Biofilter Removal of VOCs and Toxics from Airborne Emissions: Design Optimization

Sewage treatment plants can emit significant quantities of volatile organic compounds (VOCs) and toxic air contaminants, but emission control by conventional methods has been difficult to achieve. The biofilter technology developed in a previous contract can satisfactorily control emissions from these plants and possibly from other sources of high-volume, low-concentration emissions such as landfills. The purpose of this study was to determine process design parameters and constraints so that this technology can be successfully commercialized. The study was conducted by the University of California, Davis.

Volatile organic compounds (VOCs) and toxic air contaminants (TACs) are emitted in significant quantities from wastewater treatment and landfills. However, the concentrations are low -- generally less than one part per million by volume - and the volumes of air that must be treated are very large, presenting a challenge for an emissions control system. Results from Phase I of this study (ARB contract number A032-127, Research Note 1992-9), a concept demonstration, verified the potential application of microbial packed-bed systems for the removal of contaminants from gases resulting from wastewater treatment operations.

Background:

A pilot scale biofilter was built for the Phase I study. It is the size of a dumpster, and consists of a reactor chamber, a gas intake system, a humidification chamber, gas flow measurement systems, and a filter bed containing compost. The biofilter was installed at the headworks for incoming sewage at a wastewater treatment plant. Removals of benzene, toluene, and hydrogen sulfide were generally over 90 percent. Although removal of chlorinated compounds was generally below 40 percent, more satisfactory removal of chlorinated organics has since been achieved at the wastewater treatment plant.

The Phase I performance verification study successfully demonstrated that this technology could be optimized for general application. The purpose of this study (Phase II) was to optimize the operation of the biofilter by
obtaining and using information on several of the process variables. This study provided process information for variables such as gas and organic loading rates, temperature, and humidity. Other fundamental parameters, such as mass transfer rate, nutrient requirements, and pH control, were investigated. Biological factors were also studied. The resulting database will expedite application of biofilter technology to control of VOC and TAC emissions from facilities such as wastewater treatment plants.

The researchers conducted a set of experiments designed to:

- Evaluate the rate of VOC degradation in biofilters.
- Distinguish between adsorption and biodegradation as removal mechanisms.
- Determine the significance of the compost source and composition in process performance.
- Determine the limitations and effects of gas flux on system performance.
- Determine the effect of VOC concentration and loading rate on system performance.
- Determine the response characteristics of biofilters to transient loadings.
- Investigate the impact of damping transient loadings (through the use of an activated carbon layer at the base of the biofilter).

**Methods:**

The experiments used three compounds, each representing a class of compounds expected to be metabolized differently. Toluene is an easily degraded aromatic, methylene chloride (dichloromethane) is a directly biodegradable chlorinated organic, and trichloroethene is a chlorinated organic requiring co-metabolism.

Batch experiments were conducted in half-liter jars to determine the fate of the target compounds and the rates of the various removal processes. The kinetic properties and adsorption equilibria of several systems were evaluated in the batch studies using initial VOC concentration, VOC species present, and compost type as independent variables. Kinetic data were obtained on the rates of conversion per unit mass of solid medium. The batch rates were compared with rates along the length of the biofilter to determine whether the batch experiments could be used to predict biofilter performance. Target compounds were added, and gas samples were taken periodically and analyzed to determine the extent of conversion. A total of six pure compounds and various mixtures were added at several concentrations ranging from 25 ppb to 500 ppb. Compost for the batch experiments was obtained from several specified sources.

A laboratory-scale biofilter unit was used for continuous flow experiments to measure system response characteristics. Experiments were performed with
varying gas flux, VOC loading, and transient loadings. The gas flux experiments were directed toward determination of limiting gas flux values, and determination of the relationship between flux and VOC removal performance. The purpose was to develop design recommendations for process configurations, such as area versus depth. The purpose of the VOC loading experiments was to determine the impact of low concentrations upon VOC removal. In the transient loading experiments, the concentration of a VOC was increased and decreased in sequential steps to determine the response of the system.

The analytical methods used in the experiments were similar to those used for Phase I, with the addition of a purge-and-trap automatic sampling system. Gas chromatography/mass spectrometry (GC/MS) was used to analyze samples collected on sorbent tubes.

Biofilters were found to be effective in degrading low-concentration emissions of aromatic hydrocarbons. Greater than 99% removal efficiency was obtained for toluene. Adaptation of microbial populations to aromatic compounds occurred within a short time of operation startup. Steady-state conditions were observed within two weeks of startup and both field and laboratory systems were able to recover after shut-downs of over one week. Toluene removal was high, both in compost media amended with activated sludge and in media inoculated with a specialized microbial culture. Biodegradation rates were higher after this bioaugmentation. The system responded well to rapid changes in inlet concentrations. During periods of extreme loading, high mass removals were observed.

Dichloromethane (DCM) degradation was found to be dependent on the presence of particular organisms capable of degrading it. Once populations for DCM degraders were established in the reactor, DCM removal efficiencies of greater than 98% were achieved. DCM-degrading organisms withstood shock loads and interruptions in operations. However, removal of trichloroethylene (TCE) was not observed, even after conditions favorable to TCE co-metabolism were established in the biofilter. This is in contrast to what was observed in the Phase I pilot study.

Hexane removal rates were greater than those observed for toluene, implying that this system might work well for gasoline-contaminated soils.

The researchers developed a biofilm model that accurately predicted DCM concentration profiles in the compost column system. The model also accurately predicted that toluene removal efficiency was independent of inlet levels. Based on the model, there appears to be a potential for increasing mass transfer efficiency (and thereby compound removal rate) by increasing the surface of the biofilter medium. Also, higher biodegradation rates may be possible with specialized strains of organisms or higher biomass densities.

An important conclusion of this study is that commercial composts may be limited in nitrogen, and that it would be useful to develop a method to add nitrogen to biofilters.
Significance and Application: This study provides important engineering design parameters for the operation of biofilters as devices to control airborne emissions of both VOCs and toxic air contaminants. With this information that can optimize biofilter technology, it is hoped that the commercial promise of biofilters for air pollution control will be more rapidly achieved. In particular, the finding that commercial composts may be limited in nitrogen has led to the recommendation that nitrogen be added to biofilters. Nitrogen analysis is therefore an important feature of design and operation of compost biofilter systems.

Related Projects: The ARB has also funded these related studies (ARB contract number in parentheses): Biodegradation Technology for Volatile Organic Compound Removal from Airstreams; Phase I: Performance Verification (A032-127) and Assessment of Airborne Emissions from Bioremediation Processes (A132-083).

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Copies of the research report upon which this Note is based can be ordered from:
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