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Interaction of gaseous aromatic and aliphatic compounds in thermophilic biofilters

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HIGHLIGHTS

- The removal performance of benzene was unaffected by the addition of hexane.
- Benzene inhibited the degradation of hexane significantly.
- Hexane had a slight effect on the microbial communities treating benzene.
- Benzene improved the microbial communities treating hexane significantly.

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ABSTRACT

Two thermophilic biofilters were applied in treating a mixture of gaseous aromatic (benzene) and aliphatic compounds (hexane) to evaluate the interaction of the compounds. The performance of the biofilters was investigated in terms of removal efficiencies, elimination capacity, kinetic analysis, interaction indices, and microbial metabolic characteristics. Results showed that the removal performance of benzene was unaffected by the addition of hexane. The removal efficiencies of benzene were maintained at approximately 80% and the biodegradation rate constant was maintained at 120 h^{-1}. However, the removal efficiencies of hexane decreased significantly from 60% to 20% and the biodegradation rate constant exhibited a distinct decrease from 93.59 h^{-1} to 56.32 h^{-1}. The interaction index of benzene with the addition of hexane was −0.029, which indicated that hexane had little effect on the degradation of benzene. By contrast, the interaction index of hexane by benzene was −0.557, which showed that benzene inhibited the degradation of hexane significantly. Similar conclusions were obtained about the substrate utilization. Moreover, the utilization degree of carbon sources and the microbial metabolic activities in the biofilter treating hexane were significantly improved with the addition of benzene, whereas the addition of hexane had a slight effect on the microbial communities in the biofilter treating benzene. Conclusions could be obtained that when mixtures of benzene and hexane were treated using biofilters, the degradation of benzene, which was more easily degradable, was dominant and unaffected; whereas the degradation of hexane, which was less easily degradable, was inhibited because of the changing of microbes.

1. Introduction

Large volumes of volatile organic compounds (VOCs) are released into the atmosphere during industrial manufacturing process every year, leading to the air quality degradation and posing hazard to public health [1]. Therefore, the increasing need for economic and sustainable technologies to reduce industrial gaseous pollutants has drawn more attention for VOC treatment [2–4]. Among the various treatment technologies, biofiltration has been widely and successfully applied for the treatment of VOCs [5–8]; this technology is highly efficient, cost-effective, and environmentally friendly [9,10]. Most of the previous studies are about the degradation performance of biofilters treating a single VOC under mesophilic conditions (20 °C to 35 °C). However, industrial stream emissions are usually mixtures of various VOCs [11] and frequently demonstrate high temperatures (40 °C to 70 °C) [12]. Therefore, examining the effects of the mixed gases on the removal efficiency (RE) of biofilters under thermophilic conditions has practical significance.

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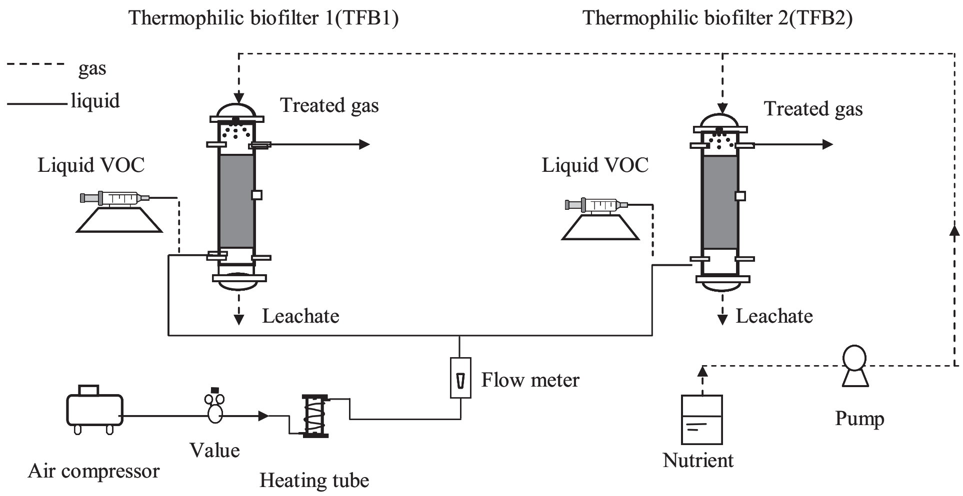

Fig. 1. Experimental setup for the biofilters.

Some previous studies have reported the feasibility of biofilters in treating VOC mixtures. Rahul et al. [13] evaluated a biofilter treating benzene, toluene, ethyl benzene, and *o*-xylene (BTEX). The results showed that the maximum RE was found more than 96% for all four compounds and a maximum elimination capacity (EC) of 61 g m^{-3} h^{-1} was obtained at inlet BTEX load of 63 g m^{-3} h^{-1}. Zamir et al. [14] investigated the performance of a biofilter subjected to periodic intermittent loads of hexane and toluene with concentrations below 4 g m^{-3}, respectively. More than 90% of the REs were reached for both the pollutants and the maximum EC was found to be 62 g m^{-3} h^{-1}. Other studies [15–17] have also indicated the effectiveness of the biofilters to handle mixtures of gas-phase VOCs.

A few further studies have shown that there were interactions of VOC mixtures when treated by biofilters. The interaction mainly presented inhibition among compounds. Research showed that the microbial metabolic activity of biodegraded acetone was inhibited by introducing methyl ethyl ketone (MEK) and was more pronounced at higher MEK inlet concentration and lower acetone inlet concentration [1,18]. Similar result was obtained in a mixing system of *n*-butanol and sec-butanol [19]. According to the study of Shim et al. [11], the addition of methyltert-butyl ether (MTBE) inhibited the degradation of benzene, toluene, xylene, and the mixture of the three gases. In some cases, stimulation in mixture systems was also observed. For instance, MTBE alone was not degraded by biofilters, but it could be co-metabolically degraded in the presence of toluene, benzene, or xylene [11]. Similarly, the presence of *p*-xylene had an enhancing effect on the RE of toluene according to the study of Gallastegui et al. [20].

However, studies on the interaction of different kinds of VOCs under thermophilic conditions are limited. The evaluation of the interaction can provide useful information and theoretical guidance regarding the treatment of different kinds of VOCs in practical projects. In addition, the enormous expense of cooling process before biological reactors seriously restricts the application of biofiltration. Direct treatment of gases under thermophilic conditions presents significant cost savings. Therefore, in the current study, aromatic (benzene) and aliphatic (hexane) VOCs were treated using thermophilic biofilters. That is mainly because aromatic and aliphatic VOCs are common gaseous contaminants and suitable for the treatment of biofilters [11–15]. Benzene and hexane is a typical aromatic and aliphatic VOCs, respectively, which are widely found in industrial air emissions such as chemical manufacturing plants and various hazardous sites [8,14–16]. The thermophilic biofilter 1(TFB1) and the thermophilic biofilter 2 (TFB2) were operated to evaluate the effects of adding hexane on benzene (TFB1) and the effects of adding benzene on hexane (TFB1), respectively, which would help discover the interaction of these compounds. The removal performance, the microbial characteristics, and the interaction between the compounds were evaluated.

2. Materials and methods

2.1. Microorganism inoculation

About 8 L of concentrated activated sludge was obtained from a sequencing batch reactor for treating municipal wastewater. The activated sludge was divided into two parts and then cultivated with 10 mL of liquid benzene and hexane every two days under aerated conditions. After 10 d of cultivation, perlite was added into the sludge, mixed to allow microorganisms to attach, and then filled into the biofilters.

2.2. Experimental set-up

The biofilters were established as shown in Fig. 1. They were identical in configuration with an internal diameter of 8 cm. The biofilters were constructed using a stainless steel and then packed with perlite up to a depth of 30 cm. A gas stream was heated to 50 °C and then fed into the biofilters.

2.3. Operating conditions

The two biofilters were continuously and separately operated for 210 d. The overall experiment included two stages treating single benzene or hexane (phase 1 and phase 2) and mixture of benzene and hexane (phase 3), respectively. The operating conditions are showed in Table1. In the phase 3, the ratio of benzene: hexane was 1: 1 by volume in both biofilters. The flow rate was

Table 1
Biofilters operating conditions.

		Inlet concentration (mg m^{-3})		
		Phase 1	Phase 2	Phase 3
TFB1	Benzene	500 ± 150	850 ± 200	500 ± 100
	Hexane	–	–	350 ± 50
	TVOC	500 ± 150	850 ± 200	850 ± 150
TFB2	Benzene	–	–	500 ± 100
	Hexane	250 ± 100	850 ± 200	350 ± 50
	TVOV	250 ± 100	850 ± 200	850 ± 150