United States
Environmental Protection
Agency

EPA/540/SR-93/521
September 1993

EPA

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Emerging Technology Summary

Bioscrubber for Removing Hazardous Organic Emissions from Soil, Water, and Air Decontamination Processes

An advanced biofiltration system has been developed for the removal of trace organic contaminants in air. This bioscrubber uses activated carbon as a support for biogrowth. An advanced engineering design was incorporated into the bioscrubber to allow biomass removal and nutrient supplement if necessary. In a bench-scale study, >95% removal efficiency has been consistently demonstrated in an air stream containing 5 to 40 ppm of toluene for >11 mo. It shows a much higher degradation efficiency than the existing practice of using compost and other naturally occurring media under the same operating conditions. This bioscrubber also provides several operational advantages over conventional activated carbon adsorbers for soil, water, and air decontamination processes.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see ordering information at back).

Introduction

Biofiltration is now a well-established air pollution control technology in several European countries. As many as 500 biofilters are currently believed to be active in Germany and the Netherlands. Control efficiencies of more than 90% have been achieved for many common air pollutants. Bio-filtration when applied to systems can provide significant economic advantages over other air pollution control devices. Environmental benefits include low energy requirements for operation and complete degradation of the pollutants.

This bioscrubber was developed under the Superfund Innovative Technology Evaluation (SITE) Emerging Technology (ET) Program. The SITE ET Program is part of the U.S. Environmental Protection Agency's (EPA's) research into cleanup methods for hazardous waste sites throughout the nation. Through cooperative agreements with developers, alternative or innovative technologies are refined at the bench-scale and pilot-scale level and then demonstrated at actual sites. EPA collects and evaluates extensive performance data on each technology for use in remediation decision making for hazardous waste sites.

Most biofilters have been built as open single-bed systems. Open, multiple story systems are also built if space constraints exist. Some European firms have developed enclosed systems usually with stacked beds. Media used include compost, mineral soil, and peats. Microscopically, concentration profiles exist from the bulk gas stream through the biofilm and then to the solid surface.

Biofiltration, in its most general sense, is the removal and decomposition of contaminants from gases into nonhazardous substances through the use of microorganisms. Biofilters are believed to be the most economical way to treat low level contaminants (up to several thousand ppm) in gas streams. The advanced biofiltration system developed here under the SITE ET program uses a selected activated carbon as a microbial support and incorporates unique engineering features to maintain a steady environment for biogrowth. The report summarized here documents the results of bench-scale tests of the bioscrubber to remove trace organic contaminants from air.

For efficient operation, the filter media must meet several requirements:

- provide optimum environmental conditions for the resident microbes,
- exhibit uniform pore size and particle structure (for low-bed pressure drop, minimizing gas channeling, high reactive surfaces), and
- exhibit minimal bed compaction (minimize maintenance, media replacement).

The composition of existing, commercially available biofilters utilizing compost and other naturally occurring media generally satisfies the first requirement by providing sufficient nutrients for the microorganisms (typically bacteria). Some problems with composting, however, are the huge space requirement, continual loss of effective surface area during biomass build-up (slothing), and inefficient biodegradation of particularly refractory contaminants (i.e., chlorinated compounds).

The carbon-based biofiltration module developed here addresses the current deficiencies of composting and other naturally occurring media-based biofilters by:

- having minimal pressure drop because of no slothing,
- having much smaller bed requirements (allowing the use of compact filters),
- accommodating removal of biomass as necessary, thus no replacement of disposal requirement of spent media, and
- retaining high water in the microporosity (long shelf life while not in use during start up/shut down, minimal requirements for adding water).

Additionally, activated carbon media beds provide another key separation mechanism for biofilters—the desorption of gases onto the carbon. This increases surface concentration of contaminants and removes hydrophobic gases that would not typically be absorbed into the aqueous phase.

These qualities enhance biodegradation of typical organic contaminants, as well as substances (i.e., refractory compounds, low concentration, operating concentration fluctuations) that would not be efficiently degraded in commercially-available biofilters. This study focused on the conventional degradation of a dilute hydrophobic contaminant, 10 to 20 ppm of toluene in air, with a biofilter using activated carbon as the medium. Bench-scale units designed and operated for more than 11 mo in the laboratory are discussed.

Bench-Scale Apparatus

The bench-scale bioscrubber testing unit assembled in the laboratory consisted of five parallel glass columns (2.5 x 61 cm) packed with a selected activated carbon. The columns were inoculated with activated sludge in a synthetic media containing benzoic acid and other inorganic nutrients. After inoculation, an air stream containing 10 ppm of toluene was fed to each column and their degradation efficiencies were monitored through sampling ports, A, B, and C, located at 13, 25, and 61 cm, respectively, from the inlet of the stream. In addition, an inorganic nutrient solution was supplied to the columns at 1 cc/hr for the dual purposes of inorganic requirements and additional humidification to the filter. The effluents were measured by gas chromatography with a method detection limit of 0.86 ppm of toluene.

Process Description

Before 1992, the bioscrubbers operated steadily for 3 mo before the removal efficiency declined. Channeling the air flow, drying the filter media, and a poor inoculation procedure were considered possible sources of this activity decline. An improved inoculation and maintenance procedure led to a steady operation for more than 11 mos.

To improve inoculation, activated sludge was collected from a local sewage authority and 100 ml of supernate was added to the benzoic acid media in batch mode. The municipal microbes were grown in this solution for 5 days and then put into columns. A dilute benzoic acid solution supported the biomass and allowed impregnation without clogging the bed. A portion of the benzoic acid solution was removed from each column after 24 hr and analyzed. The initial feed concentrations of inoculation were more than 1500 mg/L of COD; by the fourth day, Column B had a COD concentration range of 20 to 50 mg/L. After 96 hr, the columns were drained of excess solution and placed online. The biofilters were fed on influent in a down flow mode. All influent variations were corrected immediately without causing any alteration in column performance.

Biodegradation

The filters were operated from 3/23/92 to 2/28/93 with varied flow rates, (0.5,1,2,4 L/min). From 3/21/92 to 6/30/92, all filters were fed air with ~10 ppm of toluene at 0.5 L/min. During this period, no toluene breakthrough was observed at Port A for any column. More importantly, the mass transfer zone (MTZ) remained stationary for the entire period. Biodegradation of toluene evidently was effective and complete, showing no signs of accumulation of contaminants or metabolic byproducts. Bioregeneration of activated carbon has been discussed in the literature as a means to prolong its service life in water and waste water treatment. This filter extends the concept to air pollution control, which offers a suitable environment for biogrowth.

To ensure that biodegradation, instead of carbon adsorption, was responsible for the removal of toluene, the filter was presaturated with ~10 ppm of toluene in air before inoculation. The substantial breakthrough, or "roll-over," of the preadsorbed toluene on the carbon observed at Ports B and C after inoculation resulted from desorption of the preadsorbed toluene. The roll-over declined drastically and eventually disappeared within 2 to 3 wk. That toluene is removed by biodegradation is evident based on the appearance and disappearance of the "roll-over" observed during the initial operations. In field start-up operations, no roll-over will be observed since the contaminants need not be preadsorbed and biodegradation will take place immediately.

Effect of Flow Rate

The flow rates were increased to 1, 2, and then 4 L/min. from 0.5 L/min to study its effect on the degradation efficiency. During these increased flow rates, the system showed some breakthrough ranging from 0 to 5 ppm at Port A. Nevertheless, only trace amounts of toluene were detected at Port B. The MTZ's were estimated to be 19 cm and 25 cm for the flow rates of 2 and 4 L/min., respectively. Before the end of the study, the flow rate was reduced to 0.5 L/min. on 1/21/93; no toluene breakthrough was detected at Port B as had been observed previously. The recovery of the column to the original MTZ indicates that the increase of the MTZ from 13 to 25 cm is most likely due to degradation kinetics versus the linear velocity of the contaminant. The MTZ requirement (i.e., the bed-depth requirement) is extremely shallow and stationary, indicating that the *in-situ* bioregeneration effectively restored the carbon capacity.

Under the highest flow rate tested (about 80 g/m^3/hr of toluene), the degradation rate was estimated with an empty bed contact time of about 1 sec. This degradation efficiency was about 40 to 80 times higher than those reported in the literature for existing biofilters using compost and other naturally occurring media. The degradation efficiencies observed here were very likely enhanced by the adsorption of activated carbon. It also offered an advantage as a sink to adequately cushion any feed fluctuations. During the 11 mo of operation, a consistent removal efficiency was observed although the feed fluctuated from 5 to 40 ppm.

Biomass Removal

The biomass generated and accumulated in the filter as a result of the degradation of contaminants was expected. Biomass was visually detected occupying the interparticle space. This buildup would eventually result in a pressure drop increase. Biomass was occasionally removed manually to maintain a minimal pressure drop throughout the operation period. Although the excess biomass was removed from the column, sufficient amounts of biomass were retained on the carbon to maintain effective biodegradation when the bed was replaced. The biofilter efficiency was not reduced as a result of the biomass removal The biomass generated from the filter is expected to be similar to the sludge generated from the fixed-film biological treatment practiced routinely in water and wastewater treatment. The biomass should be disposed according to the current practice in water and wastewater treatment.

Pilot Unit

The pilot bioscrubber developed in this program is as simple as a carbon adsorber system incorporating a nutrient delivery system and a biomass removal capability. Because of the simple configuration, it can be integrated into existing production processes or added downstream from existing remediation processes, such as air stripping towers, soil vacuum vents, biological wastewater treatment, etc. The system consists of four major components: (1) a gas delivery system, (2) the biofilter, (3) a nutrient delivery system, and (4) a biomass removal system. Through our extended operating experience, an advanced engineered filtration technology has been incorporated into the pilot testing unit to become a reliable and usable biological treatment system.

Applications

The proposed technology will have wide application to clean up Superfund sites. Potential areas include: (1) organic emission control for groundwater decontamination using air strippers, (2) emission control for biological treatment of ground and surface water, and (3) emission control for soil decontamination. These primary treatment processes currently under development or practice, have not been designed to prevent volatile organic compound emissions from discharging into the atmosphere. The requirement to treat these airborne pollutants may, however, cause these treatment processes, to become expensive or economically prohibitive. The proposed technology is an ideal posttreatment for these processes because of its effectiveness in handling trace organic volatiles economically and effectively.

This bioscrubber, which uses activated carbon as a medium, provides several operational advantages over conventional activated carbon adsorbers for the above-listed applications. The bioregeneration keeps the maximum adsorption capacity available constantly; thus, the MTZ remains stationary and relatively short. No expensive, off-site carbon regeneration is required, and the bed length is greatly reduced. These features translate into reduced capital and operational costs. The bioscrubber's advantages would be fully used when off-gas contains weakly adsorbed contaminants, such as methylene chloride or adsorbates competing with moisture in the stream. Finally, the chromatographic effect (or premature desorption) commonly experienced in an adsorber would not exist because the maximum capacity is available constantly. The bioscrubber is expected to replace some existing biofilters that currently use activated carbon.

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 750-071/80094

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The complete report, entitled "SITE Emerging Technologies: Bioscrubber for Removing Hazardous Organic Emission from Soil, Water, and Air Decontamination Process," (Order No. PB93-227205; Cost: $19.50, subject to change) will be available only from:

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