BIOFILTERS FOR ODOR CONTROL: The Scientific Basis

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Of all the potential pollutants that get the public's immediate attention, odor ranks number one. Complicating the odor problem is the highly subjective nature of odor. What one person finds acceptable, another may find extremely objectionable. Odors are produced by municipal sewage sludge, and a variety of waste management activities, including composting. The problem has become so severe in some locations that facilities have had to shut down. The origin of odors and their effective control using a relatively new biotechnology, biofilters, or soil filters, are discussed in this fact sheet.

ORIGINS OF ODORS

Odors are produced during incomplete microbial oxidation of organic materials, principally carbohydrates and proteins. Carbohydrates are chemicals that consist of carbon, hydrogen, and oxygen in the general form-(C\textsubscript{n}H\textsubscript{2n}O\textsubscript{n})-. Most common of the carbohydrates are cellulose and sugars found in virtually all natural products. In the absence of adequate oxygen, carbohydrates break down into alcohols, esters, aldehydes, and organic acids such as butyric acid: compounds that are very odorous. Proteins consist of carbon, hydrogen, nitrogen, oxygen, and sulfur. Odors produced from proteins consist of ammonia, amines, mercaptans, and others. Most of these odors are very intense and may be evident at very low atmospheric concentrations in the parts per million and parts per billion range.

EXPERIENCE WITH ODOR CONTROL

Attempts at odor control have included masking agents (covering up the odor with another, more acceptable odor), oxidation of the odorous material with ozone, potassium permanganate, or chlorine-containing compounds; adsorption using activated carbon filters; thermal oxidation using afterburners; and absorption/biological oxidation using biofilters. The success of the biofilter to control odors is related to two processes: sorption and regeneration.

BIOFILTER FUNDAMENTALS

Sorption processes. The soil's odor removal capability is due to adsorption onto the soil particles, absorption or dissolving in soil water, chemisorption, catalytic contact on the soil particle surface, and ion exchange on the particle surface. Odorous compounds flow through the soil matrix and become attached through adsorption or absorption onto particle surfaces, removing odors from the air stream. Thus the first step in odor control is a function of the surface area of the organic matter and soil particles in the biofilter. The surfaces of these particles provide the active sites.

Sorption process examples. For example, hydrogen sulfide is precipitated onto the soil particles as iron or other metal sulfides. Hydrogen sulfide is first dissociated into HS\textsuperscript{-} and H\textsuperscript{+} and then precipitated out as the metal sulfide. In the case of ammonia, the ammonia is dissolved in soil water, ionizing to NH\textsubscript{4}\textsuperscript{+} and OH\textsuperscript{-} with sorption of the ammonium ion by clays and reaction of the hydroxide ion with soil acidity. Volatile organic molecules are sorbed most effectively by moist soil and organic matter. Although the sorption capacity of the particles is limited, regeneration of the soil's sorption capacity is achieved by chemical and microbial oxidation of the odorous compounds. When the biofilter is in long-term use, the sorption-regeneration processes reach steady-state conditions.
Regeneration processes. Regeneration of the sorbed chemicals is moderated by microbial biodegradation, thermal processes, and chemical reactions. Thermal and chemical removal play a small role in odor removal because of their high energy requirements. In contrast, microbial processes are the dominant mechanisms in biofilters. Soil possesses an abundance of diverse soil bacteria and other organisms which participate in these processes. Because the organisms are dependent on the moisture in the soil for their biological processes, biodegradation and oxidation of sorbed odors is most efficient in moist soil.

Regeneration process examples. As an example, hydrogen sulfide and HS\(^{-}\) are oxidized by Thiobacillus to hydrogen ions and sulfate ions which are odorless chemical entities. In the case of ammonia, the NH\(_4^+\) is oxidized to nitrite by Nitrosomonas bacteria and then to nitrate by Nitrobacter bacteria. Volatile organics such as the odorous butyric acid are oxidized to carbon dioxide and water by a succession of various bacterial groups.

STEADY-STATE OPERATION
The soil’s capacity to remove odorous chemical depends on the simultaneous operation of both the sorption processes and regeneration processes. As a result, the soil filter’s odor removal potential can be exceeded by overloading the system through excessive air flow rates, so that sorption rates are lower than the rate at which the chemicals pass through the filter. Once all the sorption sites are occupied, odor removal is rapidly diminished. A second limiting factor is the microbial regeneration rate of the sorbed chemical which must equal or exceed the sorption rate. Toxic chemicals can interfere with microbial processes until a bacterial population develops which can metabolize the toxic chemical. Soil acidity can also reduce the removal efficiency due to the presence of an inhospitable environment for soil bacteria. In most cases of biofilter failure, the limiting factor is the overloading of the filter rather than microbiological processes because of the great diversity and numbers of soil bacteria.

SUMMARY
The success of the biofilter is derived from a combination of physical, chemical, and biological processes that occur in the soil. Odors are sorbed by the organic matter and clay particles, dissolved in moisture and broken down and destroyed by microorganisms. The process is self-sustaining and no supplemental energy or chemicals are needed. Consequently, little maintenance is required.


SORPTION OF ODORS AND REGENERATION OF ACTIVE SITES

![Diagram of soil particle with sorption and regeneration reactions]

**SORPTION OF ODORS**
- Ammonia (NH\(_3\)) and hydrogen sulfide (H\(_2\)S) sorbed on the soil particle surface.
- Water in the soil.

**REGENERATION REACTIONS**
- Odorous hydrogen sulfide is oxidized to odorless sulfate:
  \[ \text{H}_2\text{S} + 2\text{O}_2 \rightarrow \text{SO}_4^{2-} + 2\text{H}^+ \]
- Ammonia is dissolved in water and oxidized to odorless nitrate:
  \[ \text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^- \]
  \[ 2\text{NH}_4^+ + 3\text{O}_2 \rightarrow 2\text{NO}_3^- + 8\text{H}^+ \]
- Bacteria oxidize odorous volatile organics to odorless carbon dioxide and water:
  \[ \text{volatile organics} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]