Chemical Engineering Journal 279 (2015) 689–695

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Biofiltration performance and characteristics of high-temperature gaseous benzene, hexane and toluene

Qing-yuan Hu, Can Wang *, Kai-xin Huang

Tianjin Key Lab of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China

HIGHLIGHTS

- The biodegradation preference was toluene > benzene > hexane.
- The removal rate and the CO_2 production of the toluene biofilter were the highest.
- Toluene and benzene biofilters presented faster biomass accumulation.
- The toluene biofilter showed a higher mass distribution coefficient.
- The toluene biofilter showed a lower flooding velocity.

ARTICLE INFO

Article history:
Received 22 December 2014
Received in revised form 4 May 2015
Accepted 5 May 2015
Available online 27 May 2015

Keywords:
Biofilter
High-temperature
Benzene
Hexane
Toluene

ABSTRACT

Three biofilters were developed to treat high-temperature (50 °C) gaseous benzene, hexane, and toluene. The performance of the biofilters was investigated; the parameters included removal efficiencies, kinetic analysis, biomass accumulation, pressure drops, and leachate TOC content. Results showed that the removal efficiency of toluene was the highest (more than 90%), followed by benzene (more than 70%) and hexane (more than 50%). The mass distribution coefficients (K_m) of benzene, hexane, and toluene were 4.99, 3.50, and 6.36, respectively. And the yield coefficients (Y) were 0.91, 1.29, and 1.50 g dry biomass/g removed VOC for benzene, hexane, and toluene, respectively. A faster biomass accumulation resulted in lower flooding velocity of the biofilter treating toluene (210 m/h) than that of the biofilter treating hexane (257 m/h). The leachate from the biofilter treating toluene presented the highest TOC contents. Mass balance was similar among the three biofilters, suggesting that more than half of the removed VOCs were converted to CO_2 and about 40% were converted to biomass.

1. Introduction

Removal of volatile organic compounds (VOCs) through biofiltration is highly efficient and exhibits the advantages of low operation costs, convenient maintenance, and environmental friendliness [1–3]. Currently, biofiltration technology is mainly used to treat room-temperature (20–35 °C) VOCs [4,5]. However, many industrial streams emitted from different processes demonstrate high temperatures (40–70 °C) [6,7]. High-temperature gases are traditionally treated by cooling the exhausts below 40 °C prior to biological reactors, but this process is expensive and complex [8]. Direct treatment of gases at high temperature with thermophilic microorganisms is another option, which presents significant cost savings [9].

Few studies have been performed regarding the treatment of waste gases at high temperature. Wang et al. [6] treated gaseous toluene at 55 °C with a thermophilic biofilter (TBF) and a mesophilic biofilter (MBF). The results showed that TBF achieved a high-performance removal efficiency of 90% when the inlet loading was lower than 100 g/m^3 h. TBF also exhibited a slower accumulation process, lower pressure drop, and more stable operation than MBF. Moussavi et al. [10] investigated the removal of methyltert-butyl ether from a waste air stream by using TBF at 52 ± 3 °C and observed a removal efficiency higher than 99% with an inlet loading lower than 330 g/m^3 h. Dhamwichukorn et al. [11] examined compound removal with influent concentrations of 110 ppmv methanol and 15 ppmv α-pinene through two bench-scale TBF systems. The results showed that more that 95% of methanol and α-pinene were removed at a residence time of 18.24 min. Similarly, previous study reported that the removal efficiency of BTEX using TBF (50 °C) was approximately 100% but only

---

* Corresponding author. Tel./fax: +86 22 27406057.
E-mail address: wangcan@tju.edu.cn (C. Wang).

http://dx.doi.org/10.1016/j.cej.2015.05.019
1385-8947/

10% when MBF (20 °C) was used with an inlet loading of 213 g/m^3 h [12]. These findings indicate that thermophilic biofiltration is an effective and promising process for treatment of high-temperature waste air streams.

Previous experiments focused on removal of specific VOCs, whereas comparison of the removal characteristics of different VOCs through thermophilic biofiltration has received minimal attention. In this study, three TBFs were used to treat gaseous benzene, hexane, and toluene. Kinetic analysis, carbon dioxide production, biomass accumulation, pressure drop, total organic compounds (TOCs) of the leachate and mass balance were investigated.

2. Materials and methods

2.1. Experimental set-up

Three biofilters were established as shown in Fig. 1. The biofilters were identical in configuration with an internal diameter of 8 cm and constructed using a stainless steel. The packing chosen in this study was porous perlite (5–8 mm in diameter), which had bigger specific surface area to make microorganisms attach more easily. An air compressor was used to feed air into the biofilters, and a syringe pump (ALCBIO ALC-IP900) was used to inject liquid VOCs into the air to form VOCs gas at the desired concentrations. The inlet gas stream was heated to 50 °C and the relative humidity was 15–40%, which would be different with the change of seasons and the ambient humidity.

2.2. Microorganism inoculation

About 12 L of concentrated activated sludge was obtained from a sequencing batch reactor for treating municipal wastewater. The activated sludge was divided into three parts and then cultivated with 10 mL of liquid benzene, hexane, and toluene every two days under aerated conditions, respectively. After 10 days of cultivation, perlite was added into the sludge, mixed to allow microorganisms to attach, and then filled into the biofilters to make the packing reach a depth of 30 cm.

2.3. Operating conditions

The three biofilters were continuously and separately operated for 95 days. The operating conditions are shown in Table 1. The biofilters were supplied with 200 mL of nutrient solution in 3 min every 12 h to maintain the moisture of packing media and to supply sufficient nutrients to the microorganisms [6,13]. Solution was sprayed onto the filter beds using an electromagnetic metering pump (Iwaki, EHC-B220R, Japan) [14]. The nutrient solution was changed every 3 days. Benzene, hexane, and toluene were selected as typical VOCs to compare the different performances of aromatic and aliphatic compounds and analyze the effect of substituent on the benzene ring when treated with the biofilters [15,16].

Table 1
Biofilters operating conditions.

Parameter	Condition
Flow rate	0.2 m^3/h
VOCs concentration	Day 0–55 Benzene: 350–550 mg/m^3 Hexane: 150–400 mg/m^3 Toluene: 350–500 mg/m^3 Day 56–95 Benzene: 800–1200 mg/m^3 Hexane: 550–950 mg/m^3 Toluene: 700–1200 mg/m^3
Empty bed residence time (EBRT)	27 s

2.4. Analytical methods

VOCs concentrations were analyzed using a gas chromatograph (Beifen 3430) with an FID and a packed column (3 m × 3 mm). Nitrogen was selected as the carrier gas, while pure hydrogen and air were supplied to the FID. The temperatures of the column oven, injector, and detector were 100, 150, and 200 °C, respectively. Gas sample was obtained using the method described by Wang et al. [6].

Biomass inside the biofilters was intermittently measured using a weighing method described by Okkerse et al. [17]. The weight gain of the biofilters represented the accumulated biomass during the experiment.

CO_2 concentrations were analyzed using a CO_2 analyzer (AZ 7752), and TOCs in the leachate were measured with a TOC analyzer (Shimadzu, TOC-V_{CPH}). The pressure drop of the biofilters was monitored using a piezometer (Bolaite JJG540-88). The differences of the pressure between the import and export expressed the pressure drop of the filter bed.

2.5. Kinetic model

VOCs removal using biofiltration consists of mass transfer and degradation. The overall process includes diffusion, convection, adsorption and biodegradation. The movement of gas in the pores

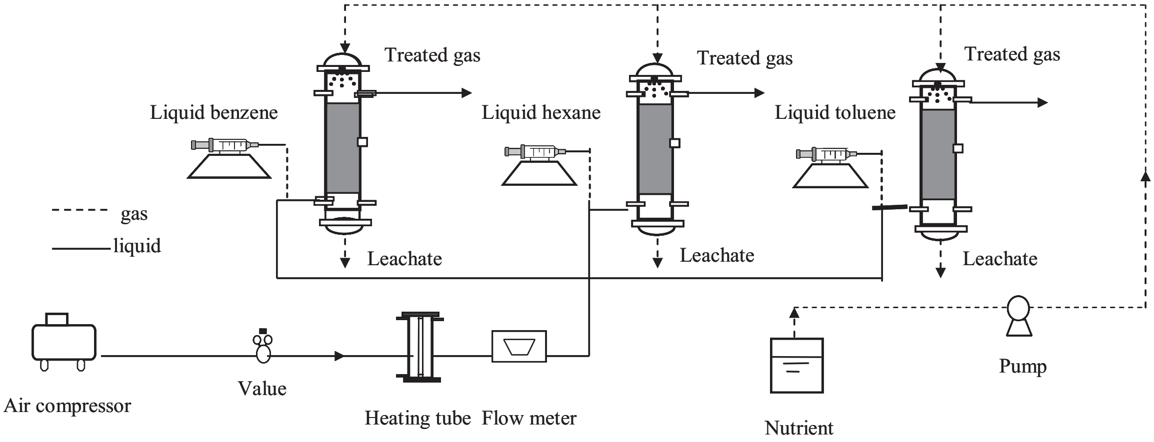

Fig. 1. Experimental setup for the biofilters.