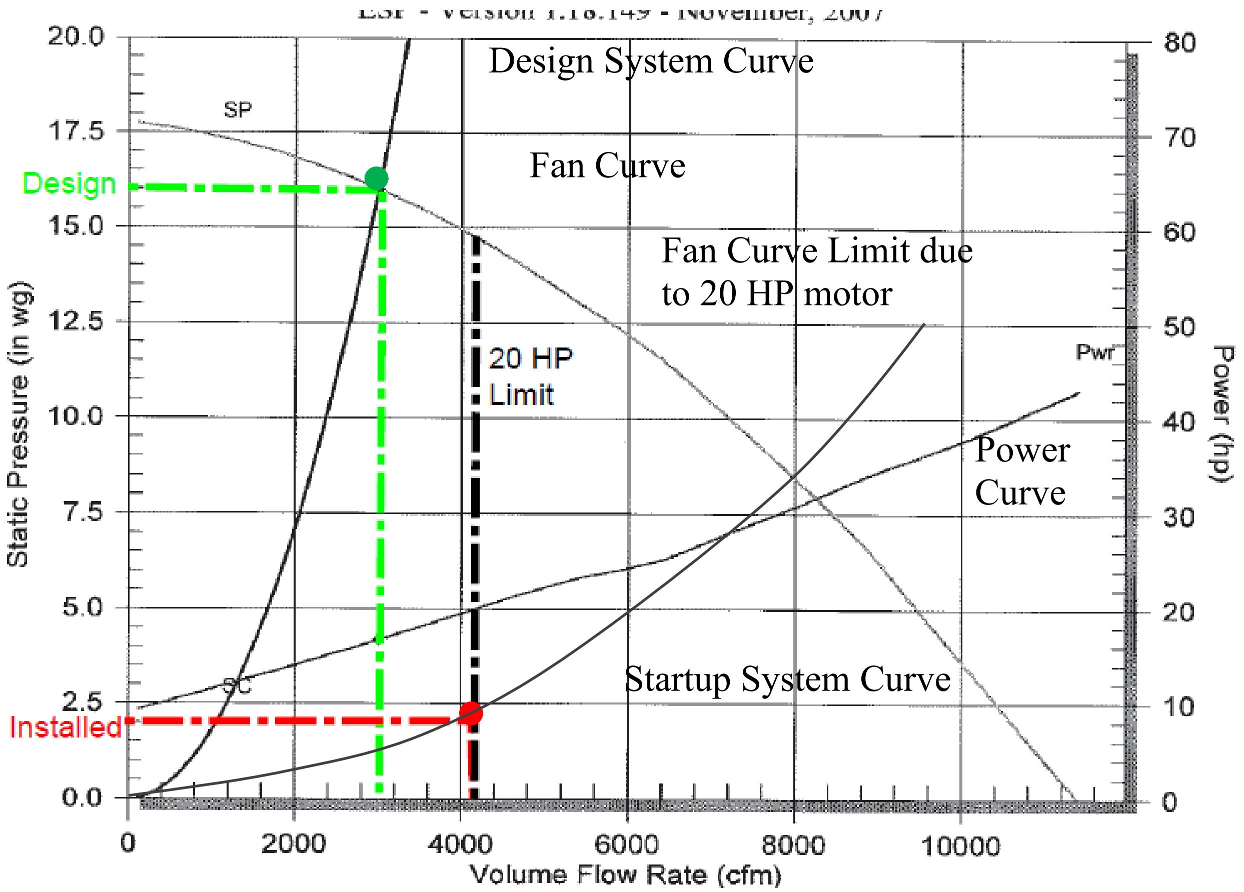


Figure 19: Fan curve with system curve for a blower with a 20 HP motor. The design point in green represents the flow and pressure near the end of the bed life. The installed point in red indicates the pressure and air flow at startup. Ideally, the blower would have a 50 HP motor to be able to operate over the full range.

*Designing for Public Places*

When designing a biofilter bed for a public place, the engineer should consider the values and special needs of the neighborhood. Components should have a minimal visual impact and be concealed to the greatest extent possible. Typically this means burying the biofilter bed, piping, and the blower enclosure. If the blower enclosure is above ground, consider using an architecture style that matches surrounding buildings.

The blower noise level should be minimized so that people walking nearby are not disturbed and conformance with any municipal noise ordinance. A suggested goal is to limit the noise at the nearest walking traffic (such as a sidewalk) to 55 dBA. A rule of thumb is that an increase of 10 dBA doubles the noise. Another rule of thumb is that doubling the distance from the source will drop the noise experienced by 3 dBA. A 5,000 cfm blower may produce noise at 100 dBA or more within a few feet. A blower enclosure will lower this noise significantly, especially if partially or fully buried; however, noise can still pass through hatches, windows, doors, and ducts. Consider adding sound absorption materials or offsets to these features. It may also be helpful to initially reduce the blower speed with a variable frequency drive, as blowers are less noisy when running slower, and only increase the speed as the bed headloss increases in time.

The irrigation system can be concealed by using pop-up rotor heads. The control valve and backflow preventer can be hidden, as shown in Figure 20.

Figure 20: Irrigation valve and backflow preventer concealed by an artificial rock.

### *Plants on the Bed*

Using a compost soil mixture for the bed surface provides a medium for plant growth. The compost can also support bacteria growth and contribute to odor treatment. A problem is that the compost tends to crack, as shown in Figure 21, allowing air to bypass and creating bubbling when the surface has standing water, such as after a rain event. A recommended soil mixture is 50% coarse sand, 45% compost, and 5% fines (silts or clays). Racking and tilling of the bed surface have been found to restore uniformity to a cracked bed.

### *Cold Weather*

Winter operation of an outdoor biofilter bed can be a concern when snow exists on the bed surface. The warm sewer air will melt the snow to produce muddy patches, as shown in Figure 21, which may draw negative attention from the public.

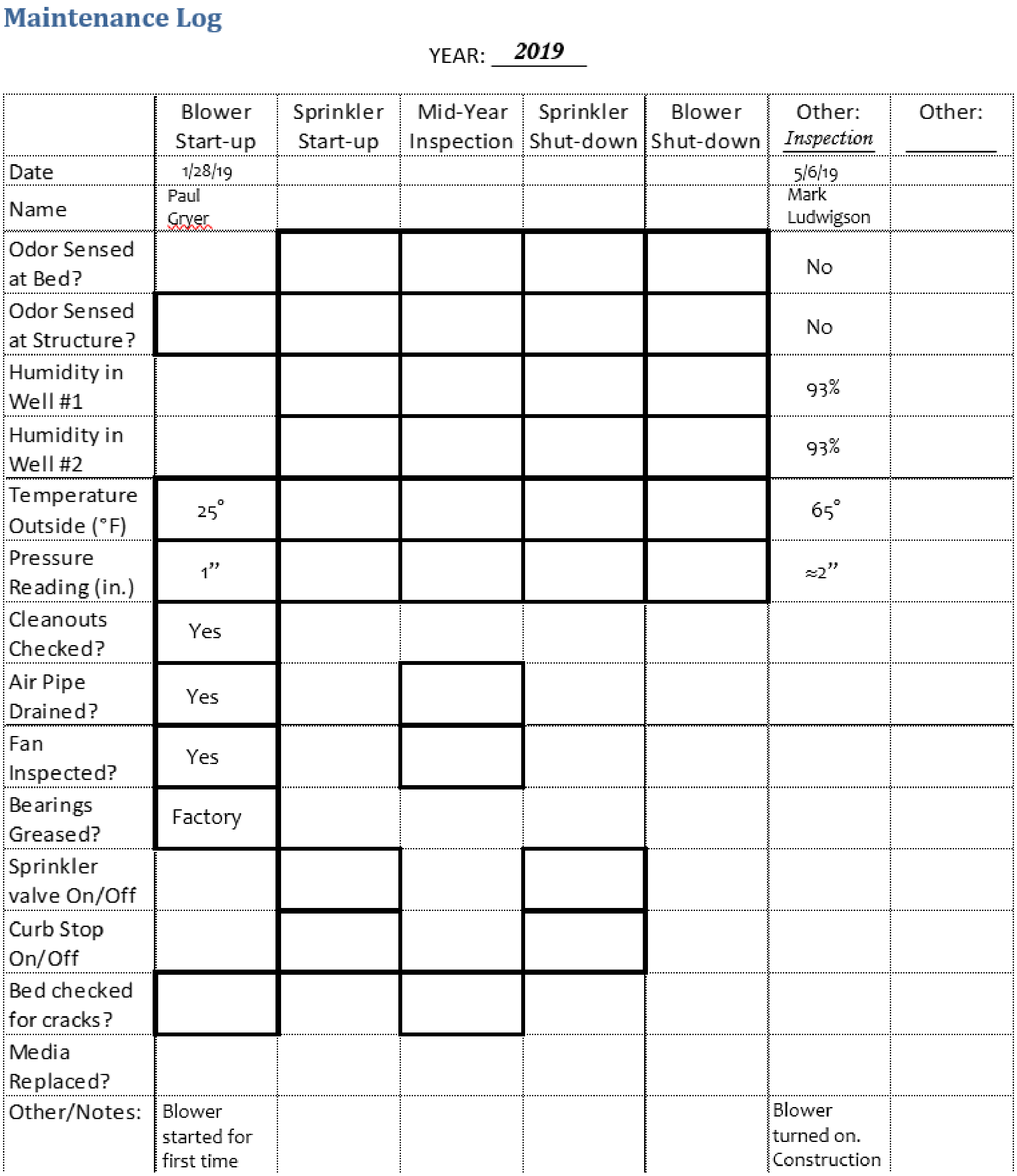
Figure 21 – Cracking of compost on a bed surface (left) and bubbling through the snow on the bed surface (right).

Another problem is that the irrigation system cannot be operated in freezing conditions, so if the odorous air is not saturated, odor removal performance will suffer. For wastewater applications, $H_2S$ levels are normally lower in the winter because the bacteria in sewerage pipes responsible for converting sulfur and sulfates to sulfide gases slow down in the cold. Therefore, it is often found that odor levels are acceptable during the cold months, even if the removal efficiency is lower.

*Maintenance*
Media removal and replacement is the most labor and equipment-intensive process associated with the maintenance of the odor control system. When removing the media, care should be taken to not crack the air distribution piping. Figure 11 shows media material being delivered in a dump truck, piled onto the bed with a backhoe, and spread manually.

The frequency of media replacement is to be determined by monitoring odors, moisture, and pressure. Monitoring wells in the bed are a convenient way to take regular humidity, temperature, and odor readings.  These readings can be recorded in a maintenance log, as shown in Figure 22.

When poor odor removal occurs, it is important to consider if the high odors are the result of an unusual or extreme condition, such as a sudden high concentration of $H_2S$ or an extremely hot and dry day. Next, consider if the humidity is low and adjust the irrigation system as needed. Also, check the blower pressure readings. A sudden spike in pressure suggests the air piping is blocked. A gradual increase in pressure over many months to the point of an unacceptably low flow rate indicates the bed material needs to be replaced. The bed design life is difficult to predict and has been reported to vary from 1.5 to 10 years. A period of 3 to 5 years can be assumed during design.



**Maintenance Log**

YEAR: *2019*

| | Blower Start-up | Sprinkler Start-up | Mid-Year Inspection | Sprinkler Shut-down | Blower Shut-down | Other: *Inspection* | Other: |
|---|---|---|---|---|---|---|---|
| Date | 1/28/19 | | | | | 5/6/19 | |
| Name | Paul Gryer | | | | | Mark Ludwigson | |
| Odor Sensed at Bed? | | | | | | No | |
| Odor Sensed at Structure? | | | | | | No | |
| Humidity in Well #1 | | | | | | 93% | |
| Humidity in Well #2 | | | | | | 93% | |
| Temperature Outside (°F) | 25° | | | | | 65° | |
| Pressure Reading (in.) | 1" | | | | | ≈2" | |
| Cleanouts Checked? | Yes | | | | | | |
| Air Pipe Drained? | Yes | | | | | | |
| Fan Inspected? | Yes | | | | | | |
| Bearings Greased? | Factory | | | | | | |
| Sprinkler valve On/Off | | | | | | | |
| Curb Stop On/Off | | | | | | | |
| Bed checked for cracks? | | | | | | | |
| Media Replaced? | | | | | | | |
| Other/Notes: | Blower started for first time | | | | | Blower turned on. Construction | |

Figure 22: Example of a biofilter maintenance log.

Example Problem 1:
Foul air is venting from a sewer structure located in a park in Arlington, Texas. Engineer Reneisha explained the benefits of a biofilter bed to the Director of the Parks Department. The Director requested that she proceed with a design that has a positive aesthetic impact. The design consists of blowing sewer gases through a bed of wood chips. Reneisha calculates the required air flow rate based on the sewer pipe size, maximum sewage velocity, and estimated air space in the sewer at this velocity. She calculates an air flow rate of 3,000 cfm. There is an area of 1,800 square feet available for the biofilter bed. Assuming an EBCT of 60 seconds, what is the recommended bed depth, rounded up to the nearest 6 inches?

Solution:
Reneisha rearranges the EBCT formula to solve for bed depth:

$$\begin{aligned} \text{Bed depth} &= \text{EBCT} * \text{flow rate} / \text{surface area} \\ &= 60\ \text{sec} * 1\ \text{min}/60\ \text{sec} * 3{,}000\ \text{ft}^3/\text{min} / 1{,}800\ \text{ft}^2 \\ &= 1.67\ \text{ft} \end{aligned}$$

Reneisha rounds up to a bed depth of 2’-0”.  She also recognizes that the actual volume of the bed and EBCT will need to be double-checked once the bed is drawn out including any sloped sides.

Example Problem 2:
Continuing from Problem 1, what is the recommended air pipe size?

Solution:
Reneisha uses the common design velocity of 2,000 fpm to calculate the ideal pipe diameter.

$$\text{Pipe area} = \text{flow rate} / \text{velocity}$$
$$\pi * \text{dia}^2 / 4 = 3{,}000\ \text{ft}^3/\text{min} / 2{,}000\ \text{ft/min}$$
$$\text{dia} = 1.38\ \text{ft} = 16.6\ \text{in}$$

Reneisha chooses the closest nominal pipe size of 16”.

## Biotrickling Filters

Biotrickling filters are also called trickling biofilters. Figure 6 shows the common features of a typical biotrickling filter. They function very similarly to biofilter beds, so many of the design principles reviewed in the previous section apply. The main differences are as follows:

- Biotrickling filters consist of a pre-fabricated vessel or tank filled with synthetic media.
- Biotrickling filters use a constant spray of water on the top surface, while biofilter beds may only require duct spraying or periodic surface watering. The water can be recycled, as shown in Figure 23.
- Biotrickling filters often include the addition of nutrients to maintain healthy bacteria.

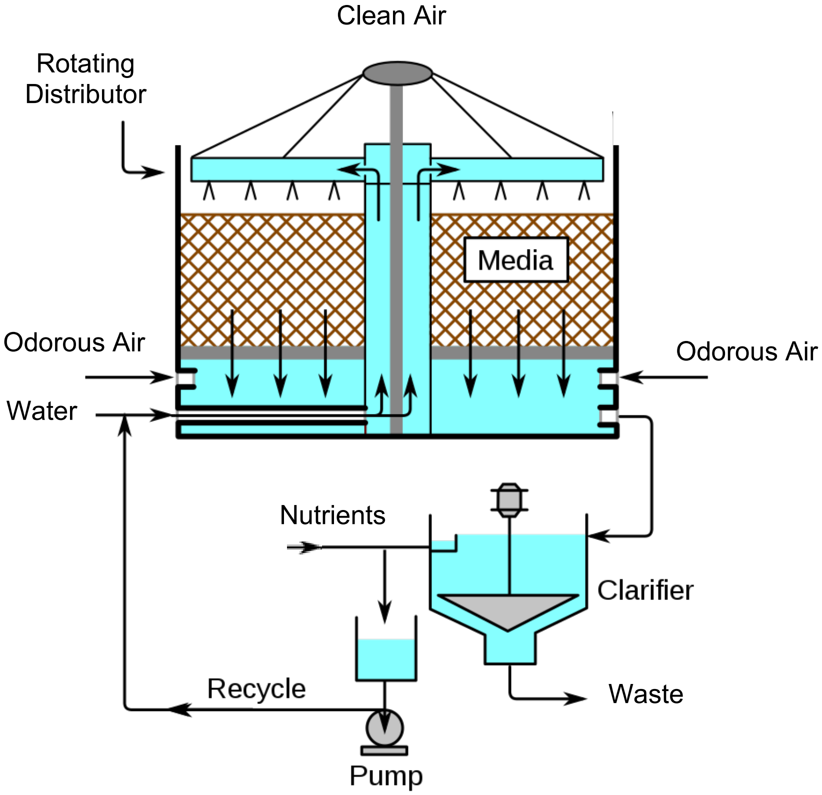


Figure 23: Schematic of a large diameter biotrickling filter with a rotating distributor, water recirculation system, and nutrient addition.

*Media*

A variety of plastic media is available for us in biotrickling filters. The most common is random plastic rings. However fixed packing media is also available. See Figure 24 for examples. Media with greater surface areas allow more bacteria to live on the media. The media options are essentially the same for both biotrickling filters for odor control and trickling filters for wastewater treatment.

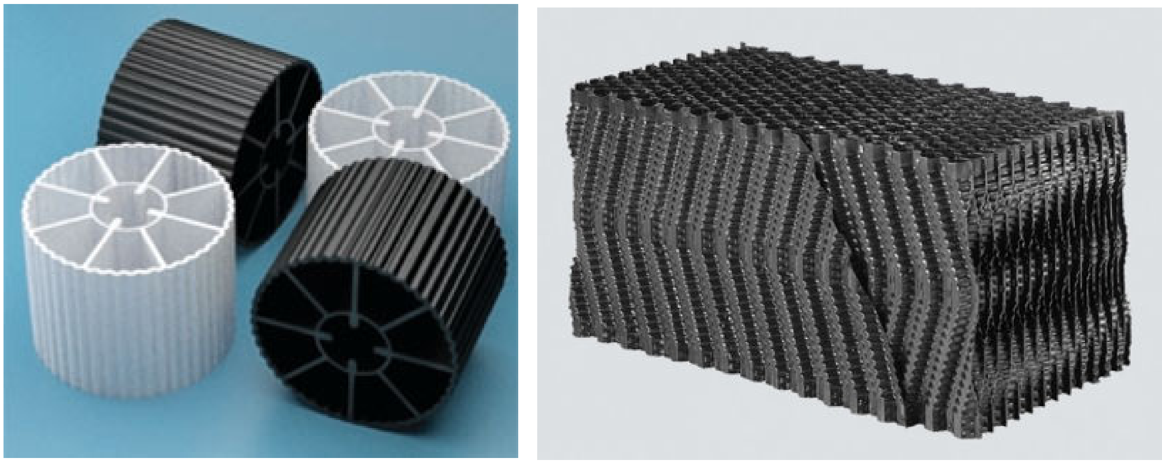


Figure 24: Examples of random plastic media (left) and fixed packing media (right).

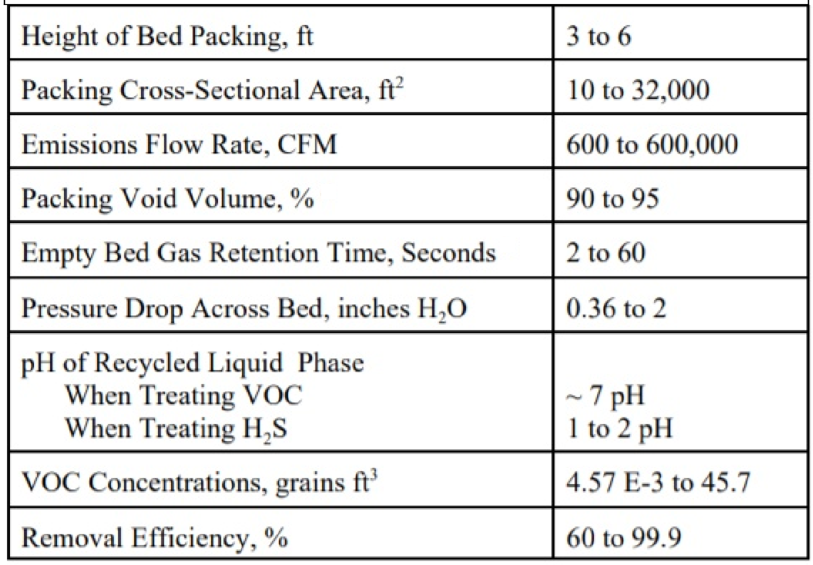
*Bed Sizing*

The media bed is sized based on the same general principles as biofilters. The EBRT is the primary factor utilized. Biotrickling filters require a lower EBRT for the following reasons:

- Consistent water supply and a saturated bed.
- Consistent media throughout the bed.
- Long-lasting media with consistent pressure drop.
- Ability to add nutrients or modify water supply to optimize performance.

See Table 2 for typical design characteristics of a biotrickling filter. For hydrogen sulfide removal, typical loading rates are 0.18 to 0.20 lb. $H_2S$ / $ft^3$ / hr.

Table 2: Biotrickling Filter Design Characteristics

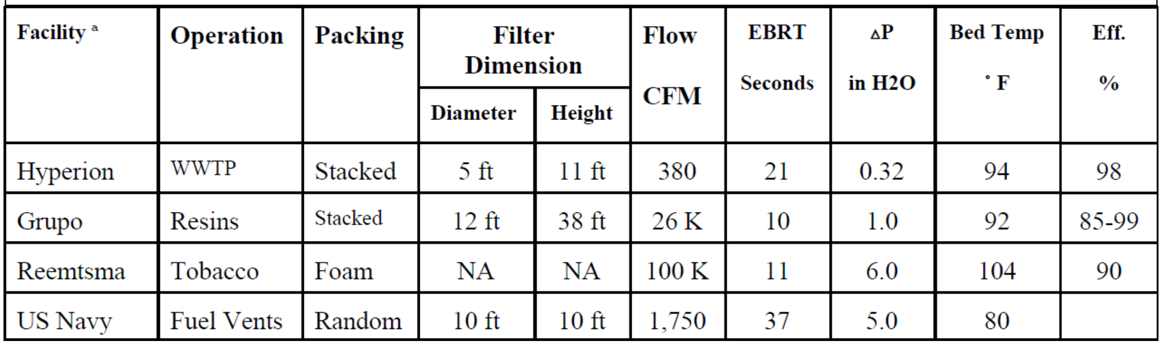


| | |
|---|---|
| Height of Bed Packing, ft | 3 to 6 |
| Packing Cross-Sectional Area, $ft^2$ | 10 to 32,000 |
| Emissions Flow Rate, CFM | 600 to 600,000 |
| Packing Void Volume, % | 90 to 95 |
| Empty Bed Gas Retention Time, Seconds | 2 to 60 |
| Pressure Drop Across Bed, inches $H_2O$ | 0.36 to 2 |
| pH of Recycled Liquid Phase<br>When Treating VOC<br>When Treating $H_2S$ | <br>~ 7 pH<br>1 to 2 pH |
| VOC Concentrations, grains $ft^3$ | 4.57 E-3 to 45.7 |
| Removal Efficiency, % | 60 to 99.9 |

Source: Using Bioreactors to Control Air Pollution, EPA-456/R-03-003

See Table 3 for a list of biotrickling filter installations with EBCT (EBRT), pressure drop/headloss through the bed (ΔP), and odor removal efficiency (Eff). Note how the EBCT is an average of 20 seconds and removal efficiency exceeds 90%.

Table 3: Biotrickling Filter Installations with Key Characteristics



| Facility [a] | Operation | Packing | Filter Dimension | | Flow CFM | EBRT Seconds | ΔP in H2O | Bed Temp ° F | Eff. % |
|---|---|---|---|---|---|---|---|---|---|
| | | | Diameter | Height | | | | | |
| Hyperion | WWTP | Stacked | 5 ft | 11 ft | 380 | 21 | 0.32 | 94 | 98 |
| Grupo | Resins | Stacked | 12 ft | 38 ft | 26 K | 10 | 1.0 | 92 | 85-99 |
| Reemtsma | Tobacco | Foam | NA | NA | 100 K | 11 | 6.0 | 104 | 90 |
| US Navy | Fuel Vents | Random | 10 ft | 10 ft | 1,750 | 37 | 5.0 | 80 | |

Source: Using Bioreactors to Control Air Pollution, EPA-456/R-03-003

### *Spray Water*

Spray water flow rates are effective with a surface loading rate of approximately 6.0 to 6.5 ft/hr (1.8 to 2.0 m/hr). The water can be recirculated, however a portion of the recirculating water must be replenished with fresh water. This can be controlled by a timer, ratio control valve, pH meters, and/or electrical conductivity meters. For the timer or ratio control valve approaches, a water turnover period of 2 hours is common for hydrogen sulfide removal. For example, if the recirculation flow rate is 10 gpm (600 gph), then the fresh water should be 300 gph (5 gpm) to turn over all the water ever 2 hours. This results in a ratio of 2:1 of recirculated water to fresh water. A control valve can be partially closed to provide this flow balance.

### *Nutrients*

Bacteria need nutrients to grow and produce new cells. Some air and water sources are lacking in certain nutrients such as nitrogen, phosphorous, and potassium, which limits bacterial growth and thus limits odor removal efficiency. Chemicals with these nutrients can be added to the bed, typically by injecting the chemical into the spray water supply. Several commercially available chemical solutions are designed to provide essential nutrients for the growth of bacteria.

## Bioscrubbers

A bioscrubber is very similar to a biotrickling filter, except with the following enhancements:

- Bacteria are stored and recycled with the spray water. This is accomplished with a bioreactor or similar process.
- The media bed is often partially submerged in water, allowing odor compounds in the bubbling air to rapidly dissolve into the water where bacteria can treat them. This also neutralizes the typically acidic/low pH zone at the bottom of the bed.
- Ozone can be added for the oxidation of certain odor compounds.
- Nutrients, pH control chemicals, and air can be modified for select bacteria.

Bioscrubbers are common for high concentrations of odor compounds (<200 ppm), especially organic compounds. They are typically designed by specialized suppliers. Bench-scale testing is sometimes done to size the components and select the proper nutrient chemical. See Figure 7 and Figure 25 for example arrangements.

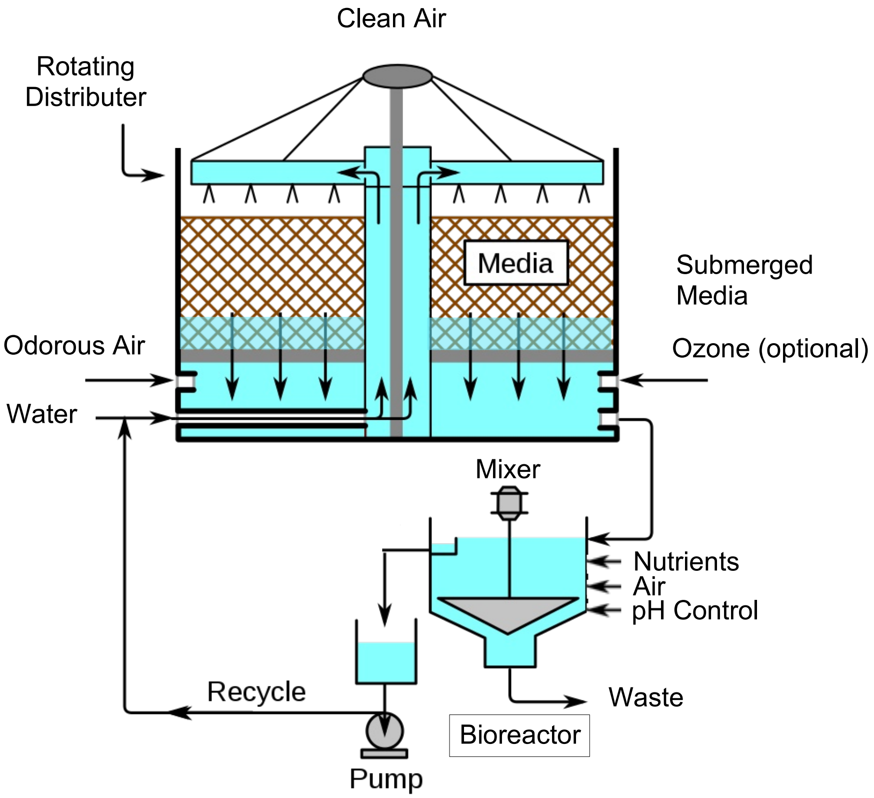


Figure 25: Schematic of a bioscrubber with a bioreactor and ozone addition.

Example Problem 3:
Dylan is an Engineer-in-Training (EIT) working under Fernando, a Professional Engineer (P.E.). Fernando asks Dylan to help with the sizing, layout, and a schematic diagram for a new bioscrubber system for a food processing facility. Fernando explains that the bioscrubber is to be located in the northeast corner of the main processing room, in a space of 12'-0" by 45'-0". Air flow comes from the west and should discharge out the east wall. The bed height can be a maximum of 10'-9" tall due to duct work and lights hanging from the ceiling in that area. The design flow rate is 4,000 cfm and minimum EBCT is 25 seconds. The bioscrubber manufacturer can provide vessels in 8', 10', or 12' diameter, and a single bioreactor that is size 4' diameter with a 2'x3' square pad for each recirculation pump. A 4' square pad is needed for a nutrient chemical tote. Also a 2'x4' pad is needed for an air blower. A clearance of 3'-0" is required between each component.

Solution:
First, Dylan determines the minimum media surface area based on the EBCT formula:

$$\begin{aligned}\text{Surf. area} &= \text{EBCT} * \text{flow rate} / \text{bed depth}\\ &= 25\text{ sec} * 1\text{ min}/60\text{ sec} * 4{,}000\text{ ft}^3/\text{min} / 10.75\text{ ft}\\ &= 155\text{ ft}^2\end{aligned}$$

Next, Dylan determines the quantity of 8' and 10' diameter vessels would be needed to exceed the minimum surface area required. He does not consider 12' diameter vessels due to the limited space available.

No. of vessels = surface area required / surface area per vessel

No. of 8' vessels = $200\text{ ft}^2 / (\pi\ (8\text{ ft})^2 / 4) = 155\text{ ft}^2 / 50.24\text{ ft}^2 = 3.08$ (round up to 4)

No. of 10' vessels = $200\text{ ft}^2 / (\pi\ (10\text{ ft})^2 / 4) = 155\text{ ft}^2 / 78.55\text{ ft}^2 = 1.97$ (round to 2)

The length of (4) 8' vessels in a row with 3' clearance between is (4) * 11' = 44'-0". This barely fits in the 45'-0" space available, and does not leave room for the other components. Therefore, he chooses (2) 10' vessels.

Next, Dylan uses the common design velocity of 2,000 fpm to calculate the ideal air pipe diameter.

Pipe area = flow rate / velocity
$\pi$ * dia $^2$ / 4 = 4,000 ft$^3$/min / 2,000 ft/min
dia = 1.59 ft = 19.15 in

Dylan chooses the closest nominal pipe size of 20”. Since the flow will be divided between two vessels, the pipes in and out of each vessel are sized as follows:

$\pi$ * dia $^2$ / 4 = 2,000 ft$^3$/min / 2,000 ft/min
dia = 1.13 ft = 13.5 in

Dylan chooses the closest nominal pipe size of 14”.

With the tanks and pipes sized, Dylan creates the layout shown in Figure 26 and the schematic diagram shown in Figure 27.

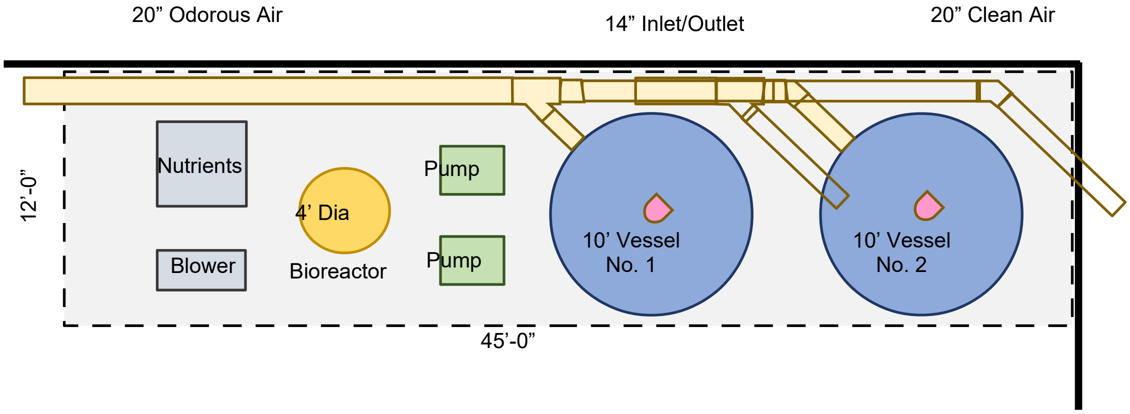


Figure 26: Bioscrubber system layout for Example 3.

Fernando reviews Dylan’s work. He asks him to also show the control panel location and to check the safety data sheets for the nutrients chemical and add a safety shower if necessary.

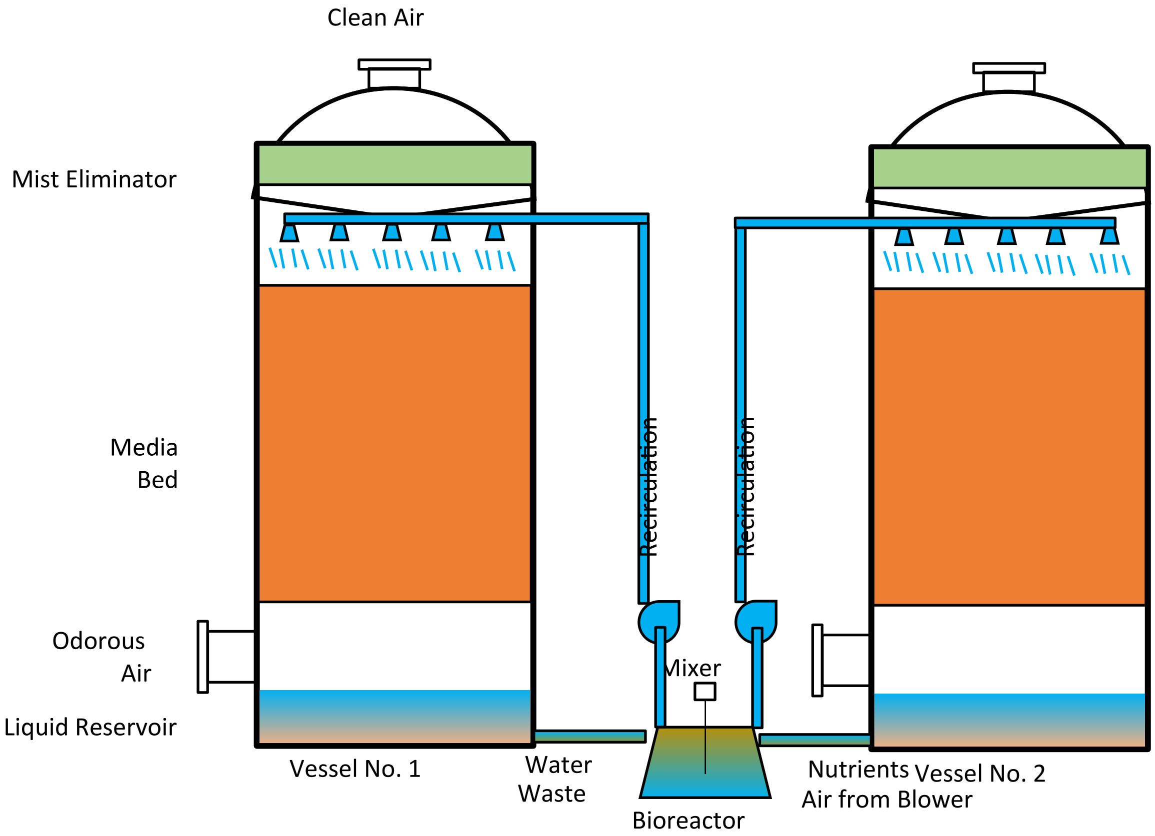


Figure 27: Schematic of the bioscrubber system for Example 3.

## Comparison of Biological Treatment Systems

Often Engineers are expected to compare alternatives and provide a recommendation. Often it is sufficient to provide a high-level qualitative comparison with advantages for each alternative. If this does not present a clear selection,

### *Qualitative Comparison*

A qualitative comparison of the three biological odor control systems is provided in Table 4.

Table 4: Comparison of Biological Odor Control Alternatives

| | Capital Cost | Lifecycle Cost | Footprint | Reliability | Flexibility | Aesthetics | Chemical Use |
|---|---|---|---|---|---|---|---|
| Biofilter | Best | Ok | Worst | Worst | Worst | Best | Best |
| Biotrickling Filter | Ok | Best | Ok | Ok | Ok | Ok | Ok |
| Bioscrubber | Worst | Worst | Best | Best | Best | Worst | Worst |

### *Lifecycle Cost*

Since odor control systems include substantial operations and maintenance costs, it is appropriate to compare the lifecycle cost of each alternative. Lifecycle cost refers to the total cost of ownership over the life of an asset. This whole-life costing includes costs incurred after an asset has been constructed or acquired, such as maintenance, energy usage, operation, and disposal.

The lifecycle cost can be calculated using the present worth approach. The formula is as follows:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

where: $PWF = Present\ Worth\ Factor = \text{¿}\ \frac{(1+i)^T - 1}{i*(1+i)^T}$

$i = interest\ rate$

$T = number\ of\ years$

Example Problem 4:
Engineer Frantz is comparing odor control alternatives and needs to calculate the 40-year lifecycle cost of a biofilter bed system. The capital costs are $80,000 and the annual maintenance costs are $19,000. The interest rate is 5%. There is no salvage value at 40 years.

Solution:
Frantz starts by calculating the present worth factor, PWF:

$$PWF=\frac{(1+0.05)^{40}-1}{0.05*(1+0.05)^{40}}=\frac{6.04}{0.35}=17.25$$

Next, Frantz calculates the lifecycle cost:

$$Lifecycle\,Cost=Capital\,Cost+Annual\,Maintenance*PWF-Salvage\,Value$$

$$Lifecycle\,Cost=\$80,000+\$19,000*17.25-0=\$407,750$$

## Helpful References

BioAir (2020) "The Introductory Guide to Industrial Odor Control" www.bioairsolutions.com

Devinny, J.S. (1999) "Biofiltration for Air Pollution Control". Lewis Publishers; Boca Raton, FL.

Environmental Protection Agency (2003) "Using Bioreactors to Control Air Pollution". EPA-456/R-03-003.

Potumarthi, R.; Anupoju, R. G.; Mugeraya, G.; Jetty, A. (2009) "Hydrogen Sulfide Removal in Biofilter: Evaluation of a New Filter Material by Immobilization of Thiobacillus sp.". International Journal of Chemical Reactor Engineering, Vol. 7, Art. A17.

Shareefdeen, Z.; Singh, A. (2005) "Biotechnology for Odor and Air Pollution Control". Springer; New York.

Water Environment Federation (2004) "Control of Odors and Emissions from Wastewater Treatment Plants". Manual of Practice No. 25; Alexandria, Virginia.