Journal of Hazardous Materials 170 (2009) 144–150

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Effects of adsorptive properties of biofilter packing materials on toluene removal

Dong Ik Oh [a,*], JiHyeon Song [b], Sun Jin Hwang [c], Jae Young Kim [d]

[a] Korea Environmental Industry and Technology Institute, Seoul, Republic of Korea
[b] Department of Civil and Environmental Engineering, Sejong University, Seoul, Republic of Korea
[c] School of Environment and Applied Chemistry, Kyunghee University, Yongin, Republic of Korea
[d] School of Civil, Urban and Geosystem Engineering, Seoul National University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 18 November 2008
Received in revised form 27 April 2009
Accepted 28 April 2009
Available online 5 May 2009

Keywords:
Biofilter
Compost
Granular activated carbon (GAC)
Ground tire rubber (GTR)
Nutrient limitation

ABSTRACT

Various adsorptive materials, including granular activated carbon (GAC) and ground tire rubber (GTR), were mixed with compost in biofilters used for treating gaseous toluene, and the effects of the mixtures on the stability of biofilter performance were investigated. A transient loading test demonstrated that a sudden increase in inlet toluene loading was effectively attenuated in the compost/GAC biofilter, which was the most significant advantage of adding adsorptive materials to the biofilter packing media. Under steady conditions with inlet toluene loading rates of 18.8 and 37.5 g/m^3/h, both the compost and the compost/GAC biofilters achieved overall toluene removal efficiencies greater than 99%. In the compost/GAC mixture, however, biodegradation activity declined as the GAC mass fraction increased. Because of the low water-holding capacity of GTR, the compost/ground tire mixture did not show a significant improvement in toluene removal efficiency throughout the entire operational period. Furthermore, nitrogen limitations affected system performance in all the biofilters, but an external nitrogen supply resulted in the recovery of the toluene removal efficiency only in the compost biofilter during the test periods. Consequently, the introduction of excessive adsorptive materials was unfavorable for long-term performance, suggesting that the mass ratio of the adsorptive materials in such mixtures should be carefully selected to achieve high and steady biofilter performance.

1. Introduction

Vapor-phase biofilters have been used successfully in the removal of volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene, xylenes, and styrene emitted from various industrial sources [1–3]. The pollutant-removal processes in biofilters rely on sorption of VOCs followed by biological oxidation in the aqueous, biofilm phase attached to the surface of packing materials. To achieve a stable biofilter performance, therefore, it is important to choose packing materials with appropriate physical and chemical properties, as the surface of the packing materials should allow microorganisms to develop the necessary biofilm structure and should also play a role as a reservoir for moisture, nutrients, and substrate. The preferred characteristics for packing materials used in biofilter applications are: (1) large specific surface area, (2) high porosity, (3) less tendency for compaction, (4) low pressure drop, (5) low cost, (6) high water and nutrient holding capacity, and (7) appropriate adsorbing capacity [4,5].

A number of different packing materials have been studied and employed in biofilter systems for off-gas treatments [4–8], but additional optimization and improvements in efficiency are needed for large-scale applications. Compost is widely used as a packing material because it naturally provides indigenous microorganisms and essential nutrients for microbial growth. On the other hand, compost must be mixed with bulking agents such as wood chips and perlite in order to improve air and water distribution and minimize the compaction of the packing bed.

Because of its ability to adsorb large quantities of target VOCs, granular activated carbon (GAC) can be used as an additive in compost-based biofilters [8]. Furthermore, a biofilter packed with GAC alone has been suggested to treat VOCs [9]. GAC has been used in the treatment of polluted air streams to (1) improve the mass transfer of hydrophobic VOCs from the gas to the biofilm phase, (2) reduce fluctuations in the pollutant concentrations, and (3) enhance the colonization of microorganisms and biofilm formation. Abumaizar et al. [8] used a compost/GAC biofilter to remove a mixture of VOCs in the gas phase, and they reported a higher removal efficiency and stable operation. It has also been reported [10] that a GAC biofilter operated under anaerobic conditions can enhance the removal of tetrachloroethylene. Therefore, combining adsorption and biofiltration processes is believed to be a very promising method for the treatment of recalcitrant compounds. However, a disadvantage in using GAC in biofilters is that the adsorption capacity of activated carbon can be

* Corresponding author. Tel.: +82 2 380 0623; fax: +82 2 380 0699.
E-mail address: dongiko@kiest.re.kr (D.I. Oh).

0304-3894/$ – see front matter
doi:10.1016/j.jhazmat.2009.04.120

substantially reduced by water and microbial growth on its surface [1].

Besides GAC, a number of other adsorptive materials, including natural and synthetic rubbers, have been considered for various applications in environmental engineering systems. Since disposal of waste tires is an environmental problem in many countries, the possibility of recycling tires by using shredded tire strips or ground tire rubber (GTR) in various pollution-preventing applications [11] is an attractive option. GTR has already been used both as a sorption medium in a permeable reactive barrier and as a supplemental aggregate in a slurry cutoff wall for the treatment of VOC-contaminated groundwater [12]. GTR can also be a substitute for activated carbon in liquid-phase biofilters because of its low cost and moderate adsorption capacity for VOCs [13].

The objectives of this study were (1) to investigate the feasibility of mixing different adsorptive materials (i.e., GAC and GTR) with compost, the most common packing material used in vapor-phase biofilters, and (2) to provide guidelines for the selection of suitable packing materials. Additionally, the effects of adsorptive properties and nitrogen availability on biofilter performance were examined. For this study, lab-scale biofilters packed with compost and different adsorptive materials were operated for 70 days each using toluene as a model VOC.

2. Materials and methods

2.1. Packing materials and batch isotherms

The compost used in this study was made from food waste in a composting facility (Saehan Environment Work Co., Seoul, Korea). The compost was sieved through a 2-mm sieve to remove large particles and then sieved through a 1.18-mm sieve to exclude small particles before its use in the biofilters. The GTR was obtained from the Korea Resources Recovery & Reutilization Corporation (Seoul, Korea), and then it was air-dried and passed through a 0.6-mm sieve to obtain uniform particle sizes. The GAC was purchased from an activated carbon company (Samchully Co., Chonan, Korea), and it was also air-dried and passed through a 0.6-mm sieve. The physical and chemical properties of the packing materials used in this study are listed in Table 1.

Batch isotherm tests were performed to determine the packing materials' adsorption capacities for toluene vapor. The packing materials were first sterilized by autoclaving, and their moisture contents were adjusted in a range of 50–60%. The batch isotherm tests were then conducted at 20 ± 2 °C by adding two grams of the wet materials and toluene vapor at various gas-phase concentrations into a 40-mL vial equipped with a Mininert® screw cap. The vials were shaken in a tumbler at 10 rpm for one day, and headspace gas samples were taken and analyzed periodically.

Table 1
Physical/chemical properties of the packing materials used in this study.

Compost	Bulk density[a]	970 kg/m^3
	Original water content[a]	48%
	Water-holding capacity	70%
	pH	8.7
	Volatile solids[b]	82.5%
	Total nitrogen as in TKN	22,500 mg/kg
	Ammonium–nitrogen	2390 ± 80 mg/kg
	Nitrate–nitrogen	130 ± 50 mg/kg
Granular activated carbon (GAC)[c]	Bulk density	430–480 kg/m^3
	Water-holding capacity	50%
	pH	8–10
	Iodine adsorption	950 mg/g
	BET surface area	950 m^2/g
	Total pore volume	0.6–0.9 mL/g
	Average pore diameter	16–28 Å
Ground tire rubber (GTR)	Bulk density	330 kg/m^3
	Specific gravity	1.15
	Water-holding capacity	5% or less
	BET surface area	180 m^2/g

[a] Wet weight basis.
[b] Dry weight basis.
[c] Specification supplied from the producer.

Table 2
The composition of the packing materials and their volume and mass ratios in the mixtures.

Biofilter	Packing materials		
	Compost (g)[a]	Granular activated carbon (GAC) (g)[b]	Ground tire rubber (GTR) (g)[b]
CA (compost alone)	1475	–	–
CG (compost/GAC 1:1)	575	630	–
C2G (compost/GAC 2:1)	705	400	–
C4G (compost/GAC 4:1)	896	225	
CT (compost/GRT 1:1)	529	–	631

[a] Wet weight basis.
[b] Dry weight basis.

2.2. Biofilter set-up and operation

Five different mixtures of packing materials were used in the biofilter experiments: (1) compost alone (referred to as "Biofilter CA"), (2) compost and GAC mixture in a volume ratio of 1:1 ("CG"), (3) compost and GAC in a volume ratio of 2:1 ("C2G"), (4) compost and GAC in a volume ratio of 4:1 ("C4G"), and (5) compost and GTR mixture in a volume ratio of 1:1 ("CT"). The biofilter columns were packed with 2.0 L of media at an estimated bulk density of approximately 500 kg/m^3 on a wet weight basis. Table 2 lists the composition and mass ratio of each mixture in each biofilter column. Throughout the biofilter experiments, no attempt was made to inoculate the packing materials with pre-acclimated microbial cultures, so that the toluene biodegradation was carried out by microorganisms that originated from the compost. Because compost naturally contains a wide variety of essential nutrients, external nutrients were not supplied to the packing materials prior to the biofilter experiments.

Each lab-scale biofilter consisted of a 0.3-m-long stainless steel column with an internal diameter of 0.1 m. An airflow generated from a compressor was first passed through an activated carbon filter to eliminate particulates, oil, and residual organics, and then it was split into two streams. A syringe pump (Model 100, KD Scientific, USA) was used to inject research-grade pure toluene into the first air stream, while the second air stream was sparged through a 5-L column filled with distilled water to humidify the air. The two air streams were then combined and introduced into the top of each biofilter column at an air flowrate of 0.09 m^3/h, corresponding to an empty bed residence time (EBRT) of 1.6 min. All tubes and connections in the systems were made with stainless steel, Teflon, or glass to minimize toluene adsorption, and the temperature was controlled at 20 ± 2 °C. Prior to the biofilter experiments, the moisture content of filter beds was adjusted to approximately 55% on a wet weight basis. In addition to the humidification of the air stream from the bubble column, 10 mL of water was sprayed over the top of each biofilter column once a day to compensate for the water loss from the bed.

First, a series of experiments (Task I) was conducted using three biofilters packed with the various packing materials (Biofilters CA, CG, and CT) for a 70-day period. On days 0–16 (Phase I of Task I), the biofilters were started at a toluene inlet concentration of 0.5 g/m^3 (130 ppm) and an EBRT of 1.6 min, corresponding to an inlet toluene loading of 18.8 g/m^3/h. On days 17–27 (Phase II), the inlet toluene concentration introduced to each biofilter was increased to 1.0 g/m^3