Characteristics of One- & Two-Stage Biofiltration System : Removal of Volatile Organic Compounds

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Abstract

Biofiltration is a biological process which is considered to be one of the more successful examples of biotechnological applications to environmental engineering, and is most commonly used in the removal of odoriferous compounds. In this study, we have attempted to assess the efficiency with which both single and complex odoriferous compounds could be removed, using one- or two-stage biofiltration systems. The complex gas removal scheme was applied with a 200 ppm inlet concentration of ethanol, 70 ppm of acetaldehyde, and 70 ppm of toluene with EBCT for 45 seconds in a one- or two-stage biofiltration system. The removal yield of toluene was determined to be lower than that of the other gases in the one-stage biofilter. Otherwise, the complex gases were sufficiently eliminated by the two-stage biofiltration system.

Introduction

Emissions of volatile organic compounds (VOCs) can be controlled using a variety of chemical, physical, or biological technologies, including incineration, adsorption, chemical scrubbing, bioscrubbing, and biofiltration. Within the two last decades, biological treatment protocols including bioscrubbers, trickling beds, and biofilters have been employed successfully in the control of both

VOCs and odors. Biofiltration is a biological process which is considered to be one of the more successful examples of biotechnological techniques applied to environmental engineering, and has been most commonly employed in the removal of odoriferous compounds and VOCs. The contaminants are transferred from the air to the biofilm, where they are subsequently biodegraded into carbon dioxide and water. Odor and VOCs are similarly transferred from the air into a biofilm (bio-active layer) which surrounds the organic or inorganic matter in the biofilter. The odorous gases are then degraded into a variety of end products, or subsumed into the biomass. The end products appear to depend on the nature of the odors. The packing material in the biofilter also functions as a carrier for the microbes, nutrients, and water. The packing material must possess a number of characteristics in order to ensure high deodorizing performance: wide surface area for gas contact; high levels of microbial immobilization; high water retention capacity; and easy removal of deodorization wastes. Also, the carrier is required to be extremely durable, with no clogging/blocking and a low pressure drop in the packed bed during its operation. Currently, a variety of carriers which fulfill these criteria are actually in use. The objective of this research, then, was to determine the effectiveness of hydrophilic and hydrophobic VOC mixtures in biofilters packed with polyurethane foam carrier. The findings presented in this paper are focused on the performance of the biofilters operating under transient operating conditions during the start-up period, and after step changes in the biofilter inlet loads.

Materials and Methods

All of the biofilters were inoculated with a microbial consortium, primarily composed of a variety of microbes able to degrade ethanol, acetaldehyde, and toluene, and enriched from the sludge isolated from compost at composting facilities in Seosan, Chungnam, Korea. The nutrients provided for the growth and maintenance of the microbes in the biofilter was a mineral medium consisting of Basic Mineral Salt (BMS) solution supplemented with: KH_2PO_4 1.50 g/L, Na_2HPO_4 6.00 g/L, $(NH_4)_2SO_4$ 3.00 g/L, $MgSO_4$ 0.05 g/L, and $CaCl_2$ 0.01 g/L. In order to prepare the biofilter packing material, polyurethane foam was cut to pieces of 1.9cm×1.9cm×1.9cm in size, and these were used in all experiments. The biofilter was constructed from a transparent acryl tube with an inner diameter of 18 cm. This was then divided into three 80 cm sections, and each two sections were filled to a volume of 3.1 L (packing ratio 30.5%), with equal amounts of the prepared filter-bed materials. In order to control the humidity of the input gas, air was passed though a humidifier before being mixed with the prepared gas, and then the mixed gas was introduced into the bottom portion of the biofilter. The biofilter was inoculated with a microbial consortium consisting of an enriched version of that reported previously. In order to feed the microorganisms, 4×BSM nutrient solution was periodically fed into the biofilter via peristaltic pump. Water was also sprayed, in order to protect the biofilter media from drying at the upper nozzles of the reactors. The operation temperature was set to 30°C, and pH levels were not controlled. In order to determine the removal characteristics and yields at a variety of loading concentrations of mixtures of ethanol, acetaldehyde, and toluene, the mixed gases were introduced to the bottom portion of the biofilter at a variety of loading concentrations, under continuous flow conditions for a period of one month. In this system, we applied a two-stage biofilter and compared the results to those associated with the one-stage biofilter. The introduced gas mixture of ethanol, acetaldehyde, and toluene was prepared via the evaporation of a liquid solution of this mixture by flowing air, and the input concentrations were controlled with a flowmeter. Experiments concerning the removal of the gas mixtures were conducted as was previously described. The applied range of gas concentrations of the ethanol, acetaldehyde, and toluene were 50-200 ppm, 20-70 ppm, 10-70 ppm, respectively.

Both the VOCs and the odoriferous gases samples were determined with a gas chromatograph (GC-14A, Shimadzu) which was equipped with a FID. We used a DB-WAX column in this phase of the experiment (30m×0.53mm×1mm). The oven temperature was set to 50°C, and detector temperature was 200°C. Helium was used as the carrier gas, and the column flow rate was set to 8 mL/min. The air flow rate was 140 mL/min, and the hydrogen flow rate was set at 40 mL/min. A portable VOC detector (Multi gas monitor PGM-50, RAE SYSTEM, USA) was also used.

Results and Discussion

The effectiveness with which a given biofiltration protocol can effect the removal of VOCs appears to be principally dependent on the solubility of the compounds in the biofilm of the biofilter. Hence, the hydrophilic and hydrophobic characteristics of a given pollutant is thought to significantly influence the capacity of a biofilter setup to remove it. Therefore, in this paper, we attempted the removal of hydrophilic compounds with a one-stage biofilter, and tried to remove hydrophobic compounds with a two-stage biofilter. In order to model this experiment, we employed ethanol and acetaldehyde as hydrophilic compounds, and used toluene as the model hydrophobic compound. The mixture gas was then applied with the following inlet concentrations: ethanol 200 ppm, acetaldehyde 70 ppm, and toluene 70 ppm, with EBCT for 45 seconds. This part of the procedure was the same in the single- and double-stage biofiltration systems. Two identical bench-scale biofilters (Reactor I and II) were operated in parallel, in order to characterize the influence of step loads on the systems efficacy with regard to the removal of toluene, a hydrophobic VOC, and ethanol and acetaldehyde, both hydrophilic VOCs. The ethanol/acetaldehyde and toluene were introduced and stabilized in Reactors I and II, respectively. In order to stabilize the biofilter during the initial period, 20 ppm of ethanol and 10 ppm of acetaldehyde were introduced into the system (EBCT=1 min). The toluene input concentration was controlled at 10 ppm and stabilized (EBCT=2min). After the adaptation period, Reactors I and II were connected in order to simultaneously remove three odoriferous gases in a two-stage biofilter. The ethanol, acetaldehyde, and toluene were then applied to the bottom portion of Reactor I, then passed through Reactor II. The removal characteristics and yields of the odoriferous gas mixture in the two-stage biofilter are shown in Fig. 1. The removal yields of the ethanol and acetaldehyde were maintained at over 95% throughout the 6 days of processing, and after that period, input concentration and retention time of 15 sec was controlled. When we had confirmed that the removal yields of the three odor gases were maintained at over 95% for 14 days, Reactor I and II were vertically connected, and then the mixed gas was supplied to Reactor II, being passed through Reactor I. Input concentration and retention time (30 sec) were controlled. After the two biofilters had been connected, ethanol and acetaldehyde were removed at rates of over 97% and 92-98%, respectively, in all of the experimental concentrations (Fig. 1(A) and (B)). Also, the toluene removal yield was maintained at between 95-98% (Fig. 1(C)).

In order to determine the removal characteristics and yields in the one-stage biofilter, mixed odor gas (ethanol, acetaldehyde, and toluene) was applied to Reactor II, with initial input concentrations of 20, 10, and 10 ppm, respectively. During this adaptation period, the retention time was set at 3 min in order to stabilize the biofilter. After 8 days, the input concentration and retention time (30 sec) were controlled in order to determine the characteristics of the removal of the mixed odor gases. Fig. 6 lists the removal characteristics and the yields of mixed odor gas generated in the one-stage biofilter. After the completion of the adaptation period, the removal yield of ethanol was maintained at over 97% (Fig. 2(A)). Approximately 94% of the acetaldehyde was removed, and approximately 70-80% of the toluene was removed (Fig. 2(B) and (C)).

When comparing Figs. 1 and 2 the removal profiles of ethanol and acetaldehyde exhibited similar patterns in the one- and two-stage biofilters. However, the toluene removal yield was determined to be approximately 70-80% in the one-stage biofilter, but was above 95% with the two-stage biofiltration treatment. The toluene removal yield was generally lower than was that of the other gases in the one-stage biofilter. However, the gas mixture was properly eliminated by the two-stage biofilter. Our results may be attributable to the fact that, in the continuous treatment of complex odors cause by hydrophilic and hydrophobic materials, the microorganisms which feed on hydrophilic materials exhibit outgrowth in one-stage biofilters, as reported previously. This can attenuate the efficacy inherent to the treatment of hydrophobic materials in such a system. Otherwise, we found that the hydrophilic and hydrophobic compounds could effectively be removed separately by Reactor I (hydrophilic) and II (hydrophobic), in a two-stage biofiltration scheme.

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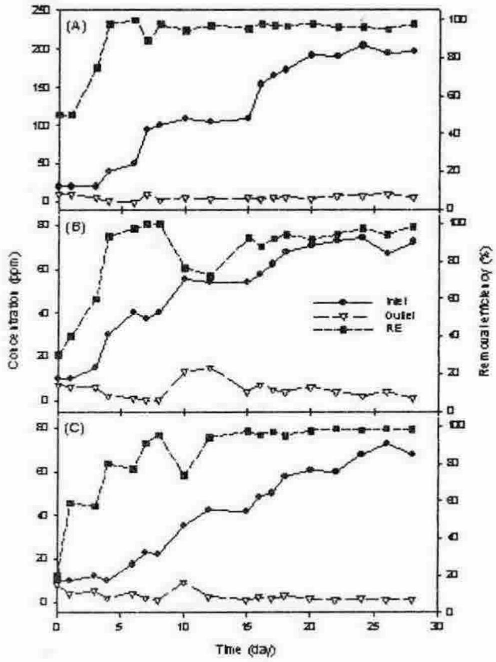

Fig. 1. Removal characteristics of ethanol, ace taldehyde and toluene in two-stage biofilter. (A) ethanol, (B) acetaldehyde, (C) toluene

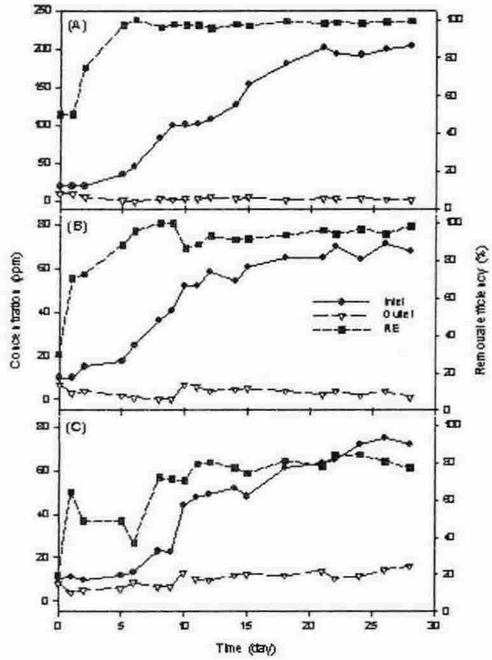

Fig. 2. Removal characteristics of ethanol, ace taldehyde and toluene in one-stage biofilter. (A) ethanol, (B) acetaldehyde, (C) toluene

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