BioCycle
ARTICLE SERIES
COMPOST ODOR MANAGEMENT

Managing Odors In Organics Recycling

The quality of feedstock mixing also influences odor generation. With food scraps composting, the round nature of many fruits and vegetables makes it hard to keep them in the pile, much less adequately mixed.

New series looks at odor management during composting and anaerobic digestion. First article explores how odors are created, odor sources and regulatory considerations.

Part I

Craig Coker

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

OVER the next several months, *BioCycle* is publishing a series on odor management at composting and anaerobic digestion facilities. Failure to control and manage odors is the single biggest cause of adverse publicity, regulatory pressures and facility closures in the organics recycling industry. The article series examines the intricacies of odor management — how and where odors are generated, how they are measured and perceived, management through good process control as well as with technology, and addressing the neighbor and community relations of organics recycling odors. This first article explores how odors are created, odor sources and approaches to regulating their emissions and control.

Aerobic composting and anaerobic digestion facilities have one thing in common: they manage the process of decomposition. Decomposition begins immediately after the death of a living plant or animal, whether that's an orange plucked from a fruit tree, an animal rendered to feed people, or a shrub branch pruned by an avid gardener. Decomposition is a biological and chemical process whereby complex biochemical compounds are broken down into their constituent building blocks. For example, acetic acid (vinegar) decomposes aerobically into water (H_2O), carbon dioxide (CO_2) and ethane (C_2H_6).

Aerobic decomposition is the cornerstone of composting. Aerobic composting is an *oxidation* process, whereby decomposition raises the oxidation state of the building blocks. Oxidation — the same process that turns an apple skin brown, a bicycle fender rusty or a copper penny green — is defined as the interaction between oxygen molecules and all the different substances they may contact, from metal to living tissue. Oxidation occurs on a molecular level, but we see it when the free radicals formed by oxidation break away (rust flakes, copper oxide particles, brown spots on fruit). In the vinegar example, the three decomposition products are said to have a higher oxidation state than the acetic acid.

In food scraps composting, the main components are proteins, carbohydrates and fats, which contain various combinations of carbon, hydrogen, oxygen, nitrogen and sulfur. Decomposi-

Figure 1. Decomposition sequence of compounds in food scraps composting

CH_4 (Hydrocarbon) → CH_3OH (Alcohol) → $H_2C{=}O$ (Aldehyde) → $HCOOH$ (Acid) → $H_2O + CO_2$ (Products of complete oxidation)

tion of these compounds follows a well-evolved sequence of events (Figure 1).

Each of these categories of decomposition products has several subcategories, many of which are intermediate by-products of the decomposition process. For example, proteins decompose into their component polypeptides, which in turn, decompose into their component amino acids. At each stage of the decomposition process, there are a variety of different organic compounds, each with its own volatility characteristic. Think of a compound's volatility characteristic as its potential to generate odor.

An odor is a volatile chemical gas. Volatility is the tendency of a substance to vaporize, which is proportional to a substance's vapor pressure. At a given temperature, a substance with higher vapor pressure vaporizes more readily than a substance with lower vapor pressure. As an organic material decomposes, the mix of volatile compounds change, so the mix of vapor pressures changes, which in turn can change the characteristic odor. Some odors are produced by the biological changes in compounds by microorganisms; others are due to chemical changes in the composting pile (e.g., raising the pH of a pile by adding wood ash will shift the equilibrium between gaseous ammonia and soluble ammonium in favor of the gaseous ammonia, thus causing an ammonia odor). The major odor-causing compounds in composting are sulfur-, nitrogen-, and carbon-based. Table 1 lists odorous compounds and their distinguishing odor characteristic(s).

Figures 2 and 3 are schematic representations of two odor molecules, dimethyl disulfide (DMDS) and skatole. The odor detection threshold (DT) is the lowest concentration of a certain odor compound that is perceivable by the human sense of smell. DMDS has a detection threshold of 2.2×10^{-3} parts per million (ppm) while skatole's DT is over 1,000 times less (5.6×10^{-6} ppm). As a basis for comparison, a concentration of one ppm would be like one inch in 16 miles.

FACTORS INFLUENCING ODOR GENERATION

A composting pile is a highly dynamic ecosystem, constantly changing over the 21- to 60-day life of the active composting phase. Factors that influence odor generation include: feedstock composition, metabolic activity rates of the decomposers doing the work, availability of the nutrients in the feedstocks to the microbes, how well mixed the feedstocks are, and several physical factors, such as moisture content, particle size, oxygen content and diffusion, and temperature.

Different composting feedstocks have different odor characteristics, or profiles. Biosolids have around 0.8 percent sulfur content (8,000 ppm) and anaerobic conditions in the wastewater conveyance systems allow the reduction of the organic sulfur contained in amino acids in human waste (cysteine, methionine) to foul-smelling compounds like dimethyl disulfide, methyl mercaptan (the odorant they put in natural gas) and hydrogen sulfide. Feedstocks found in typical yard trimmings composting operations contain terpenes — the primary constituents of the oils found in plants and flowers, including limonene, menthol and alpha-pinene. While some find odors from yard trimmings composting unacceptable, most fully aerobic green waste composting odors are the sweetish earthy smells most composters find to be a pleasant smell.

Figure 2. Dimethyl Disulfide $(CH_3)_2S_2$
Detection threshold = 0.0022 ppm

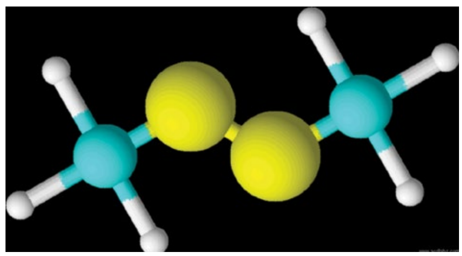
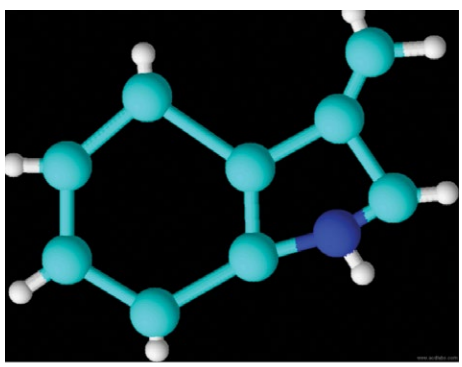


Figure 3. Skatole C_9H_9N
Detection threshold = 0.0000056 ppm



Food scraps composting introduces other odorous compounds, for example, acetaldehyde. Acetaldehyde occurs naturally in coffee, bread and ripe fruit, and is produced by plants as part of their normal metabolism. It is also produced by oxidation of ethanol and is popularly believed to be a cause of hangovers from alcohol consumption. The odor that arises from a garbage can is largely acetaldehyde. Other common odorous compounds found in food scraps include volatile fatty acids (VFAs) formed from the anaerobic decomposition of foods. Two acids commonly found in food scraps, lactic (from dairy) and acetic (a preservative), will depress the pH in a food scraps composting pile. If the pile is allowed to go anaerobic with a depressed pH, more VFAs will be formed, with consequent odor problems.

Degradability of a feedstock also influences odor generation. For example, seafood processing residuals are highly degradable and consume a lot of oxygen very quickly as they decay. (Highly degradable residuals reach a complete oxidation state faster than more slowly-degradable materials; for example, a rotting piece of fruit versus a rotting piece of wood.) Two problems occur with highly degradable materials. The first is that oxygen is consumed faster than it is replenished, with the formation of anoxic conditions. Second, the initial odorous by-products of decomposition (methylamine) don't oxidize to less odorous forms (ammonia) fast enough, resulting in a build-up of the first-stage odorous by-products.

Composition of the microbial community in a composting pile can influ-

Table 1. Odorous compounds and nature of the odors they cause

Compound	*Nature Of The Odor*
Sulfur Compounds	
Hydrogen sulfide	Rotten egg
Methyl mercaptan	Pungent, rotten cabbage, garlic
Carbon disulfide	Rotten pumpkins
Dimethyl disulfide	Putrid, sulfurous
Nitrogen compounds	
Ammonia	Pungent, sharp, eye-watering
Methylamine	Putrid, rotten fish
Cadaverine	Putrid, decaying animal tissue
Indole/Skatole	Fecal
Carbon compounds	
Acetic acid	Vinegar, pungent
Butyric acid	Rancid butter, garbage
Iso-valeric acid	Rancid cheeses, sweaty
Acetaldehyde	Green, sweet, fruity
Formaldehyde	Acid, medicinal
Limonene	Sharp, lemony
α-Pinene	Sharp, turpentine

ence odor generation. Temperature is a major factor in determining microbial species diversity, and different microorganisms have different assimilative capacities for odorous compounds (a measure of the ability or capacity to absorb and degrade odors). Odor compounds consist of various combinations of carbon, hydrogen, oxygen, nitrogen and sulfur. Fungi can assimilate 30 to 40 percent of the carbon in compounds that can be metabolized; aerobic bacteria can only assimilate 5 to 10 percent and anaerobic bacteria can only assimilate 2 to 5 percent. Because fungi do not dominate a composting pile hotter than 55°C (131°F), the pile has less assimilative capacity to degrade odor compounds. The lack of fungi in a thermophilic pile results in a lower C:N ratio (due to lack of carbon availability to bacteria), contributing to greater nitrogen losses at higher temperatures. In addition, elevated temperatures raise the microbial metabolic rate, which increases degradation rates, but it also increases the vapor pressure (and thus volatility) of most odorous compounds.

The quality of feedstock mixing can also influence odor generation. In an ideally mixed pile, a thin layer of the nitrogenous feedstock would evenly cover the carbonaceous amendment in the pile. Typically, however, it is impossible to mix feedstocks that finely or completely. More often, wetter heavier materials (like sludges and manures) will form "balls" that simply roll around in the mixing device. These clumps of largely nitrogenous material will not compost completely and if they are broken open by mechanical agitation during composting, they will release odors. With food scraps composting, the round nature of many fruits and vegetables makes it hard to even keep them in the pile, much less adequately mixed.

SOURCES OF ODORS IN COMPOSTING

Decomposition began when the living material now making up the feedstock died. So odor formation begins almost immediately with the onset of decomposition. Virtually every composting facility has had to deal with a very odorous feedstock coming into the receiving area.

A previous study (Epstein and Wu, 2000) correlated odor emissions by source at a windrow composting facility. Figure 4 illustrates their findings.

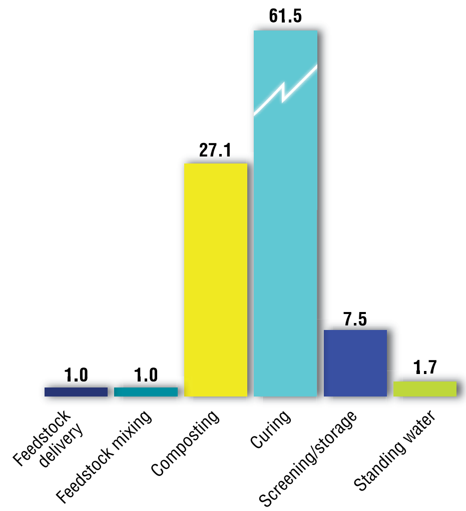
The study noted the following: "As shown, 27 percent of the odors were generated by composting windrows and 62 percent of odors were generated by curing piles. Although turning was generating the strongest concentration of odors, the short duration of turning, as compared with the constant surface area source of large curing piles, actually resulted in fewer odor units overall. An odor balance is a good preliminary indication of what the primary odor sources on a site are; odor mitigation measures can therefore be designed for maximum effectiveness.

"It should be noted however that odor dispersion from a site is not simply a matter of the number of odor units generated; there are many parameters to consider including source dimensions, topography, and the hours of emissions. Odor balances also do not take odor intensity into account; for example, while new compost piles may not produce the highest number of odor units, the intensity of the odor generated may be higher because of the types of compounds formed during the early stages of composting. Higher intensity odors are detectable at lower concentration and therefore have a relatively higher potential to cause odor impacts."

PERCEPTIONS AND REGULATION OF ODORS

Odor science is a very precise field of endeavor. Measurements are made in units of micrograms per cubic meter (1 $\mu g/m^3$ =1.6 x 10^{-9} lbs/CY). Impacts are measured in "dilutions-to-threshold" (the number of volumes of clean air needed to dilute an odor to its recognition threshold). And unusual terms like "olfactometry" are used (the science of measuring the acuity of the sense of smell). Yet, those affected by odor episodes at composting facilities inevitably respond in purely emotional contexts, with complaints using words

Figure 4. Percentage contribution to odor emissions by source



like "disgusting," "nauseating" and other highly-charged descriptors.

It is human nature that our reactions to odors are subjective and emotional. After all, an odorant is an air pollutant, and few things frighten people more than breathing in air that is "contaminated" with a chemical, particularly if their reaction to that chemical is unpleasant. What makes regulation and management of odors so difficult is that no two people will react the same way to an odorant. Everyone is different in how they perceive an odor, how pleasant or unpleasant they think it is, and how strong the odor is before it becomes noticeable, annoying or truly objectionable.

As a result, the majority of odor laws in the U.S. are written around a nuisance standard. Under the common law, persons in possession of real property (land owners, lease holders, etc.) are entitled to the quiet enjoyment of their lands. If a neighbor interferes with that quiet enjoyment, either by creating smells, sounds, pollution or any other hazard that extends past the boundaries of the property, the affected party may make a nuisance claim. For a "bad" odor to be considered a nuisance, it must alter one's daily activities. Simply smelling an odor is not a nuisance; therefore, in most cases single, mild, short-lived odor events are not considered nuisances. However, if the same event is not short-lived, even a mild odor could be considered a nuisance.

State environmental regulators have a difficult time enforcing odor regulations against any source, not only composting facilities. To start with, they must detect the odor at the point of complaint, and with sufficient strength and repetition to give credence to the complaint. Even then,

Table 2. Sample odor characterization using FIDO process

	Frequency				
Duration	*Single Occurrence*	*Quarterly*	*Monthly*	*Weekly*	*Daily*
1 minute	n/a	n/a	Very strong	Strong	Moderate
10 minutes	n/a	Very strong	Strong	Moderate	Light
1 hour	Very strong	Strong	Moderate	Light	Very light
4 hours	Strong	Moderate	Light	Very light	Very light
12 hours+	Moderate	Light	Very light	Very light	Very light

the regulator may not perceive the odor with the same distaste as the complainant.

Many regulators will try to get complainants to be systematic in recording their observations of odor episodes. One program was developed by the Texas Commission on Environmental Quality (TCEQ), and is known as FIDO.

FIDO stands for Frequency, Intensity, Duration and Offensiveness. The steps in the FIDO process include:

1. Characterize the odor to determine which *Offensiveness* table to use (Not Unpleasant to Highly Offensive).

2. Assess the *Intensity* of odor (Very Light to Very Strong).

3. Determine the total *Duration* of the odor(s) (1 minute to 24 hours).

4. Evaluate the *Frequency* of odor occurrence (Single Occurrence to Daily).

5. Identify the block on the chart that corresponds to the information from Steps 1-4 and determine if a nuisance condition exists.

TCEQ developed four different "Offensiveness" charts to help regulators decide if a nuisance had indeed been created. Table 2 illustrates a chart where odors are characterized as highly offensive.

Odor management and control in organics recycling may be the single most important responsibility of facility managers. It is a highly complex topic. Part II of this series, to appear next month, focuses on how process control can manage odors. ■

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COMPOST ODOR MANAGEMENT

Odor Defense Strategy

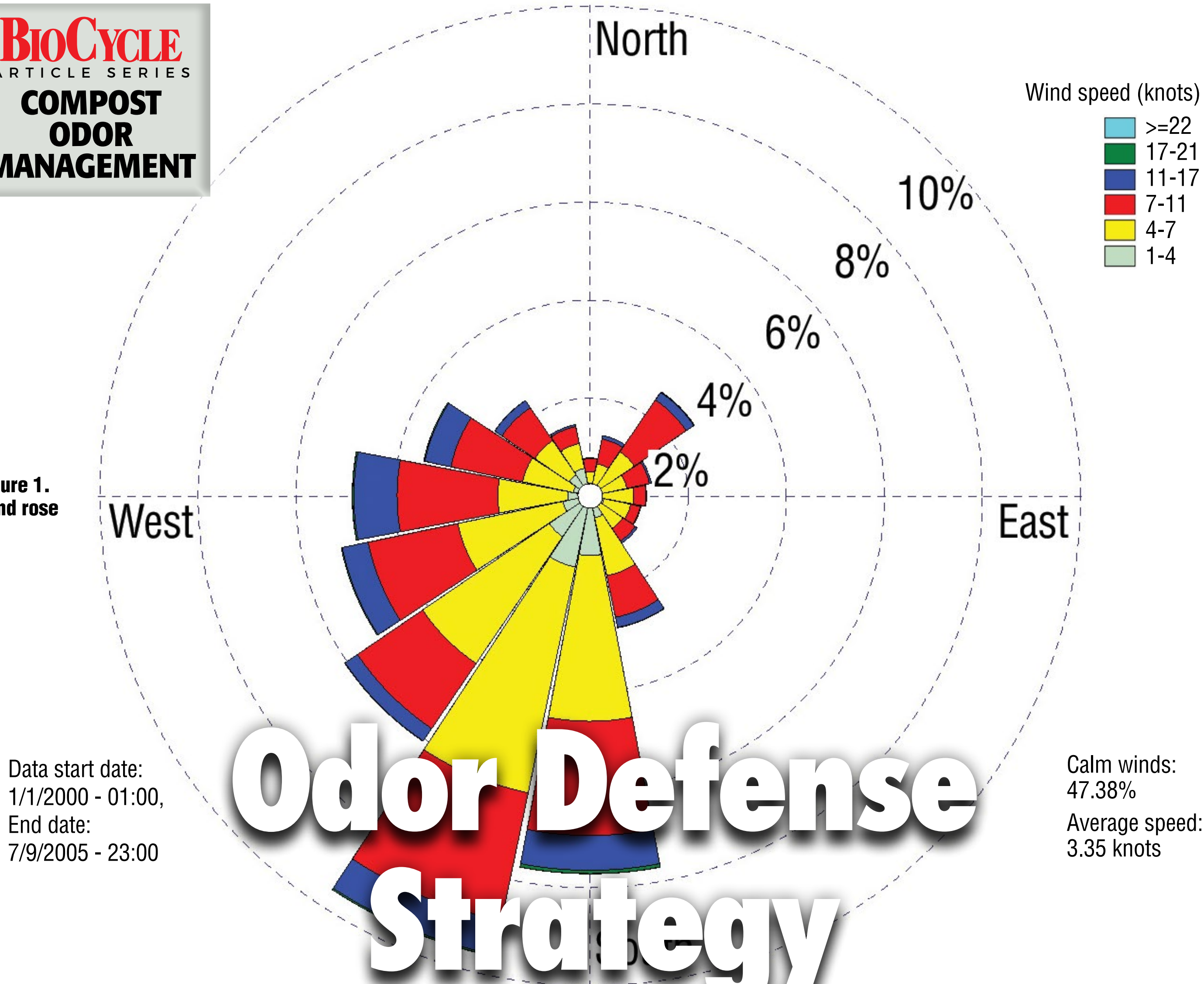


Figure 1. Wind rose

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

Good site design and not erring from composting process fundamentals are keys to odor control at composting facilities.

Part II

Craig Coker

A SUCCESSFUL composting facility requires careful consideration of siting factors that can influence how neighbors react to odor episodes. This article applies to both new and existing facilities. The first step is to construct a wind rose (Figure 1), an illustration of the direction and speed of the wind. Two items are needed to build the wind rose: Hourly weather observations at a nearby official weather station (usually an airport) from the National Climatic Data Center (http://www.ncdc. noaa. gov/oa/ncdc.html) and a software package like WRPLOT (freeware from Lakes Environmental, http://www.weblakes. com/products/wrplot/index.htm). Use at least five years worth of data to create an accurate wind rose.

Once the prevailing wind directions and speeds are known, the layout and operation of the site can consider potential impact of odors on receptors. A sensitive receptor can be defined as any place where members of the public may gather, such as a house, school, park, church or shopping area. For initial siting and site layout, locate waste management aspects of the facility (e.g., waste receiving, mixing and active composting) at least 1,000 feet (and preferably 1,500 feet) from any sensitive receptors in the predominantly downwind direction (south, south-southwest, and southwest in Figure 1). Plan on a thickly vegetated buffer of fully developed vegetation in that direction so

Bench Scale Reactors

(and how to build your own)

Having a bench-scale reactor on site to test different recipes before trying them at full-scale helps predict odor generation. Here are some quick tips on building one:

Windrow System: Use a backyard wire-cage composter

Forced Air Reactor: Fit a large aquarium air pump to a plastic 55-gallon drum

that vegetative surfaces can intercept and filter particulate matter that may contain odorous compounds.

Orient the site so that odor-producing activities are sheltered by trees, hills, buildings, walls and other features that break up the wind pattern to create turbulence. Turbulent wind patterns disperse odors faster than laminar, or smooth, wind patterns. Turbulent dispersal is important, as the odor detection and recognition thresholds of some compounds is extremely low. Other site planning and development steps that can reduce potential for odor problems include: leaving room for equipment to get to piles or windrows for implementing odor-related best management practices (BMPs) as needed (such as installing a compost cap or watering windrows prior to turning), and designing the site for rapid and effective runoff and drainage management to prevent odorous puddles from forming.

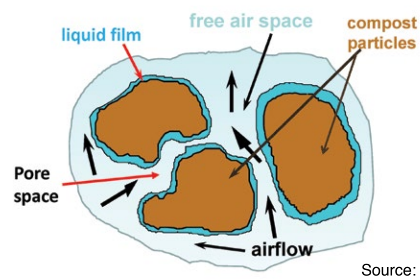
In Figure 1, note that the predominant wind speeds are less than 11 miles per hour, meaning there are significant blocks of time with very low wind speeds (i.e., less than 4 miles/hour) so there is little dispersal and dilution of odorants. During low wind speed events, activities that might generate odors should be avoided as much as possible without unduly constraining operations. These activity restrictions might include delaying waste mixing, pile building, windrow turning, etc. until the wind picks up. Operational decisions and practices that can minimize the potential for odor episodes will be covered in a future article.

OPTIMUM CONDITIONING

Composting is *never* odor-free. Even under optimum conditions for aerobic decomposition of organic matter, odors are going to form. However, failure to develop those optimum conditions is guaranteed to make odors worse, particularly those odorants that people find annoying or unpleasant. The more odors that are formed due to poor composting conditions, the more quantities of that odorant escape into the atmosphere, and it becomes much harder to disperse those quantities below the recognition thresholds. The detection threshold of an odor is the minimum concentration that the human nose can perceive something in the air but not identify it; the recognition threshold is the minimum concentration that a human receptor can identify the odorant. The recognition threshold of an odor is much higher than the detection threshold; for example, ammonia has a detection threshold of 0.037 ppm, but a recognition threshold of 47 ppm.

Optimum conditions of a good compost pile or windrow are illustrated in Figure 2. The microbes live in that thin biofilm around each particle in the pile and draw their life-sustaining oxygen from the air flowing through the pore space in the pile. So the first step in controlling the microbial activity is a mix that adheres to the right nutrient balance between carbon and nitrogen (at least 25 parts of carbon for each part of nitrogen), adequate moisture to form and maintain the biofilm (around 50-55%) and enough structural porosity to ensure a free air space of at least 40 percent to keep oxygen levels above an 8 to 10 percent minimum. Free air space can be measured using a bucket test similar to the bucket test often used to measure bulk density (see sidebar).

Figure 2. Optimum composting conditions



Source: US Composting Council

"It all starts with the mix," says Tim O'Neill, President of Engineered Compost Systems. "You have to start as close as you can to this mix or odor control technology won't help. I've worked with quite a few biosolids composting facilities that started out with a C:N ratio that was too low; they had not accounted for the fact that some of the carbon in an amendment is not available to the microbes." O'Neill recommends that facilities have bench-scale reactors on-site (see box) to test different recipes before trying them in full-scale applications to learn more about the odors with each recipe.

CONTROLLING MICROBIAL ACTIVITY

No one practice influences odor generation potential more than another; rather it is a combination of smaller steps to be managed, including particle size, moisture content and air flow.

Particle Size

As illustrated in Figure 2, the effectiveness of microbial metabolism on the compost particle is defined, in part, by the surface area-to-volume (SAV) relationship of the particle. The SAV explains why finely-ground salt dissolves in water faster than coarsely-ground salt. If SAV is too high, the interior of that particle will take a very long time to compost. If it is too low, then the particles in the pile can't support themselves and they collapse the free air space between them, reducing the ability of the pile to stay aerobic. Particle sizes should be in the 2- to 3-inch range.

One way to manage this in the field is with bulk density (the ratio of mass to volume of a specific material). A high bulk density means there are smaller particle sizes and narrower pore spaces; it also means there is more organic material to decompose in a given volume of mixed feedstocks. Initial compost mixes should have a mixed bulk density below 1,100 pounds per cubic yard (lbs/cy).

Moisture Content

The correct moisture content advances the rate of decomposition. There are three types of water in a compost pile: free (gravitational) water, which drains out by gravity (a soaked pile after a rainstorm); capillary water, which is

Top 5 Signs Of Impending Odor Problems

(and how to troubleshoot them)

1. Excessive Moisture: If windrows, mix in dry material (compost, sawdust, etc.); don"t just turn windrow. If aerated static pile (ASP), turn up fan airflow and keep fans running.
2. Low C:N Ratio: Mix in high available carbon material, ideally sugars, starches, etc.
3. Low pH: Mix in wood ash; High pH: Mix in acidic material (food scraps).
4. "Heavy Air" (low ground fog): Don't turn windrows; if ASP, check biofilter for short-circuiting.
5. Post-rainfall puddles: Soak up with absorbent material (compost, sawdust, etc.).

Measuring Free Air Space

(and how to make sure you have enough)

THE 5-gallon bucket test is a simple way to measure free air space in a compost pile — before it's built. The materials needed include a 5-gallon pail, a 1-gallon plastic milk jug, and the typical mix of materials added to the compost pile (manure, grass clippings, straw, wood chips, shredded bark, etc.)

1. Check the volume of the 5-gallon pail by filling the 1-gallon jug and emptying it into the 5-gallon pail 5 times. Mark the 5-gallon "full line" on the pail.
2. Fill the pail one-third full with a typical mix of compost materials and drop the pail 10 times from a height of 6 inches onto a cement floor or sidewalk (being careful to keep all the material in the pail).
3. Add more compost material to fill the 5-gallon pail two-thirds full and drop the pail 10 times from a height of 6 inches onto a cement floor or sidewalk.
4. Add material to fill the 5-gallon pail up to the "full .line" and drop the pail 10 times from a height of 6 inches onto a cement floor or sidewalk.
5. Add material to fill the pail to the "full line."
6. Now add and keep track of the amount water you can add to the 5-gallon pail before it overflows.
   - If you can add 2.75 to 3.25 gallons of water to the pail without it spilling over the top, you have adequate free air space. Your initial free air space is correct.
   - If you cannot add at least 2.75 gallons of water to the pail without it spilling over the top, you have inadequate free air space. Add more bulking material like straw, coarse wood chips or shredded bark.
   - If you can add more than 3.25 gallons of water to the pail without it spilling over the top, you have too much free air space and you need to reduce the particle size. This can be done by grinding or shredding the materials or by adding finer materials to the mix.
7. Make the needed corrections and retest until the test shows the correct initial free air space.

Source: "Composting and Mulching: A Guide to Managing Organic Yard Wastes", University of Minnesota Cooperative Extension, BU-03296, 2000

cohesively- or adhesively-bound to the particle and forms the biofilm in which the microbes live; and intracellular water, which is contained inside the cells of plants and animal tissue. The capillary water is most important to good composting, but variations in moisture from release of intracellular water need to be considered.

If the biofilm around the particles dries out, microbial activity will go dormant and composting will stop. As piles dry out, the concentration of potential odorants in the biofilm increases. This can cause a chemical equilibrium shift between soluble and volatile forms for odorants such as ammonia or the terpenes found in green wastes. As mentioned in Part 1, when a chemical volatilizes, it becomes a gas and migrates out of a compost pile by either passive or forced aeration. Conversely, if moisture is allowed to climb above 60 percent or so, the free air space channels between the particles clog with water. This thicker biofilm reduces the amount of oxygen available to the microorganisms on the surface of the particle as the rate of oxygen transfer in water is much slower than the rate of transfer in air. Material with an optimum moisture content of around 50 to 55 percent has the consistency of a wrung-out sponge that is wet but not freely dripping water.

One of the challenges in composting food scraps containing large amounts of vegetable and fruit material is that the plant cell walls break open readily under the heat of initial decomposition, flooding the pile with water. Without adequate structural porosity to allow that flush to drain out, the pore spaces in the pile will fill with water and risk formation of anaerobic conditions.

Air Flow

Transfer of oxygen across the biofilm requires a steady flow of air through the pile. Whether by natural or passive means, or forced through a pile by a blower, aeration serves several critical functions in process management, including replenishment of oxygen, removal of carbon dioxide (and volatile odorants), and removal of heat. Compost piles and windrows have both macro aeration and micro aeration characteristics. Macro aeration refers to the overall uniformity of the structural porosity of a pile. A compost pile comprised of wet dairy manure mixed with sawdust has low macro aeration characteristics. A compost pile of chipped tree waste has good macro aeration characteristics. Good macro aeration characteristics are necessary where passive aeration is the primary means of oxygen transfer, like in windrows.

Micro aeration characteristics refer to how well air moves inside the pile. Fine particles, such as those produced by processing woody wastes with a hammermill, can impede aeration rates and create air-starved sections in a pile. Piles with a lot of paper in them also can create poor micro aeration characteristics. "The agglomeration of the paper particles can clog air channels in the pile," notes O'Neill. "Poor micro aeration in food scraps compost piles can depress pH, which leads to formation of volatile fatty acids that make that sickly sweet smell."

RELEASE OF ODORANTS

Part 1 of this series noted that odorants are produced at various stages in the decomposition process and that there is a sequence of events in which the odorants generated by initial stage decomposition are degraded by microorganisms in the pile during composting. Forced aeration systems, particularly those with deliberately-elevated aeration rates, can strip odorants out of a pile before they have had time to decompose. This can be a problem if the fans strip odorants out of air-starved portions of the pile, putting pressure on the external odor control system (e.g., biofilter) to handle the load. This should be factored into the system design, e.g., gas (odorous air) retention time should be more like 60 to 70 seconds instead of the minimum 45-second retention time. This requires a deeper biofilter (versus more area).

In windrow systems that rely on the "chimney effect" of passive aeration, the high temperatures of early composting enhance the air flow through the windrow, potentially carrying off odorous compounds. That can be minimized by covering windrows with a 4-inch layer of unscreened compost to act as an *in-situ* biofilter. However, it is easy to overload a compost cap and suffocate the windrow.

As feedstocks decompose, they provide nutrients to the microbes, which use them to sustain their metabolism. Excess nutrients are not processed and can accumulate. As the biological and chemical changes in a pile shift the equilibrium between soluble and volatile forms of a chemical, these nutrients can be volatilized and become an odorant. The most notable example of this is ammonia emissions from a pile with a C:N ratio below 20:1. Conversely, composting piles with high C:N ratios, like leaves and green waste, can emit odors from volatile carbon-based chemicals like

Table 1. Adjusting C:N ratios for nonavailable carbon

Feedstock	*% C*	*% N*	*$[C/N]_{total}$*	*$[C/N]_{biodegradable}$*
Food scraps	39.65	3.2	15.6	12.4
Yard trimmings	28.61	1.95	22.9	14.5

hexanal ($C_6H_{12}O$), pentanal ($C_5H_{10}O$), acetone and methanol. Hexanal is the odor of fresh cut grass and pentanal has an acrid, pungent odor.

Not all carbon is available for microbial metabolism. A chemical found in all plants, lignin, is very difficult for bacteria to decompose. Lignin is a phenolic polymer and fills the spaces in the cell wall between cellulose, hemicellulose and pectin components. Lignin is particularly abundant in paper and wood, where it can comprise 18 to 22 percent of hardwoods (on a dry weight basis) and 26 to 33 percent of softwoods. So, a compost pile with wood chips as a bulking agent will have a lower *bioavailable* C:N ratio than would be indicated by a laboratory analysis of Total Carbon and Total Nitrogen. This has the potential for odor episodes characteristic of a low C:N pile, such as the heavy, sour smell of a low C:N food scraps compost pile.

Das (2000) presents a procedure for adjusting C:N ratios based on lignin content; one example calculation is shown in Table 1. Adjusting compost recipes for nonavailable carbon can significantly increase the volume ratio between carbonaceous and nitrogenous feedstocks from the traditional 2-3:1 to as much as 6-8:1.

Following best management practices in site layout and design and in compost pile recipe development and construction will not eliminate odors, but will greatly reduce the potential for odor episodes that will cause problems. Part III of this series will examine operational practices to minimize odor episodes. ■

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BioCycle
ARTICLE SERIES
COMPOST ODOR MANAGEMENT

Going On Offense Against Odors

Liquefaction of food waste during transport can lead to delivery of odorous materials. Mixing that material upon delivery with amendment or covering it with unscreened compost or wood grindings will help mitigate odor generation.

Photo courtesy of Brooks Contractor, Goldston, NC

Proactive management techniques, such as mixing incoming putrescent feedstocks within an hour of receipt at the facility, are effective tools to prevent odors.

Part III

Craig Coker

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

THERE are a number of proactive, positive strategies composting site managers and staff can implement to greatly reduce the risk of off-site odor episodes. It is helpful to break down the various compost processing activities that cause odors into a series of discrete elements, and then analyze each activity within that specific element to determine how odors are being formed, volatilized and dispersed off-site. By investigating each processing step, specific management practices can be identified that could help minimize these odors.

The discrete elements reviewed in Part III of this odor management series are: Feedstock Receipt, Processing and Mixing; Active Composting; and Site and Facility Management. Tips are provided by composting facility operators, researchers and project consultants.

FEEDSTOCK RECEIPT, PROCESSING AND MIXING

An important first step is to understand the odor-causing potential of each feedstock and either reject the feedstock or be sure the facility can effectively handle the material. A feedstock acceptance protocol is a good tool to understand the nature of incoming materials before deciding to accept them. With a protocol in place, a generator would supply a sample of the feedstock, a portion of which can be sent to a lab for analysis of its compostability parameters that were discussed in Part II of this series (see "Odor Defense Strategy," May 2012).

Another portion of the sample can be put into a sealed bag in order to mimic the anaerobic decomposition process. Keep the sealed bag in a warm place for two to three days (a car dashboard works well) and then have someone whose sense of smell has not be compromised by working at the composting facility open the bag and give an indication of the intensity and unpleasantness of the smell. If objectionable odors are noticed, then the composting facility operator will know to have plenty of coarse bulking agent on-hand when this feedstock arrives, to ensure that aerobic conditions prevail during composting.

Having stockpiles of certain odor-

Table 1. Troubleshooting odors in materials receiving area

Possible Cause	*Management Approach*
Materials arriving with odors	Mix materials upon receipt (increase material porosity). Stockpile bulking agent or high carbon amendments at receiving basin. Stockpile bulking agents or high carbon amendments for unexpected deliveries. Make smaller piles. Consider blanketing odiferous materials with a six inch to one-foot layer of bulking agent. Enclose the receiving floor. Aerate receiving floor. Add lime or wood ash to piles to adjust pH. Reject odorous loads if possible. Eliminate troublesome feedstocks. Incorporate wet or odorous loads directly into actively composting windrows.
Material sitting too long prior to being processed or mixed	Expedite material processing. Increase operating shifts. Reduce incoming throughput. Identify alternative outlets for incoming materials. First in, first out processing. Reduce size of material stockpiles. Increase collection frequency. Increase grinding/processing capacity (contract grinder/screener). Consider blanketing odiferous materials with a six inch to one-foot layer of bulking agent,

Source: *Comprehensive Compost Odor Response Project,* CalRecycle, 2007.

abating materials will also help. "I would add that a good stock of brown material (wood) should always be kept ready for adding to any wet odorous green material such as grass clippings to allow good air flow and drainage through the pile," says Gavin Bartlett of Shorts Composting in Berkshire, United Kingdom. "By monitoring the oxygen, moisture and carbon dioxide levels you should be able to turn compost when it's fully aerobic and produce minimal odors." Sharon Barnes of Barnes Nursery in Huron, Ohio echoes Bartlett's comment: "Always maintain a sufficient stockpile of processed yard waste to cover any unexpected odor event. Always place the more putrescent material on an improved surface so that should an issue occur the operator can get to the pile, regardless of the weather."

Putrescent feedstocks should always be a concern to operators. Commercial food scraps collection trucks have potential to deliver odorous materials, due in part to food scraps sitting in hot trucks for more than two to three days, and in part from liquefaction of the contents during transport. "Always prepare your site to receive sloppy food wastes with something like leaves, grindings, or similar amendment that will absorb material containing lots of liquid," says Heidi Ringhofer of Western Lake Superior Sanitation District in Duluth, Minnesota.

Prompt handling of feedstocks is another important odor-minimizing strategy. If possible, the operator should get incoming feedstock processed and mixed with amendment within one hour of receipt. If that is not possible, cover the material with a 3- to 4-inch layer of unscreened compost or woody grindings. In any case, mixing and placing those feedstocks in a windrow or in an aerated pile should be attempted by the end of the day. If a load comes in late, it might be necessary to cover it with compost or grindings and then mix it in first thing the following morning.

CalRecycle (formerly the California Integrated Waste Management Board (CIWMB)) published a series of odor mitigation strategies composters can consider (CIWMB, 2007). Table 1 is an excerpt from this detailed list of recommended activities related to feedstock receiving and mixing.

ACTIVE COMPOSTING

As noted in Part II, getting the mix right and keeping piles aerobic is the most important aspect of process management in odor control, but there are operational considerations that will help. Observe loader operators to be sure they are not driving up on a pile or windrow to place materials, which will compact under the weight of the loader and compress out the free air space. Once a pile or windrow is built, put a 3-to-4-inch cap of compost over it to act as an *in situ* biofilter for fugitive emissions. If windrow composting, don't turn that windrow for the first 7 to 10 days. This allows primary decomposition of highly degradable organics to occur with some degree of control (note that good structural porosity is a must for this to work). For those windrows with adequate free air space, and assuming there are no regulatory restrictions, consider reducing turning frequencies for the first two weeks, turning only to distribute moisture from a rainstorm or for improving water distribution when irrigating.

Most of the odorous chemicals that vaporize from a compost pile or windrow are highly soluble in water. This phenomenon is the main advantage of covering piles with a micropore fabric, which forms a layer of odor-absorbing water on the underside of the cover (the moisture layer traps the odorants and keeps them from volatilizing). Alternatively, one can apply water to a pile by misting or spraying to knock down odorants. One of the reasons the air smells clean after a rainstorm is the "scrubbing" effect of rain on pollutants in the air. Buyuksonmez (2011) studied the effect of watering windrows prior to turning in a study for the San Joaquin Valley Air Pollution Control District (SJVAPCD), and found that volatile organic compounds (VOCs) were reduced by 19 percent by watering for 20 minutes. The term "VOCs" is used to describe a large category of compounds, many of which are odorous at composting temperatures, thus if VOCs are reduced, many odors also will be reduced. The SJVAPCD is developing a new requirement that composters in its district must water windrows before turning to reduce VOCs.

Keeping an eye on the weather, the calendar and the clock also helps. Activities that generate odors, like mixing, turning windrows and moving fresh piles, should be minimized at certain times, provided that operations can tolerate the disruptions. For example, when the air is heavy and still — defined as a wind speed below 4 miles/hour and a less than 10°F difference between the ambient and dew point temperatures — keep odor-causing activities to a minimum (Das, 2000). Restricting odor-producing activities to between 10 am and 3 pm, when the sun has heated the atmosphere to promote good vertical mixing, and refraining from those activities late in the afternoons on Fridays and the days before holidays (when neighbors are likely to be out in their yards or at public places) can also minimize odor episodes.

SITE AND FACILITY MANAGEMENT

The two most important site management practices to reduce odors are rigorous housekeeping and water management. Housekeeping is always important at a composting facility, as every bit of stray organic matter not incorporated into a pile is a potential odor source. It requires dedication to focus an hour per day on housekeeping patrol, where stray bits of mashed food scraps or clumps of grass clippings are picked up and put into a pile. Managerial complacency about housekeeping can quickly spread to the facility workers, and soon, there are so many potential fugitive odor emissions that it becomes almost impossible to get the site cleaned up and back into shape.

Rainwater puddles and storm water ponds are a potentially onerous source of odors. Compost fines wash into every puddle and pond on a site and they exert strong biological and chemical oxygen demand. This demand quickly depletes the dissolved oxygen (DO) in the water, faster than the oxygen can be replenished across the water-air interface. Anaerobic conditions in the water are created with the resultant formation of hydrogen sulfide. Larger storm water ponds, if not mixed and aerated, will stratify during the summer into different levels of temperature and DO. Compost fines washed into those ponds will accelerate consumption of DO; in the fall season, when stratification ends with cooler temperatures, the layers in the pond will mix together, bringing anaerobic waters to the surface with a release of odors. This is what caused the green waste composting facility at the Southeastern Public Service Authority in Virginia Beach, Virginia to shut down after Tropical Storm Gaston washed fines into the facility's pond in September 2008.

Part II of this series noted the importance of understanding the local weather at a composting facility site. "One strategy that I've had success with at sites already experiencing issues is to install an on-site weather station — or in some cases a wind sock or a flag — and start tracking weather data (wind speed and direction primarily) and then use that data to correlate between specific operations such as grinding, turning and screening and complaints," says Matt Cotton of Integrated Waste Management Consulting LLC in Nevada City, California. "In some cases this can help pinpoint a specific odor-causing event and perhaps suggest a need to reschedule those events until conditions improve. You can get a decent recording weather station for around $1,000 and it can really help you better understand your site — ideally before the complaints start."

As Tim Haug, author of *Practical Handbook of Compost Engineering*, famously observed, 'the prevailing winds rarely prevail,' so having a detailed record of your own site-specific conditions can be a very useful tool. Doesn't work in every case, but you'd be surprised how well it can work if you can identify times/conditions that you can operate without impact versus times/conditions that are causing issues. In some circumstances a simple (non-recording) wind sock or a flag can provide useful clues."

Ensuring good operational flexibility is another key part of the battle against odors. "I always recommend to composters that they size equipment bigger than necessary to reduce specific processing times for grinding, mixing, turning and screening," said Jeff Gage of Compost Design Services at a recent U.S. Composting Council presentation (Gage, 2012). "It's important to keep all your equipment operating properly to minimize odors, so you should keep critical spares in stock, especially for long lead time items, and have rental backup sources for common equipment like loaders."

Along with good process design and control, positive and proactive operational management measures are another tool in the tool chest composters can use to prevent off-site odor episodes. Part IV of this series will examine odor control technologies in use at composting facilities. ■

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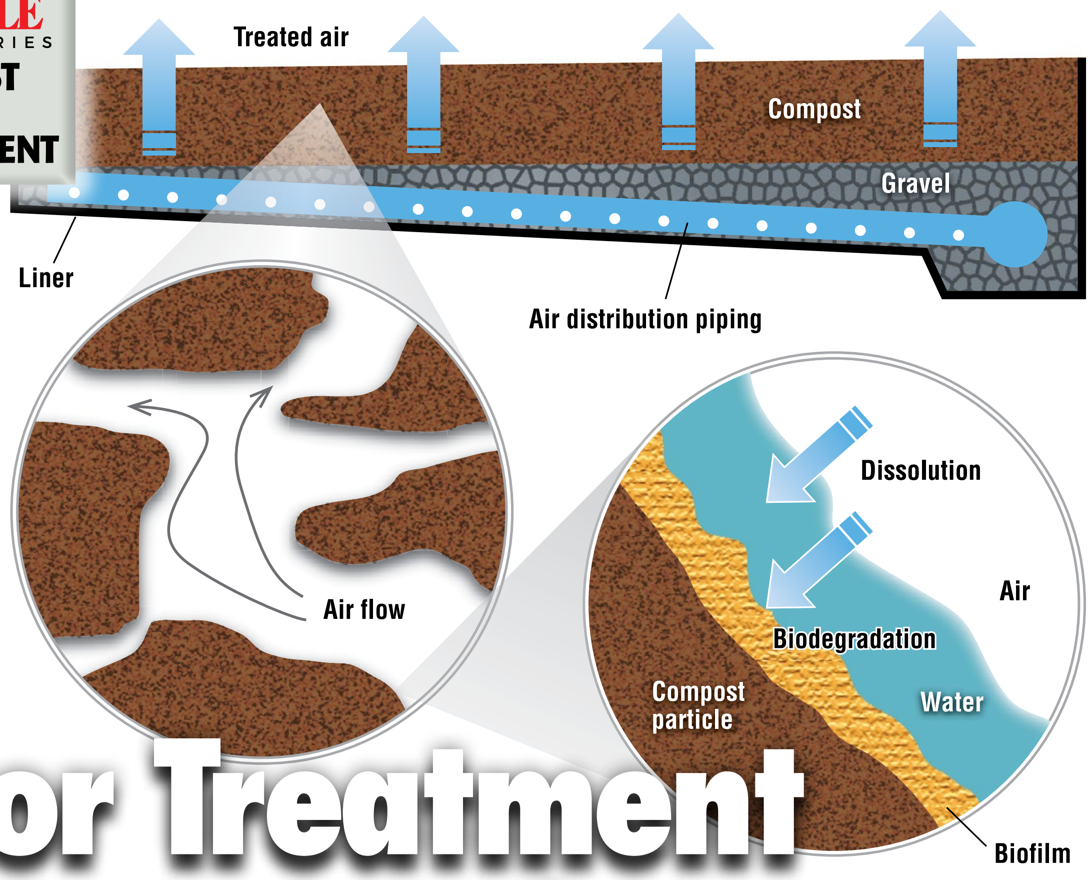


Figure 1. Biofilter cross-section

Odor Treatment At Composting Facilities

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

Biological, physical and chemical approaches are available to battle odors. Most composters would agree that simplest solutions are best.

Part IV

Craig Coker

NO matter how well planned, how well sited or how well run, composting facilities are always at risk for an off-site odor episode that can undo years of careful and thoughtful community outreach. A wide variety of odor treatment technologies have been developed to reduce the potential for an offsite episode to occur. These technologies can be characterized as biological, physical and chemical systems.

Biological systems use microbes to consume odorous compounds in the process exhaust air of composting. Many of these same microbes are also present in the compost piles. Physical systems use processes like washing, dilution or filtration to reduce odor concentrations in the exhaust air. For example, scrubbers wash pollutants out of the air in an engineered system similar to how rain makes the air smell clean afterwards. Chemical systems use a designed reaction, like oxidation, to change the chemical nature of an odor. For example, hydrogen peroxide can be used to oxidize hydrogen sulfide (the odor of rotten eggs) to elemental sulfur and oxygen.

Odor treatment technologies share a common objective — to reduce odorous chemical concentrations to below the Recognition Threshold (RT), if not below the Detection Threshold (DT). As noted in Part 3, the RT can be several orders of magnitude higher than the DT, so it can be much more difficult to reduce odors below the detection threshold. But this is where the sharp focus of odor science and the predictive nature of engineered odor solutions run up against the subjective nature of emotional personal reactions to malodors and the regulation of odors under a legal "nuisance" standard rather than a numerical emission limit. Even if an odor has been reduced below the RT, it can still be perceived, and complained about, as a nuisance.

BIOLOGICAL SYSTEMS

The primary biological system used for odor control is biofiltration. Biofiltration refers to multiple technologies, including bioscrubbers, biotrickling filters and biofilters. Most composting facilities with a biological odor control system use biofilters, which employ microorganisms to remove odorous air pollutants. The air flows through a packed bed and the pollutant transfers into a thin biofilm on the surface of the packing material. Microorganisms, including bacteria and fungi, reside in the biofilm and degrade the pollutant. The biofilter bed can be a separate unit or can be integral to the compost pile, usually as a cap or covering of the pile or windrow.

In separate bed systems —commonly used with in-vessel and aerated static pile composting — air is introduced through a network of perforated pipes at the base of the bed. These pipes are usually embedded in gravel, which acts both as an air plenum to distribute the exhaust evenly through the bed and as a barrier to keep fines from the organic layer above from clogging the pipes. A thick bed of biofilter media, usually 4- to 5-feet deep, lies on top of the gravel (Figure 1). Biofilters are usually designed for a specific gas retention time to treat the odorous air, which is on the order of 45 to 60 seconds.

With windrow composting, a cap of screened or unscreened compost on top of the windrow can act as an in-situ (in-place) biofilter. This approach was developed in California primarily to reduce odor emissions but it became quickly apparent that it was potentially a method to reduce the volatile organic chemical precursors of ground-level ozone (smog), a significant air quality problem in most of the state. A compost cap consists of 2 to 4 inches of screened compost, 6 to 8 inches of unscreened compost or 12 inches of woody overs. The cap acts as a filter media that odor molecules must pass through so using screened material increases the surface area of the particles in this filter. The advantage of higher surface area is there is more room for microbes to live on the surface of compost particles (so there is greater metabolism of odorous compounds). The drawback, however, is the finer texture of screened compost reduces air flow through this compost cap.

The author has used both screened and unscreened compost caps and they can be tricky to install properly. If the biofilter media is too finely screened and/or gets too far down the sides of the windrow, it can block off the air flow supporting the chimney effect and starve the windrow of oxygen.

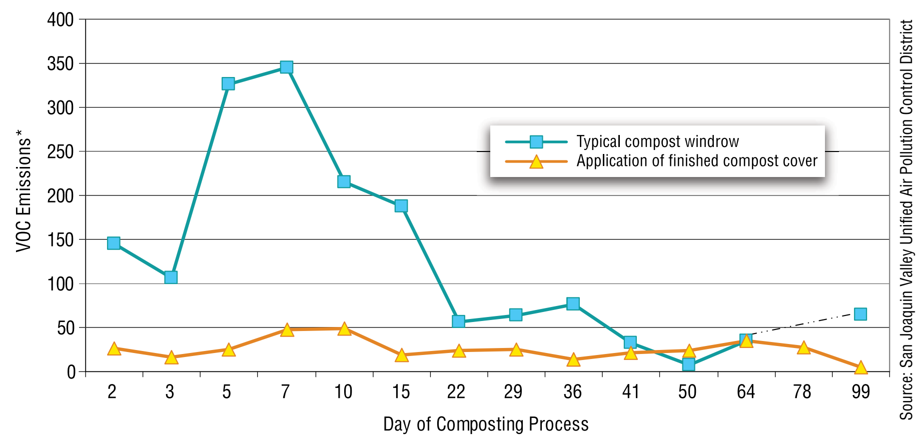
The effectiveness of compost caps has been studied by the University of California at San Diego (SJVAPCD, 2011) and found to produce significant reductions of more than 75 percent of the VOC emissions in the first two weeks. Figure 2 illustrates these findings.

Several different types of materials can be used as a biofilter media. Media normally consist of an organic substrate to house microbial communities and a bulking agent to ensure adequate porosity for air flow without significant backpressure on the blowers (too much backpressure lowers the airflow of a blower). A compost-woodchip mix is commonly used, but some biofilters use a combination of peat, soil, compost and wood chips. One configuration uses lava rock (also known as cinders or foamed obsidian) mixed with peat moss. These rock-peat combinations have been used in the treatment of gases that need long retention times to be metabolized, like carbon monoxide.

Another biological approach is to add a biocatalyst to a pile or windrow. One product on the market is made by Harvest Quest International and has been tested extensively by A-1 Organics in Eaton, Colorado, the largest composting company in the state. "We have worked with A-1 Organics to develop the Modified Static Aerobic Pile (MSAP) approach to composting using our biocatalyst, called HQB," says Andrew Gregory, Vice-President of Operations for Harvest Quest. "HQB consists of a mix of proprietary thermophilic bacteria belonging to the common actinomycetes group. The HQB are applied to the surface of windrow at the ends of the rows or in the middle and don't need to be mixed through the windrow. The bacteria spread outward and inward from the points of application at a rate of about 24 feet per day. The key to MSAP is to use a coarser grind, of 3- to 4-inch particle size and not to turn the windrow for the first 30 to 45 days."

By not turning the windrow during the primary decomposition of organic materials, odor formation and release is reduced. "The population of microbes introduced by HQB is higher on the outside of the windrow initially, which raises the temperature of the outer layers of the windrow," adds Bob Yost, Chief Technical Officer of A-1 Organics. "This higher temperature environment helps to metabolize volatile chemicals, like a well-functioning biofilter. For it to work properly, the windrow must have good structural porosity and adequate moisture."

Figure 2. Effectiveness of compost caps on VOC emissions



*VOC measurements are comparison values, not converted to per compost ton or per windrow units

PHYSICAL SYSTEMS

The main physical approach to odor management is scrubbing, where a water and/or chemical solution is sprayed against the exhaust air to absorb the pollutants in the air into the scrubbing solution. Absorption is the process where one chemical (the odorant) is dissolved into the volume of another medium (e.g., water). Scrubbers work by directing an exhaust air stream against a water-based chemical shower. This solution usually contains chemicals such as sodium hydroxide (to remove reduced sulfur compounds) or sulfuric acid (to remove ammonia). In a scrubber, ammonia and hydrogen sulfide are converted to odorless byproducts by chemical reactions, such as:

Sulfuric acid converts ammonia to ammonium sulfate:
$2\ NH_3 + H_2SO_4 \leftrightarrow (NH_4)2SO_4$

Sodium hydroxide converts hydrogen sulfide to sodium hydrosulfide and water:
$H_2S + NaOH \leftrightarrow NaHS + H_2O$

Sodium hydroxide and sodium hypochlorite convert sodium hydrosulfide to sodium sulfate, sodium chloride and water:
$NaHS + 4\ NaOCl + NaOH \leftrightarrow Na_2SO_4 + 4\ NaCl + H_2O$

Ammonia and H2S can be absorbed with 99 percent efficiency in a fraction of a second because the first two conversions above are extremely rapid acid-base reactions. How fast a base can neutralize an acid is just a matter of how quickly they can be mixed. Scrubbers often contain packing media, which work primarily by spreading the liquid over an extended plastic surface to promote contact between the liquid with the passing air. Rings or saddles with more surface area create additional liquid surface, but more plastic surface also means more obstacles to air flow.

Another physical approach is to incorporate a high-carbon wood ash into the compost pile or windrow. The mechanism at work here is adsorption, which is the deposition and adhesion of one chemical (the odorant) onto the surface of another medium, wood ash in this case. "One of my biggest clients, who is located in New Hampshire, markets wood ash generated from several biomass plants in the northeastern U.S.," says Andrew Carpenter of Northern Tilth in Belfast, Maine. "The properties of the ash vary considerably from plant to plant, and only ash that has a very high carbon content works well for odor control in composting. The high carbon ash is currently used for odor control at four aerated static pile (ASP) biosolids composting facilities in the Northeast. In addition to odor control, the low bulk density (approximately 450 lbs/cubic yard) and the relatively low moisture content improve the physical properties of the compost blend, which otherwise tends toward the moist, high bulk density end of the ideal range for composting. This ash has a surface area of 330 square meters per gram (m2/g), whereas activated carbon is around 500 m2/g."

High-carbon wood ash has properties similar to activated carbon. It is produced by the incomplete combustion of wood at temperatures above 700°C, and thus contains particles of biochar, which contribute to the odor absorption character of the ash. While the addition of a high pH (about 10.3) wood ash can raise the compost pile pH and shift the ammonia equilibrium towards gaseous ammonia volatilization, this can be managed by reducing the pH of the ash to around 8.6 by exposure to rainfall and CO2 from the atmosphere. Full-scale field research has shown that amending windrows with 12.5 percent and 25 percent high carbon wood ash by volume can reduce odor emissions by more than 73 percent and 88 percent, respectively. (See "Controlling Odors Using High Carbon Wood Ash," *BioCycle*, March 2002 for more information.)

A newer physical/chemical odor control approach is using a technology called "nonthermal plasma" (NTP) to remove odorous chemicals. NTP is one of the processes used to make ozone from oxygen, and ozone has been employed for years to oxidize odorous compounds. Nonthermal plasma uses a reactor that consists of two electrodes separated by a void space that is lined with a dielectric material (an electrical insulator that can be polarized by an applied electric field) and is filled with an insulating media. This type of reactor is called Dielectric-Barrier Discharge (DBD). A phenomenon occurs when the voltage through the system exceeds the insulating effect of the media and a large number of electrical discharges occur. In the DBD field in a NTP reactor, the following reactions can occur:

Oxygen is split into ionized oxygen atoms by the electric charge:
$O_2 \rightarrow O+ + O+$

Ionized oxygen atoms (radicals) can combine with oxygen to form ozone:
$O+ + O_2 \rightarrow O_3$

Ozone can react with diethylamine (fishy odor) to form ammonia, water and carbon dioxide:
$CH3CH2NHCH2CH3 + 4\ O_3 \rightarrow 4CO_2 + NH_3 + 4H_2O$

Ozone can react with ammonia to form ammonium nitrate (a fertilizer component):
$2\ NH_3 + 4\ O3 \rightarrow NH_4NO_3 + 4\ O_2 + H_2O$

Oxygen radicals can react with carbon monoxide to form carbon dioxide:
$O+ + CO \rightarrow CO_2$

This technology is being used at a Transform Compost Systems facility in Ontario, Canada.

CHEMICAL SYSTEMS

Chemical approaches to odor control are usually focused on oxidizing reduced-state compounds (like the chemical solutions in the scrubbers discussion above) or on breaking carbon-hydrogen-oxygen bonds to change the structure of a chemical. Others are called "sequestrants" where chemical formulations sequester, or bind, odorous chemicals like amines, ammonia and sulfur compounds. One sequestrant product on the market consists of copper sulfate (an oxidant for the conversion of primary alcohols), benzaldehyde (an almond odor flavoring), and aluminum chlorohydrate (found in deodorants).

Chemical products can be delivered in different ways — applied topically, incorporated into the pile or windrow or applied as a misting spray. The chemical formulations on the market today are proprietary so finding reliable information about how they work is difficult. A lot of controversy exists over whether these formulations work well enough to justify their costs, or whether they work at all.

Few issues in the management of composting facilities will draw more attention, require more time or cost more dollars than managing odor problems. While there are a wide variety of engineered odor control technologies in the marketplace today, most composters would agree that simple is better. A well-designed and operated biofiltration system, coupled with good process design, good process and operational management, and attention to operational details will keep odor problems from becoming off-site public relations disasters. ■

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BioCycle ARTICLE SERIES
COMPOST ODOR MANAGEMENT

Resolving Odor Challenges

Lineal distances (in feet) to odor survey stations from the Mdewakanton Sioux Community organics recycling facility are shown.

Developing productive and meaningful public relationship programs is critical to resolving odor challenges at organics recycling facilities.

Part V

Craig Coker

NO matter how well-planned, well-sited or well-run, composting facilities are always at risk for an off-site odor episode that can create challenges such as negative publicity, regulatory intervention, and the potential for lawsuits. How a composter responds to odor episodes can significantly influence the facility's public (and investor) support, financial performance, regulatory interactions, employee jobs and much more.

One composter this author knows responded to off-site odor complaints from subdivisions recently built adjacent to his composting facility with "The heck with them, we were here first." Needless to say, that is not how one wins "hearts and minds." Part V of *BioCycle's Odor Management* series examines appropriate measures for dealing with public outrage, and profiles two composting facilities that have implemented calming measures.

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

PUBLIC PERCEPTIONS OF ODORS

In general, air quality has improved considerably over the past several decades, which has reduced the levels of odors in outside air. Strides also have been made in reducing the amount of indoor odors. One unintended consequence of this improvement in air quality is that more people are intolerant of odors. "This apparent paradox is related to a concept from the field of cognitive psychology called 'signal detection,'" noted Pam Dalton, Ph.D., a faculty researcher at the Monell Chemical Senses Center (see "How People Sense, Perceive, and React to Odors," November 2003). "As we have reduced the odor background level (or what in Signal Detection Theory would be called the noise level), the presence of an intrusive odor signal becomes more apparent."

Another contributing factor is that, historically, people have associated bad odors with diseases. "Long before we understood that germs were the basis of disease transmission, there was this concept, called the 'miasma theory', that it was the odors associated with sickness and disease that were causing people to become ill, and that if they could remove those odors, they could remove the source of the disease," said Dalton. This association persists to this day. Many people believe they have suffered real health impacts from odorous air. The most frequently reported health complaints include eye, nose and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, palpitations, shortness of breath, stress, drowsiness and alterations in mood (Schiffman, 2000).

"People's reaction to odor and their beliefs about the effects from odor are influenced by a diverse set of factors, including personality traits, personal experience, and information or social cues from the community and media," said Dalton in the 2003 *BioCycle* article. "The reaction people have to odors is not simply due to the sensory impact but is also shaped by the attitudes and expectations that an individual brings to an odor experience, which has strong implications for building understanding and relationships with neighbors.

"In one experiment we conducted at the Monell Center, we exposed two groups of volunteers to an odorant, which was acetone, or nail polish remover, but we included in each group a paid actor. In each group, the actor either responded positively to the odor (e.g. helps breathing, increases alertness), or negatively (e.g. irritates eyes and nose, causes coughing). After exposure to an odor, most people adapt to a constant odor level, which decreases sensitivity to the odor and to its perceived intensity. In the negative bias group of volunteers (where the paid actor was complaining), that adjustment did not happen. People claimed significantly more adverse physical health effects, and some reported coughing although none of them actually did."

This phenomenon of the social influence on people by the actions of one, or a few, highly agitated individuals offers insights into how groups of individuals exposed to a composting facility odor may jointly complain, but individually behave in a more rational manner. The author observed this group dynamic at a civic association's odor complaint meeting regarding a biosolids composting facility in Maryland. The association members were aggressively agitated in the group meeting but significantly more relaxed and rational in one-on-one discussions both before and after the meeting.

Twelve steps to build public relationships and earn trust

There are twelve steps composters can take to build public relationships and earn trust. The first six are the most critical (Beecher and Goldstein, 2005):

1. Build commitment within your organization.
2. Determine who your stakeholders are.
3. Get input from key stakeholders as soon as possible, early in the process.
4. Build public relationships.
5. Improve communications, especially listening, dialogue.
6. Continue to monitor public perceptions and public relationships.
7. Understand the national and local context.
8. Learn more about conflict.
9. Determine what is beyond your control; work on what you can control.
10. Provide information useful to recipients.
11. Don't be afraid of conflict — work patiently through it.
12. Redefine success.

During the period 1999 through 2002, the Water Environment Research Federation sponsored work to understand public perceptions of biosolids recycling (see "Public Perceptions of Biosolids Recycling," April 2005). While focused on land application of biosolids, that work led to a greater understanding of how people perceive risk of waste management programs, which is applicable to composting facilities. Fear of the unknown or the exotic is a stress driver that can trigger perceived (or, according to Schiffman, real) health impacts believed to be attributable to the project. An offsite odor episode can be easily construed as unknown or exotic. The negative reaction to the odor, with the associated fear of breathing chemically-contaminated air, creates a perception of risk that becomes that person's reality, and is likely negative and lasting. This "perceived reality" is often reinforced by information gathered from internet sources and is based on a combination of perceived hazard and expressed outrage. That perceived reality of a person complaining about an odor episode is where the dialogue must start on restoring public trust in a composting operation.

DEVELOPING PUBLIC RELATIONSHIP PROGRAMS

Composters need to develop public *relationship* programs, not just public relations or outreach programs. A public relationship program is based on two-way communication, so listening is every bit as important as outreach. Listening begins with understanding the neighbors' "outrage factors" (Beecher and Goldstein, 2005). An outrage factor influences perception of risk and includes: involuntary, industrial, uncontrollable, exotic, unknowable, unfair, dreaded, untrustworthy and similar descriptors. Building a public relationship program requires steps to reduce, or address, the outrage factors, which is the practice of risk communication. This includes initiatives such as having an educational open house and establishing a "Neighborhood Liaison Committee" of both alienated and impartial neighbors and reviewing planned and implemented changes to address odor complaints. By helping impacted individuals understand the intricacies of composting, and providing a voice in evaluating alternatives, something "exotic" and "uncontrollable" becomes something that is known and more controllable, thus addressing outrage factors.

Composting facility managers need to resist the counterintuitive reaction that developing a public relationship program involves surrendering control over the facility or outcomes. Once an off-site odor episode has occurred, and complaints have been registered, there is simply no way to "stay under the radar." It will undoubtedly be unpleasant to deal with angry neighbors, but by giving people time to understand information, establishing two-way dialogue, treating them with respect and, most importantly, listening without judgment, the facility's management can assure the majority of neighbors that planned corrective actions will work. There will always be people who will never be satisfied until the composting facility is shut down, but a primary goal of any public relationship program is to satisfy the majority of neighbors, elected and regulatory officials and the media, that a facility's odor mitigation strategy is, or will be, effective. Also, provide tools, such as hot lines to report odor impacts, staff equipped to investigate complaints and measure odor levels and regular neighborhood liaison committee meetings to ensure the facility operator's responsiveness.

In short, earning people's trust starts with credibility. Neighbors have to believe in the credibility of the staff, the consultants and the environmental regulators. Credibility is earned by the composter's willingness to be open and transparent in its decision-making processes, to conduct or acquire information from research that is credible, legitimate and salient, and to develop the infrastructure for independent oversight of corrective actions.

USING METRICS TO TRACK PROGRESS

As communications are qualitative processes, it can be difficult to determine effectiveness. But measuring effectiveness is an important step toward monitoring, evaluating and improving public relationship programs. Composters should develop a quantitative set of metrics to measure what the public relationship program does and give insight into how well it is being implemented and performing. Metrics will not measure increased or decreased outrage and trust directly. A compost manager can only focus on the process, as the process can be controlled, but not the outcome.

The Region of Peel curing facility ran into a firestorm of odor complaints when it first opened using an open-air windrow system. Establishment of a public liaison committee and extensive outreach and education, plus installation of a GORE cover system, has yielded positive results.

Photo courtesy of Region of Peel

Metrics should have these characteristics: Measurable, Easy, Timely, Repeatable, Insightful and Controllable (Sullivan, 2004):

Measurable: A metric that can be quantified, like the number of open houses a facility offers each year.

Easy: Simply to understand and apply, like measuring the length of time for management to personally respond to an odor complaint.

Timely: The process is being measured as close to real-time as possible. An example would be developing information systems that track wind speed and direction on a continuous basis on-site as opposed to relying on periodic observations from a nearby airport.

Repeatable: Establishing fixed odor monitoring points for repeated measurements that are reported to the community.

Insightful: Provides a deeper understanding of how the process is working. For example, an odor complaint log should record more than the person's name and phone number; it should record information about the nature, duration and intensity of the odor.

Controllable: Measures something that is controllable, such as the number of community meetings held, but not the number of attendees at each meeting.

EXAMPLES FROM THE FRONT LINES

The Shakopee Mdewakanton Sioux Community owns and operates a 35,000 tons/year open-air turned windrow composting facility on tribal lands southwest of Minneapolis (see "Tribal Community Launches SSO Facility," May 2012). The facility handles primarily yard trimmings and food scraps, although it takes in residuals like shredded playing cards from the tribal casino. Even though it is situated on tribal lands and is not subject to regulatory oversight by the Minnesota Pollution Control Agency (MPCA), the facility operates as if it were in MPCA's jurisdiction.

The composting facility opened in mid-2011 and started getting odor complaints in the spring of 2012. "We've received about 60 to 70 complaints, all from our neighbors to our north, where the homes are 1,800 feet or so from our facility," says Mike Whitt, the Community's Natural Resources Manager and the Manager of the organics recycling facility. As a result of the complaints, Whitt hired a professional industrial hygienist and implemented an odor monitoring protocol of repeated measurements of odors using a St. Croix Nasal Ranger. (Aerial photograph on page 22 shows the site and the monitoring stations that staff routinely monitor.)

A Nuisance Odor Policy based on a quantitative standard was also developed. The policy states, "Odors will be found to be in violation of the nuisance odor policy if they are unreasonably unpleasant, distasteful, disturbing, nauseating, or harmful to a person of ordinary sensibilities and do either and/or both of the following: Odor can be confidently detected at 7 dilutions outside of facility fence line; Odor can be confidently detected at 4 dilutions in two separate measurements at least 15 minutes apart but within the same 1 hour period, or at a single reading of 7 dilutions, when off facility property but at the nearest point of human activity." Facility staff began monitoring in July. "We have had five readings of 7 along our northern fenceline in more than 16 weeks of monitoring," notes Whitt, "but we have never recorded an off-site value greater than 4 at any monitoring point."

Getting the residents to accept quantitative data has been challenging. "I've shared the wind speed and direction data and the Nasal Ranger monitoring results with our neighbors and they claim we're making this up," he adds. "I had one person claim we came out to do monitoring and then went back to the facility to flip some switch that turned the odors back on." The Community did have an open house in October and Whitt was pleased that almost 100 people showed up. "We had three of our neighbors visit during the open house, including one man who has been particularly difficult," Whitt says. "I was happy to see that he took the time to come over to see us and learn more about what we're doing. I think over time, we will be able to get in front of this issue."

Another example is the Regional Municipality of Peel, a community of 1.3 million people west and northwest of Toronto, Ontario, Canada. The Waste Management Division of the municipal government built a 60,000 tons/year enclosed tunnel reactor composting system in 2006 at its Integrated Waste Management Facility in Brampton. After approximately 7 to 10 days, the material is removed from the tunnels and brought to the Peel Curing Facility in Caledon. Initially this material was being cured in open air windrows. Shortly after the tunnel reactor/curing system came on-line, Peel ran into a firestorm of odor complaints from citizens in the first year of operation.

"It was a pretty ugly process to start with," says Larry Conrad, Manager of Waste Operations for Peel, speaking of their initial public outreach efforts. "Our Commissioner stood up in front of the audience and said we would close the facility until we could figure out how to fix the problem. That started a long process of operational and technology modifications to fix the problems and we reopened in 2009." One of the improvements was to install a Gore Cover System over the curing windrows. Material is now cured under the covers in 24 windrows for 6 weeks and then screened to produce the finished compost. Also during this period, Conrad implemented a public relations program that included open houses and tours, developed a daily odor/noise/dust monitoring protocol, and set up a Public Liaison Committee. The minutes of the Public Liaison Committee meetings are provided to the Waste Management Subcommittee as well as to all of the Council members for information purposes.

The nuisance monitoring protocol involves staff going out 3 times/day, everyday, to personally monitor odors, dust and noise at 10 locations around the curing facility. The Region of Peel uses a private contractor to manage a web-based meteorological monitoring system to compile data from several meteorological monitoring stations at Peel facilities. Its monitoring protocol begins by noting the weather conditions, and then traveling to each location to monitor the presence and intensity of noise, dust and odors. The monitoring forms include the ability to record the presence of odors, noise and dust from sources other than the composting facility.

The Liaison Committee consists of four citizens and the Peel Regional Councillor for the area where the facility is located. The Committee meets with Waste Operations staff quarterly. Each meeting has a standard agenda, which includes a review of an activities tracking spreadsheet, operations reports, environmental monitoring activities, compost marketing activities, a discussion of any correspondence with the community, and a discussion of any upcoming planned activities or improvements at the facility. The Committee gets reports on the number of windrow turnings and truck movements, quantities of materials received, in process and shipped, and any odor complaints received. Committee members meet with their neighbors to share the information provided by the Region of Peel and report back any questions. "While many of the neighbors were not interested in learning how our facility is operated, the members of our Liaison Committee are very interested in composting," says Conrad. "It has been a steady process of educating, rethinking and recharging to improve our relationships with the community, but it has paid off, in my view. I'm pleased that we've only had two odor complaints so far this year." ■

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Odor Dispersion Fundamentals

Vegetative canopies can help with odor dispersion.
Photo by Robert Rynk

Dispersion is the phenomenon where odor concentrations are reduced to below recognition or detection thresholds. It is influenced by meteorological conditions and topographic effects.

Part VI

Craig Coker

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

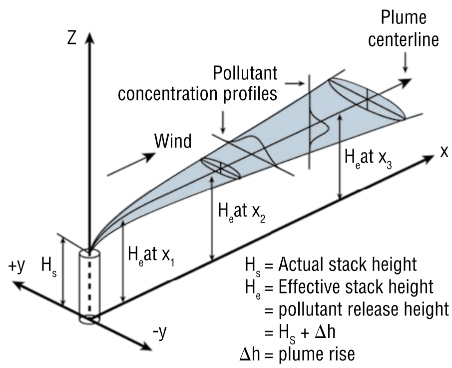
No matter how well planned, sited or operated, composting facilities are always at risk for an off-site odor episode that can create challenges such as negative publicity, regulatory intervention and lawsuits. This article series, which began in 2012, has been dedicated to helping composters understand the intricacies of odor management. Part VI looks at the fundamentals of how odors behave in the environment.

As discussed in Part I (*BioCycle*, April 2012, p. 25), an odor is an air pollutant. It is a chemical emitted in the gaseous vapor phase and behaves in the atmosphere like other gasses. Air pollutant emissions can be characterized by type, source and elevation. Types of emissions include point sources (e.g., a smokestack), line sources (e.g., cars on a highway), area sources (e.g., from a forest fire), or volume sources (e.g., from a paint shop with multiple roof vents). Emissions from composting facilities are usually considered area or volume sources. Emissions can be further characterized as mobile versus stationary and urban versus rural, as the urban heat island effect makes the atmosphere above cities more turbulent, which affects dispersion. The elevation of an emission is another discriminant, with categories of surface, or ground level, near surface and elevated surface.

Gaseous or particulate emissions from a continuous source are emitted as a "plume" of material, so-called because the flow of emissions resembles a feather in shape and appearance. The emissions of smoke or steam from an elevated source are a visible example of a plume. Emissions from an intermittent source are considered "puffs" where a cloud of material is released and moves downwind.

Emission plumes and puffs are considered buoyant, dense or passive. A buoyant plume rises with distance and time from the source (Figure 1). They are lighter than air because they are at a higher temperature and lower molecular weight (density) than the ambient air around them. For example, the molecular weight of ammonia is 17.02, while the molecular weight of air is 28.97, so an ammonia emissions plume will rise. Conversely, a dense plume sinks with distance and time as it is heavier than air. Hydrogen sulfide (H_2S) has a molecular weight of 34.08, so an H_2S emissions plume will sink, which is why H_2S can accumulate in depressed areas like storm drains and

Figure 1. Buoyant emissions plume



pose health and safety problems. Passive plumes are neither lighter nor heavier than air.

Dispersion is the phenomenon where odor concentrations are reduced to below recognition or detection thresholds. Odor dispersion could be viewed as "dilution is the solution to pollution." Plume or puff dispersion is affected by meteorological conditions, terrain, building downwash and deposition (e.g., contact with ground, vegetation or rain). Meteorological parameters that influence pollutant dispersion are wind speed and direction, as well as vertical thermal stratification or mixing. The pollutant concentration is inversely proportional to the wind speed, so that if wind speed doubles, pollutant concentration is cut in half. This is due mainly to the accelerated transport of the plume's constituents by the wind. Moreover, turbulent mixing increases with growing wind speed, which enhances dispersion.

ATMOSPHERIC DISPERSION

Atmospheric stability plays the most important role in the transport and dispersion of odors. It can be defined as the atmospheric tendency to reduce or intensify vertical motion or alternatively, to suppress or augment existing turbulence. The amount of turbulence in the atmosphere has an effect on odor dispersion by mixing uncontaminated air with the odor-laden air, reducing its concentration. Turbulence is caused by vertical motions of air in the atmosphere (convective turbulence) and by horizontal motions of air due to winds (mechanical turbulence). Vertical motions can be attributed to high and low pressure systems, air lifting over terrain or fronts and convection. Convective turbulence is caused by these rising and falling parcels of air (consider this analogous to puffs of odorous air emitted from a composting pile). Normally, the air closest to the earth's surface is warmer than the air aloft, due to solar heating of the earth. This warmer parcel of air rises. The extent to which an air parcel rises or falls depends on the relationship of its temperature to that of the surrounding air. As long as the parcel's temperature is greater, it will rise; as long as the parcel's temperature is cooler, it will descend. When the temperatures of the parcel and the surrounding air are the same, the parcel will neither rise nor descend unless influenced by wind flow.

The rate at which the temperature of the air changes with elevation is called the lapse rate and is normally 3°-4° F/1,000 ft. of elevation, but it varies widely with location and time of day. If the temperature decreases with elevation, it is called a negative lapse rate; if it increases with elevation, it is called a positive lapse rate. The lapse rate is important to vertical motion in the atmosphere since surrounding air temperature determines whether a parcel of air rises or falls. Atmospheric lapse rates are normally negative. When this normal cycle is present, it is considered an unstable air mass and air constantly flows between the warm and cool areas. As such the air is better able to disperse odors. In an unstable atmosphere, the parcel of air will rise to the atmosphere's mixing height. The volume of the atmosphere below the mixing height is called the mixing layer, and the larger the mixing layer is, the better and faster odors will disperse.

The condition when temperature actually increases with elevation is referred to as a temperature inversion. The warmer inversion layer then acts as a cap and stops vertical convective turbulence beneath it. This is considered a stable air mass and odor dispersion is constrained due to the lack of mixing. Inversion layers normally occur between 600 and 1,200 ft. in elevation, which limits the volume of the mixing layer. Temperature inversions are a result of other weather conditions in an area. They occur most often when a warm, less dense air mass moves over a dense, cold air mass. This can happen for example, when the air near the ground rapidly loses its heat on a clear night. In this situation, the ground becomes cooled quickly while the air above it retains the heat the ground was holding during the day. Additionally, temperature inversions occur in some coastal areas because upwelling of cold water can decrease surface air temperature and the cooled air mass stays beneath warmer ones.

The degree of stability of the atmosphere must be known to estimate the ability of atmosphere to disperse odors. Different methods are used for stability determination with varying degrees of complexity. Most of these methods are based on the relative importance of convective and mechanical turbulence in the atmosphere. The difference between these methods is due to use of different indicators for both convective and mechanical turbulence. When convective turbulence predominates, winds are weak and atmosphere is in unstable condition. When convection decreases and mechanical turbulence increases, the atmosphere tends to neutral conditions. Finally in absence of convective or mechanical turbulence and there is no vertical mixing, the atmosphere is in stable condition (for example, a cool morning before sunrise).

Richardson number, Monin-Obukhov length, Pasquill-Gifford stability classification and Turner stability classification are some of common methods for measuring stability. Atmospheric stability and instability are often categorized using the Pasquill atmospheric stability classes. This classification divides the atmosphere into six stability classes, with Class A being the most unstable, or turbulent, and Class F being the most stable, or least turbulent. The meteorological conditions that describe each class are shown in Table 1.

Recent developments in air emissions modeling now use the Monin-Obukhov length, rather than Pasquill stability classes, which is defined as that height at which convective turbulence is more prevalent than mechanical turbulence. EPA's AEROMOD steady-state plume dispersion model

Table 1. Pasquill Stability Class[1] meteorological conditions

Surface Wind Speed		Daytime Incoming Solar Radiation			Nighttime Cloud Cover	
m/s	mph	Strong	Moderate	Slight	> 50%	< 50%
< 2	< 5	A	A-B	B	E	F
2-3	5-7	A-B	B	C	E	F
3-5	7-11	B	B-C	C	D	E
5-6	11-13	C	C-D	D	D	D
> 6	> 13	C	D	D	D	D

[1] *Pasquill, F. 1961. The estimation of the dispersion of windborne material. The Meteorological Magazine. Vol. 90, No. 1063, pp 33-49.*

Figure 2. Vegetative canopies utilized for odor dispersion (recently planted and mature)

is based on this approach. The next article in this series will examine various dispersion models in greater detail and their applicability to composting facility odor management.

TOPOGRAPHIC EFFECTS

Topography can affect the dispersion of odors on both a micro and mesoscale. The mesoscale effects are most pronounced in coastal areas, where differential solar heating of land and water creates the on-shore sea breezes felt during the day and the off-shore land breezes at night. Mountains also have an effect on odor dispersion, as they create greater friction to air flow from increased surface roughness, which reduces wind speeds, and they also serve as physical barriers to air flow.

Air movement in valleys takes two forms: slope winds that move downgradient into the valley and valley winds that take form along drainage ways. Cool, dense air will accumulate in the lower, flatter portions of valleys, and can intensify any thermal inversions created by radiative cooling, trapping odors in the valley. With these valley inversions, the maximum inversion depth is just before sunrise and the author has observed significant early morning valley odors in the vicinity of a biosolids composting facility in the Blue Ridge Mountains in Maryland.

Buildings in the path of a dispersing air pollution plume also impart an effect. When the plume flows over the building, a cavity of turbulent eddies is formed in the downwind side of the building. These cavities can cause increased vertical dispersion of pollutants emitted from nearby sources, resulting in elevated pollutant concentrations. If the source is located closer than five times the height of the building, the plume will be forced down to the ground much sooner than it would if no impediment was present. For example, if a 25-ft. tall equipment maintenance building was located less than 125 ft. in the downwind direction from an odor source (say a forced-draft aerated static compost pile), the eddies formed behind the building could result in higher odor concentrations immediately behind that building. This suggests that buildings downwind from the composting pad should not be located close to property lines where off-site odor impacts could occur.

DEPOSITIONAL EFFECTS

Odors can be dispersed through dry and wet depositional effects. Dry deposition is the removal of odors from the air plume by contact with the ground or vegetation. Wet deposition is the removal of air pollutants by rain (essentially water scrubbing). Both effects are of primary importance to composting facilities.

Dry deposition is significantly enhanced with a windbreak or robust vegetative buffer consisting of both upper and lower vegetative canopies (see Figure 2). Vegetative buffers provide for odor dispersion through multiple means:

- Dilution and dispersion of gas concentrations of odor by a mixing effect created by windbreaks.
- Deposition of odorous dusts and other aerosols to the windward and leeward sides of windbreaks (similar to how snow lies against snow fencing).
- Collection and storage (sinks) within tree wood of the chemical constituents of odors.
- Physical interception of dust and aerosols odor particles on leaves, needles and branches.
- Containment of odor by placing windbreaks fore and/or aft of the odor source.
- Aesthetic appearance.

The water scrubbing effect of wet deposition is often observed by the fresh clean smell of the air after a rain shower. Wet deposition can be enhanced through use of area water misters that are often used at composting sites to suppress dust.

Understanding the mesoscale and microclimate aspects of odor dispersion is important in composting facility siting studies, when using odor models to predict off-site intensity and direction of odor episodes, and when taking proactive means to be a good neighbor to nearby residents and businesses. ■

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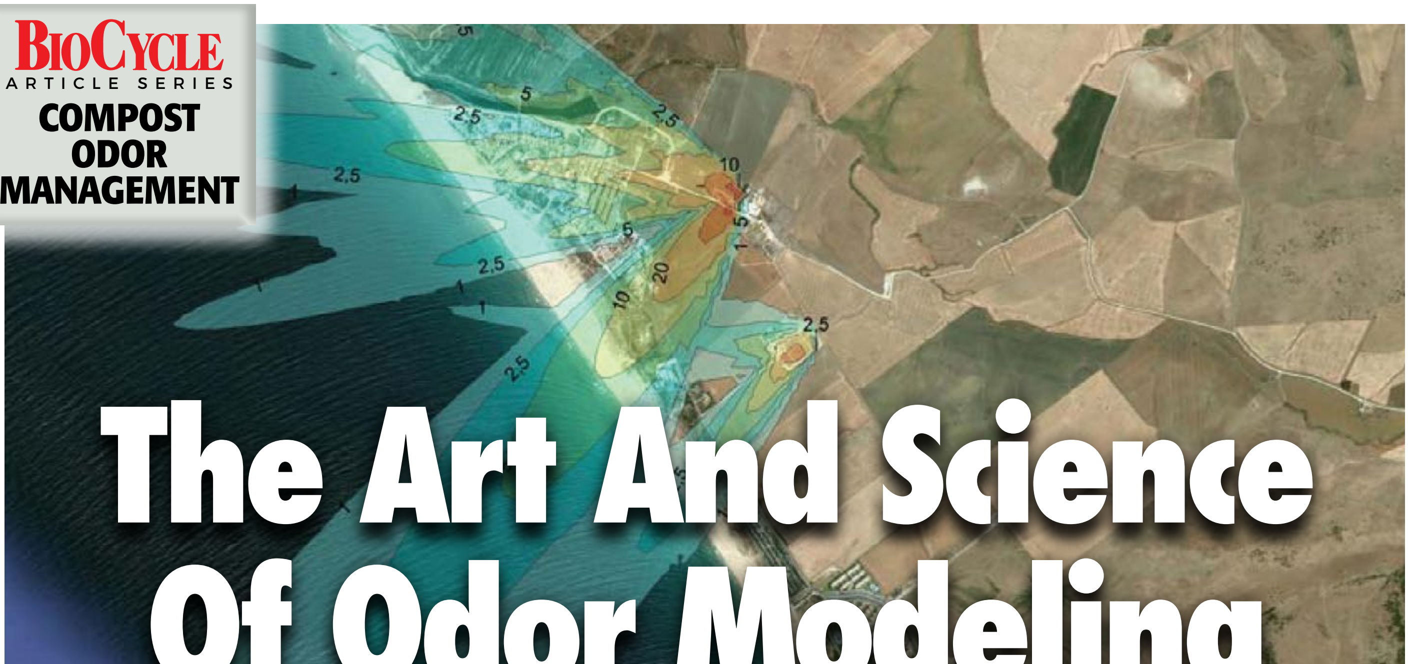
BioCycle
ARTICLE SERIES
COMPOST ODOR MANAGEMENT



The Art And Science Of Odor Modeling

Modeling tools are risk management approaches, essentially predicting the number of occurrences in a given time period when a predicted odor level will occur.

Part VII

Craig Coker

This article series examines the intricacies of odor management: how and where odors are generated, measured and perceived; how they are managed through good process control; how they are controlled with technology; and how to manage the public outreach related to organics recycling odors.

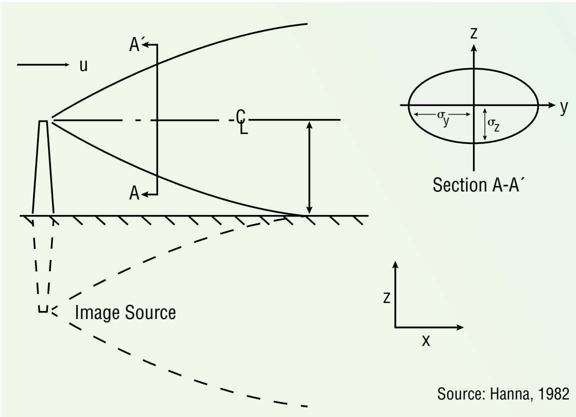
No matter how well planned, sited or managed, composting facilities are always at risk for an off-site odor episode that can create challenges such as negative publicity, regulatory intervention and lawsuits. This article series has been dedicated to helping composters understand the intricacies of odor management. Part VII looks at the topic of odor modeling and the challenges of mathematically simulating a dynamic environment.

Simulation of the movement of environmental pollutants in the natural world using computer tools is always challenging. Models have to simulate the real-world dynamics where environmental conditions can change in three dimensions (length, breadth and height) and also in time. Numerical simulations solve simultaneous equations at discrete points in 3-dimensional space, known as a grid or mesh. Calculations at each grid point have to be averaged over some time period to account for temporal changes. For environmental pollutants that can change their characteristics (such as the conversion of sulfur dioxide (SO_2) to sulfur trioxide (SO_3) by sunlight), those chemical changes also have to be interpreted by the equations in the models. These are among the computational aspects that make odor modeling so challenging and difficult.

Odor modeling is an outgrowth of the air pollutant dispersion modeling used to predict distant concentrations of criteria air pollutants from continuous point sources, like smokestacks, or from continuous line sources, like highways. These models allow for the determination of compliance with a criteria air pollution standard, such as the 0.5 parts per million (ppm) limit for a 3-hour average value of SO_2. Passage of the Emergency Planning and Community Right-to-Know Act in 1986 furthered development of air pollution dispersion models that could simulate a "one-time" release of air pollutants into the environment; these models were derived from volcanic ash emission models.

The oldest and most widely used models are known as Gaussian dispersion models, which assume pollutant dispersion is more a function of wind turbulence than vertical (temperature) turbulence. This model assumes that the average (hourly) concentration of a contaminant downwind of a source and perpendicular to the average wind direction is normally distributed and centered along the wind direction from that source (Figure 1). These models are most often used for predicting dispersion of continuant, buoyant plumes originating from ground level or elevated sources.

Figure 1. Gaussian dispersion plume



Some odorous plumes are buoyant; others are not. A plume is buoyant if it is warmer than ambient air, or if the pollutant has a lower molecular weight than air. Most odorous plumes rising from composting facilities are heated, so they tend to rise, then sink as they cool off.

Input required for Gaussian dispersion models includes meteorological data, the concentration or quantity and temperature of the pollutant source, emissions parameters, terrain elevations and dimensions of obstructions. Meteorological data inputs are wind speed and direction, amount of atmospheric turbulence (as characterized by the stability class), ambient air temperature, inversion height, cloud cover and solar radiation. Emissions parameter inputs are source location and height, type of source, and exit velocity and mass flow rate of the plume. Terrain data includes ground elevations at the source and at the locations of any sensitive receptors. Obstructions include buildings or other structures that may interrupt the plume flow path, so the dimensions of those obstructions are needed. The old computer adage of "garbage in, garbage out" applies to dispersion modeling. Accurate modeling results require that local meteorological data is used and that the other data inputs are precisely measured.

Output is usually a map of the modeled concentrations of the pollutant in question over the area modeled. These are often drawn as lines of equal concentration (known as "isopleths") that resemble the elevation lines on a topographic map. This mapping concept spatially relates dispersion of the concentration of an air pollutant at a source to the concentration at the receptor's location. This concept is illustrated in Figure 2.

MEASURING ODOR CONCENTRATION

Odor modeling is not as definitive as single-pollutant conventional air dispersion models. One odor "flavor wheel" in use lists 53 different odorous chemicals. As odors are made up of multiple chemicals, modeling becomes more difficult. Because of this multitude of odorous gases, odor modeling uses a surrogate measure of concentration. Models can be set up with the source emissions characterized in terms of dilution-to-threshold (D/T) at a source inside the composting facility where the odors are strongest, as determined by an odor panel. D/T represents a dilution factor, measured by the number of volumes of odor-free air needed to dilute odorous air to the point where 50 percent of an odor panel cannot detect the odor. The source emission rate could therefore be 50 D/T, which is modeled to be a D/T of 2 at a certain distance. As D/T is dimensionless, sometimes an artificially derived measure of odor units per cubic meter (OU/m^3) is used to create the impression that an actual odor concentration is being modeled.

"These types of odor models are essentially a risk management strategy," says Ray Porter, Knowledge Leader at Odotech, an odor monitoring and modeling consultancy headquartered in Montreal, Quebec, Canada. "Models overlay multiple worst-case scenarios in meteorology and odor emissions and predict the threat of an odor impact at levels of risk that relate to detection and recognition thresholds for odors. Modeling for odor exposure at the detection threshold is one level of risk; modeling for the recognition threshold represents a higher level of risk. The question is: 'What is the likelihood that this receptor will experience an adverse odor impact?'" Porter adds it is important to quantify the initial odor emissions estimate based on source data determined by an odor panel made up of representatives of the public.

Odor dispersion modeling is also sensitive to the time averaging period of the model. Most dispersion models were developed to predict compliance with the National Ambient Air Quality Standards, which define acceptable pollutant concentrations in ambient air averaged over exposure times of 1 to 24 hours. These models predict the concentration of a pollutant that would be present in a mixed sample of ambient air that had been sampled over a 1-hour period. Averaging over a specified period smoothes out some of the variations in the air pollutant concentration, concealing peaks that may result from short-term variations in emission rates and in meteorological conditions.

AVERAGING IMPACTS

Odors are much more transient, varying in concentration and intensity in a matter of minutes, so air models with one-hour averaging times can-

Figure 2. Odor dispersion model (odor units/m^3)

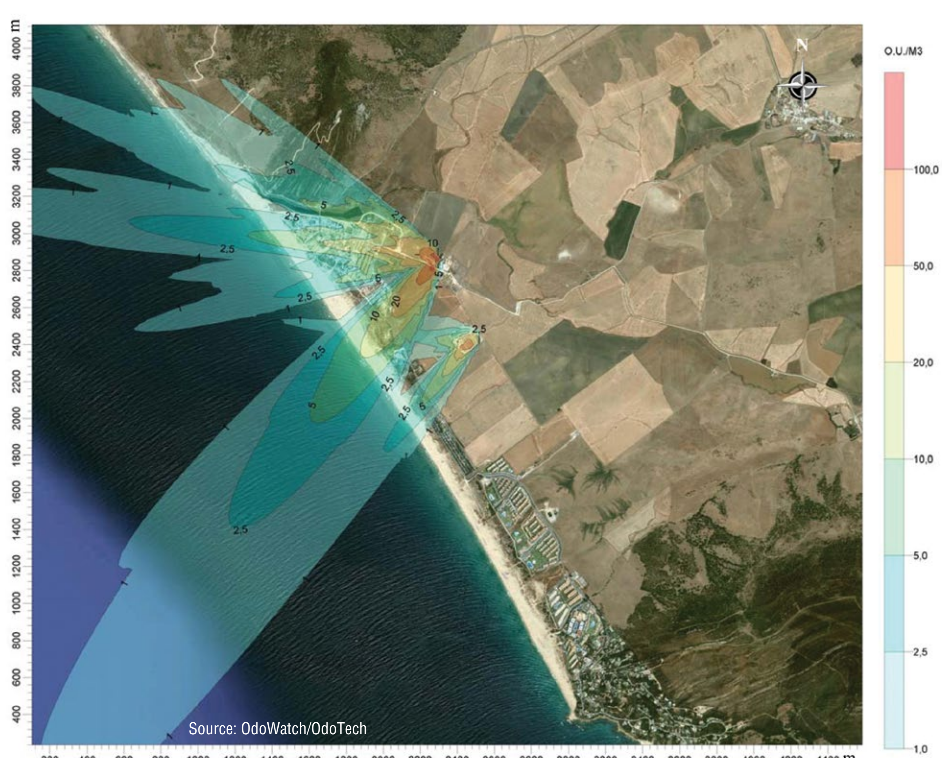
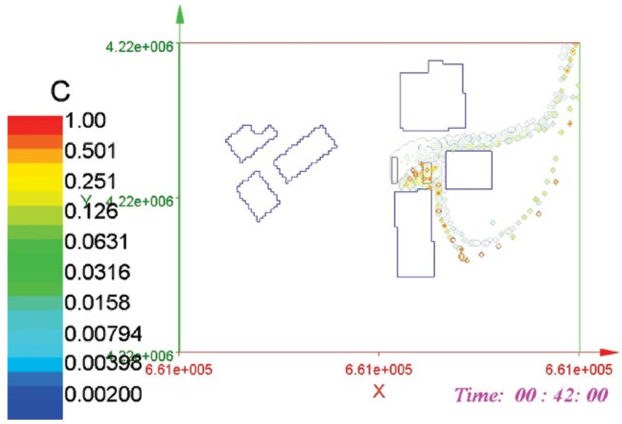


Figure 3. Output from dust study at soil products facility[1]



[1]All plots were made using ANSWER™ developed by ACRi (www.acricfd.com)

not accurately represent the short-term nature of odors. Adjustments must be made to use shorter averaging times. Peak-to-mean ratios are used to adjust model averaging times. In selecting an averaging period for an odor impact assessment, consideration must be given to the limits of such an analysis. A person might be able to detect an odor in 1 to 3 seconds, but it is more likely that a period of 3 to 5 minutes of exposure to the odor is needed to invoke an odor complaint, so 5 minutes averaging time is often used in odor modeling. Averaging times can be adjusted using a Power Law relationship, which is defined as follows:

$$C_1 = C_0 * (t_0 / t_1)^p$$

where: C_0 = the initial (1-hour average) concentration

C_1 = the concentration at the desired averaging period

t_0 = the initial (60-minute) averaging period

t_1= the desired averaging period (minutes)

p = power law exponent (varies from 0.17 to 0.68)

The power law relates the peak-to-mean concentration ratio (C_1, C_0) to the short-to-large term average time ratio (t_0, t_1). This relationship was found to provide a reasonable approximation of peak-to-mean ratios across all stability categories (Porter, 2012).

This equation was used to adjust predicted concentrations of "odor units" in an odor modeling study at a composting facility in Lisbon, Portugal (Riberio, 2010). Odor emission rates varied from 430 to 3,200 OU/m^3 at the facility, as determined by an odor panel. The regulatory standard modeled was the German standard of less than 10 percent "odor hours" per year in residential areas and less than 15 percent in industrial areas. German regulations define an "odor hour" as an hour in which there is a clear odor perception for at least 10 percent of the time. The analysts used the EPA's Industrial Source Complex Short-Term (ISCST3) dispersion model, which is widely used in conventional air pollutant modeling. They used the Power Law equation above to adjust the averaging period to 5 minutes and modeled the odor emissions on a 250 meter (m) by 250 m grid. This finer-grained level of analysis allowed them to determine that an area up to 1,500 m south of the facility would likely fail to meet the German 10 percent odor-hour standard.

Detailed quantitative analysis is possible with dispersion models adjusted to shorter time averaging periods. These models predict a numerical "dilution" at the receptor, but what is an acceptable level of probability that the predicted number (D/T or OU/m^3) will be exceeded? "It is possible to model noise impacts against a standard of maximum acceptable noise level," observes Thierry Page, CEO of Odotech, "but with odors, we're dealing with perception of nuisance. In the real world of odors, perception induces interpretation and speculation. These models, even if imperfect, are still useful, provided they are constructed by reference methods." In the U.S., the primary reference method used is ASTM Standard of Practice E679-91, "Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits," which is the reference method for the odor panel determination of initial odor concentration to be modeled mentioned above.

Other methods of modeling odors are to use Lagrangian "puff" models or computational fluid dynamics (CFD). Lagrangian models mathematically follow pollution plume parcels as they move in the atmosphere (it is said that an observer of a Lagrangian model follows along with the plume). One model in widespread use is CALPUFF, which is designed to simulate continuous puffs of pollutants emitted from a source into the ambient wind flow. As the wind changes, the path each puff takes follows a new wind direction. Diffusion of the puffs into the air is calculated as a Gaussian distribution and pollutant concentration at or near a receptor and is based on the contribution of each puff as it passes by. CALPUFF has been used to model odor dispersion from livestock operations, with agreements between model predictions and measured odor intensities ranging from 37 percent to 50 percent (Li, 2006).

CFD numerically solves the basic governing equations of mass, momentum and energy within each cell in a three-dimensional Cartesian grid. The method uses a Eulerian-Lagrangian approach to simulate atmospheric dispersion (it is said that an observer of a Eulerian model watches the plume go by). In an evaluation of odors from a 3,000-sow farrowing operation in Canada, the Eulerian-Lagrangian approach used trajectories of discrete "odor gas parcels" to predict the dispersion of odorants. The governing equations in CFD modeling are the Navier-Stokes equations, which describe the motion of fluid substances in terms of the conservation of mass, momentum and energy. These equations are applied to airflow as a fluid, modeling, for example, airflow around an airplane wing.

CFD can be used for extremely fine-grained analysis or for larger-scale odor and dust studies. "CFD models used to be run on large mainframe computers, but with the improvements in desktop PCs, CFD models can be run by mere mortals like me," says Ray Kapahi, Principal with Air Permitting Specialists based in Sacramento, California. Kapahi's firm recently used CFD to model dust emitted from bulk stockpiles of sand at a landscape supply yard near Stockton, California in response to neighbors' complaints of dust leaving the supply yard site.

"While we were doing a 2-dimensional dust study, we would use this same approach for doing an odor study," notes Kapahi. "We modeled the site by digitizing all the buildings on–site into the model from a Google Maps image, assumed a dust source emissions rate of 0.1 kg/sec, assumed a wind speed of 0.1 m/sec, and used a 500 m by 500 m grid with 1-m grid spacing." An illustration from the dust model output is shown in Figure 3. Kapahi adds that when modeling odors, it is possible to use CFD to model in three-dimensional space, thus allowing for the model to account for vertical dispersion in the atmosphere due to turbulent mixing. With grid spacing as close as 1 cm by 1 cm and a time scale of 5-second intervals, it would be possible to model odor emissions at each of the houses in a neighborhood downwind of a composting facility.

CFD was used to model odor emissions from a 3,000-head hog operation in southern Manitoba, Canada (Li, 2006). The CFD model's 3-dimensional approach used trajectories of discrete "odor gas parcels" (OGPs) to predict

MEASURING WITH AN ODOR PANEL

HERE is a quick refresher on using an odor panel to determine an odor concentration. To measure odor sensation, an odor is diluted to certain amounts to reach a detection or recognition threshold. The detection threshold is the concentration of an odor in air when 50 percent of a population can distinguish between the odorous sample and an odor free blank. The recognition threshold is the concentration of an odor in air in which 50 percent of a population can discern from an odorous sample and odor free blank. To establish the odor concentration, an olfactometer is used which employs a group of panelists. A diluted odorous mixture and an odor-free gas (as a reference) are presented from sniffing ports to a group of panelists. In comparing the odor emitted from each port, the panelists are asked to report if they can detect a difference between the ports. The gas-diluting ratio is then decreased by a factor of 1.4 or two (i.e. the concentration is increased accordingly). The panelists are asked to repeat their judgment. This continues until the panelists respond certain and correct twice in a row. These responses are used to calculate the concentration of the odor in terms of dilutions to thresholds (D/T) or odor units per square meter (OU/m^3).

dispersion of odorants. In this study, the investigators set up a modeling domain of a 5,000 m radius and 200 m tall cylinder over the farm, with a total of 200,000 computational cells in the modeling domain. The model assumed OGPs were emitted continuously, had a size of 1×10^{-6} m diameter, and had an initial emission rate of 191,923 OU/second. The model predicted odor concentration at 1.5 m height within 5,000 m after one hour. An odor standard of 2 OU/m^3 was used as a compliance boundary and the model computed that the odor travel distance for achieving 2 OU/m^3 was 860 m under unstable atmospheric conditions and 5,610 m under the most stable conditions.

A number of analytical computational tools can be used to model odor emissions and predict impacts on nearby (and distant) receptors. All modeling tools are risk management approaches, essentially predicting the number of occurrences in a given time period when a predicted odor level will occur. If odor standards were quantitative standards, like air pollution standards, then modeling would be an essential tool for composting facility siting, design and management. The reality is, though, that odor standards are subjective nuisance standards and there is lack of agreement among composters, elected and staff officials, and the general public as to what is an acceptable level of inconvenience. ■

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BioCycle ARTICLE SERIES
COMPOST ODOR MANAGEMENT

Odor Monitoring And Detection Tools

The complexity of the human nose and genetic coding that influences how odors are perceived by individuals makes odor monitoring and detection a complicated — but informative — task for composting facility managers.

Part VIII

Craig Coker

Odors vary tremendously in both time and space between where they are generated and where they are perceived. Composting facilities can utilize human and field olfactometry measurement tools to better evaluate neighborhood impacts.

This series on odor management, available in the BioCycle archives (www.biocycle.net), has covered how and where odors are generated, measured, and perceived; how they are managed through good process control; how they are controlled with technology; how to manage the public outreach related to organics recycling odors; the basics of atmospheric dispersion; and the art and science of odor modeling.

ODORS are gaseous chemicals that are emitted into the air from a variety of sources. Some are considered pleasant, like methyl salicylate (the smell of wintergreen Altoids®) or homofuronol (the smell of baked bread). Others are less well-tolerated, like skatole (the smell of manure) or dimethyl disulfide (the smell of rotting vegetables). These gases are detectable by the human nose at various levels of concentration in the air, some of which can be detected at extremely low concentrations.

Noses of mammalian species are all similar, in that they use olfactory receptor cells in the nasal passages to detect odors. These cells have tiny hair-like cilia that contain olfactory receptors. Each receptor can bind to a limited set of odorous chemicals. Changes in calcium and sodium ions in the receptor as a result of an odor binding to a receptor sends a signal through the olfactory nerve to the olfactory bulb, where the brain interprets the electrical signal received as an odor (see illustration).

The human nose has 400 types of olfactory receptors; each is paired with a matching olfactory gene in that person's DNA. By contrast, the human eye has only three types of receptors (blue, green, and red ranges of the color spectrum) and human taste buds have only five types of receptors (sweet, salty, bitter, sour and savory). Humans have around 900 genes that can code olfactory receptors, allowing us to detect up to 10,000 different odors; how each is perceived depends on the DNA sequencing of those 400 types of odor receptors (McRae, 2013). This is why the smell of 2-heptanone (the smell of blue cheese) is pleasing to some, and unappealing to others.

A helpful odor perception analogy is to envision the receptor nerves like strings on a guitar. As a single chemical odorant hits the olfactory receptor a single guitar string is plucked, producing a single note (for example, perceiving the rotten egg smell of hydrogen sulfide). When multiple chemical odorants are present and hit the receptors (multiple guitar strings) the result is a chord. For example, if Strings A, D and B (a C-major chord) are hit by three different odorants, the brain may perceive the earthy smell of good compost. Likewise, if Strings E, B and G (a D-major chord) are hit by three different odorants, the brain may perceive the smell of a sewer. The greater the number of odorant molecules present (higher concentrations) the louder the chord is played. The loudness of the chord is analogous to the intensity of the odor perception (St. Croix Sensory, 2005).

As discussed in earlier articles in this series, odors vary tremendously in both time and space between where they are generated and where they are perceived. Add to this that two neighbors detecting an odor will have different reactions to that odor based on the DNA coding of their odor receptors, and the difficulty of effectively monitoring odors in response to complaints becomes obvious. This article examines the topic of odor monitoring and the challenges of verifying odor complaints.

ODOR MONITORING METHODS

International standards are in place that dictate the scientific methods and practices of odor measurement. These standard methods for quantifying odor are: objective, quantitative, dependable and reproducible. In the U.S., the standards are ASTM E679-04: *Standard Practice for Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits* and ASTM E544-99: *Standard Practice for Referencing Suprathreshold Odor Intensity.*

There are several means to detect odors in the ambient environment including air sampling and analysis using gas chromatography-mass spectrometry (GC-MS), human monitoring and recordation of observations using field tools like olfactometers to interpret odorous conditions, and electronic noses that use gas sensors to mimic odor receptors in the nose. Each approach has its advantages and disadvantages:

GC-MS: This method requires capturing a representative sample of air and analysis of that sample by a laboratory for its specific constituents. GC-MS is extremely useful if one is analyzing a sample for a particular chemical as it provides specific identification and quantification of molecules that form parts of the odor. This technology is used in the food and beverage industries to analyze the aromatic compounds deliberately added to foods to verify correct formulation. It is also used to detect and measure contaminants from spoilage or adulteration. The drawback to GC-MS analysis is that odors are made up of multiple chemicals, some of which act synergistically to affect perception. This method cannot measure the character of the odor, and it can be expensive (between $50 to $100/chemical/ sample).

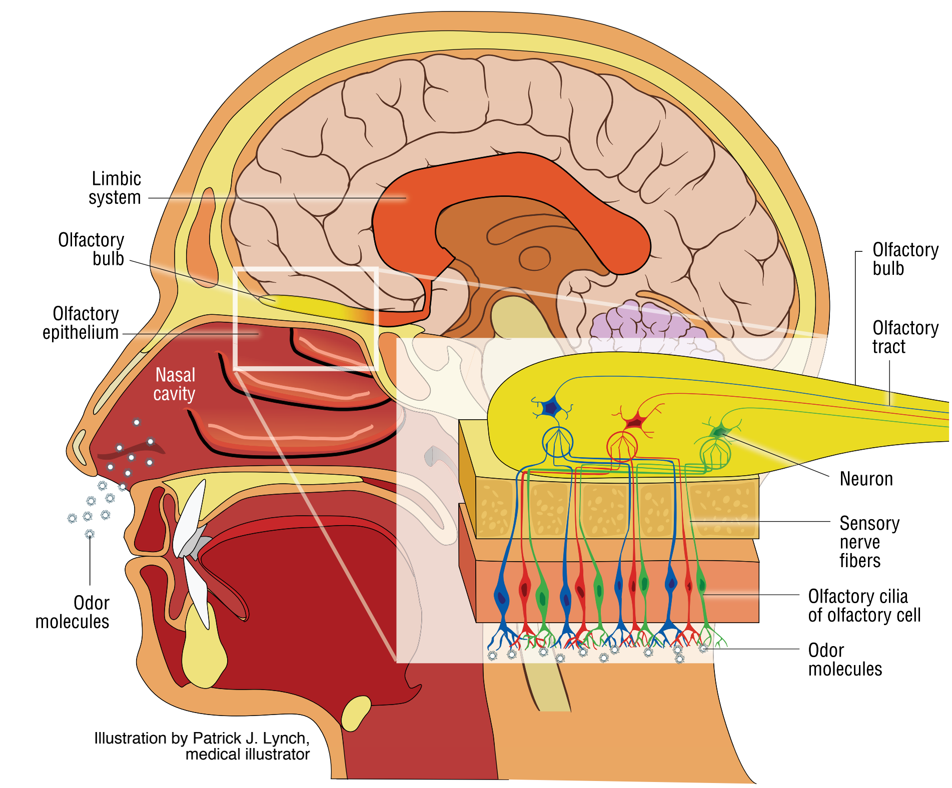


Illustration by Patrick J. Lynch, medical illustrator

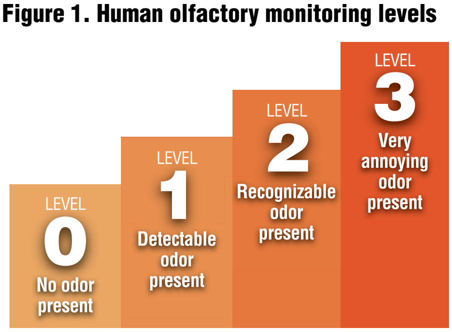
Human Olfactory Monitoring: Human olfactory monitoring was used by the compost curing facility built by the Region of Peel in Ontario, Canada several years ago. As a result of complaints, a daily odor, noise and dust monitoring protocol was established (see "Resolving Odor Challenges," November 2012). Staff from the Region of Peel went out three times per day to monitor odor, noise and dust at 10 different stations around the facility. They were instructed to travel to each of the 10 stations and monitor outside the vehicle for several minutes, as well as drive between the stations with the vehicle windows down. They recorded odor events on a daily log sheet according to four levels (Figure 1).

Similar measurement systems were used for noise and dust. Staff was also to note any other events observed during the monitoring runs, such as wood smoke, leaf fires, manure land application, and other similar odor-producing events. If a compost curing odor was detected off-site, staff would return to the facility and investigate what work might have been underway at the facility that might have produced the odor (such as receiving of immature compost, turning windrows or screening compost).

This "human substitution" for complaints from neighbors has an advantage in that staff is monitoring for odors in the same time/space as the people detecting those odors so there is a direct correlation between neighbor and staff observations. The disadvantage of this approach is the large labor resource demand requirement for multiple monitoring observations at multiple times of day.

Olfactometry Methods: Olfactometry could be defined as the science of detecting and measuring ambient odor dilution. Olfactometry can be done in the laboratory, or in the field. Laboratory olfactometry involves diluting an odorous air sample to various concentrations then having human assessors evaluate the diluted odor to determine the detection threshold of the odor

Figure 1. Human olfactory monitoring levels



(measured as Dilutions-to-Threshold, or D/T). The laboratory dilution process simulates the dilution of the odor in the ambient air. There are specific rules and guidelines that cover who is qualified to be an odor assessor; for example, someone with chronic allergies would not be qualified. Assessors receive training in olfactory awareness, sniffing techniques, descriptor standards, and similar issues. Laboratory olfactometry is well-used by the food and fragrance industries.

Laboratory olfactometry was the basis for the Odor Monitoring Project recently conducted at the Nature's Needs aerated static pile composting facility in North Plains, Oregon. In this project, samples of air were taken from 28 different locations within the property lines of the composting facility and these samples were evaluated using trained odor assessors. The odor samples were diluted to below odor detection limits and then introduced to a gas delivery system. A panel of eight members trained in odor response served as the odor "detector." Panel members were asked to smell air samples delivered to one of three nose cones, one of which had the diluted sample (the other nose cones have clean air). The odor concentrations in the diluted sample were increased until one-half of the odor panel members could detect the odor, at which point the odor measurement concluded. The odor concentration was expressed as dilution-to-threshold (D/T) level, the number of dilutions that were required for one-half of the panel members to record detection. D/T levels of 1,400 to 5,400 D/T were determined from the active composting piles, but transient emissions during transfer of compost to curing were as high as 8,000 D/T.

Field olfactometry is more commonly used in the composting industry. Field work uses trained assessors to evaluate odors using one of two approaches — a standard odor intensity referencing scale (OIRS) based on n-butanol (a reference chemical) to quantify odor intensity, or field olfactometers. Most odor-related field work in composting uses field olfactometers. As in the laboratory method, field olfactometers create a series of dilutions by mixing odorous air with carbon-filtered odor-free air to produce a D/T value. The Nasal Ranger model (from St. Croix Sensory) is an example of a field olfactometer. An orifice selector dial on the hand-held unit contains six odorous air inlet openings for six different D/T values (2, 4, 7, 15, 30 and 60). The dial is replaceable for other D/T series (e.g. 60, 100, 200, 300 and 500). The assessor has to maintain a certain breathing (sniffing) rate for the device to work correctly.

Field olfactometry with the Nasal Ranger has been used by the Shakopee Mdewakanton Sioux Community (SMSC) in Minnesota to attempt to verify neighbors' complaints about odors from its windrow composting facility. "We respond to every neighbor's complaint as quickly as we can after a complaint is recorded, and we do daily monitoring around the site," notes Mike Whitt, Natural Resources Manager for the SMSC. "We have a Nuisance Standard of no more than 4 D/Ts measured 15 minutes apart within a one hour period at our property line. We have accumulated over 1,400 monitoring data points since we began in July 2012, and have recorded one nuisance odor beyond our property line in 14 months of monitoring. And that event did not generate any complaints. Odors are subjective but I have learned as a scientist that one must make a best professional judgment, record the data, and move on to the next monitoring station. The data becomes more robust the longer one collects. I recognize that all complaints are real even when all the data is telling you that there is no odor present. Some people have decided that any odor at all, regardless of intensity, or whether it can be verified, is unacceptable."

Simeon Matthews, an industrial hygienist with the Shakopee Dakota tribe, is the staffer assigned to monitor daily 14 discrete locations around the SMSC facility with the Nasal Ranger. "Learning how to inhale at the appropriate rate has been fairly easy to learn," Matthews says, "but it's been more of a challenge to know I'm detecting an odor at a low concentration and to assign a characteristic to that odor. Also, the odor plumes move constantly and I can't predict or see them, so finding the point of strongest odor can take quite a while. You're also unaware of what the odor is around you while you're breathing filtered air, so chasing the odor can be challenging with the device over your nose."

One challenge in collecting all this data is to develop a real-time feedback system that allows a composting operation to make modifications to its procedures. In the case of the SMSC facility, the response to a detected odor level of concern is to investigate site conditions and process controls. In one case, a pile of hay and horse manure was identified as the source; in another, fine particles had washed into the storm water forebay pond (the inlet leading into the

The Shakopee Mdewakanton Sioux Community in Minnesota uses the Nasal Ranger field olfactometer to attempt to verify neighbors' complaints about odors from its windrow composting facility.

main retention basin), which turned anaerobic and needed to be cleaned out; in a third case, they found low oxygen levels in four windrows due to inadequate free air space. While these actions were reactions to the monitoring data, the staff at the SMSC facility has learned more about the correlation between process management and odor generation and is incorporating more proactive management procedures to minimize future potential problems.

ELECTRONIC NOSES

Another technology for monitoring odors in the field is the electronic nose. These devices use arrays of sensors to mimic human olfactory senses where the human nose detects a combination of chemicals that produce an odor (the guitar chord mentioned in the analogy earlier). The types of chemically-active sensors used include: metal-oxide-semiconductors, metal-oxide-silicon field effect transistors (MOSFET), conducting polymers, surface acoustic wave devices, quartz resonators, and fiber-optic chemical sensors. Odorous molecules interact with one of these sensor arrays, changing its electrical resistance, which can be measured. The electrical data can then be analyzed using various data interpretation systems.

Electronic noses must be calibrated to the odors that need to be monitored. This is done with a three-step process: Collection of representative odor samples at the site, laboratory olfactometry to establish the odor concentration of the sample(s), and calibration of the electronic nose to the concentration in the assessed sample(s). The calibration is accomplished using a statistical nonlinear multivariable correlation technique.

These electronic noses can be used to track spatial and temporal fluctuations in odor intensities in real time. Combined with real-time odor modeling, they have the potential to give a composting facility operator a proactive approach to odor management. They can also be deployed remotely and programmed to have an active alert system based on a set point such as a limiting odor concentration at a receptor's location.

Electronic noses are being used at the Everett/Marysville Community Odor Monitoring Project in Washington State, which is a program set up to monitor multiple sources of odors from the area where one of the Cedar Grove composting facilities is located. This project was set up in response to neighbors in the vicinity registering odor complaints with the Puget Sound Clean Air Agency, which regulates nuisance odor issues in this region.

"The agency's contractor [Odotech, Inc.] has set up 10 electronic noses around the Everett and Marysville area to evaluate multiple sources of odors in this area," explains Joanne Todd, Communications Supervisor for the Puget Sound Clean Air Agency. "There are four monitors owned by and at Cedar Grove, and also agency monitors at two area wastewater treatment plants, at an asphalt and concrete plant, and three ambient air monitors." All the monitors, except the ambient air monitors, were calibrated by Odotech against air samples taken from each spot where a monitor would be installed so that the monitors would record the presence of one of these calibrated odors each time it was detected.

Todd notes that data collection is still going on, so it is too soon to draw any conclusions. One aspect of the odor monitoring program that is working well is the use of citizen odor monitors. "We have 11 citizen odor monitors, all of whom underwent specific odor monitoring training," she adds. "They were all volunteers who are very interested in the odor situation in this area and are working hard to make the most conscientious choices they can. We feel it is very important to involve area citizens in this type of evaluation; after all, they know better than we do what they smell every day. One benefit of this study that we have noticed is there is a lot less skepticism about where odors are coming from than there was before we started, in that they now understand that there are multiple sources of odors in a community."

It is a challenge to monitor an environmental phenomenon like odor that changes in time, in space and in the noses of the people affected by the odor. Good technologies are available that can be deployed, and when coupled with properly trained monitors, they offer potential for more objective assessments and real-time solutions to these often-difficult issues. ■

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