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Effect of operating conditions on long-term performance of a biofilter treating gaseous toluene: Biomass accumulation and stable-run time estimation

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Abstract

To achieve a stable performance during long-term operation of biofiltration process, the effect and control of excess biomass accumulation should be investigated in detail. In this study, a biofilter treating gaseous toluene was operated continuously under different operating conditions for more than 270 days. Decrease in toluene removal efficiency and increase in pressure drops of the filter bed were simultaneously observed during the operation period due to excess biomass accumulation. The distributions of toluene concentration and gas pressure suggested that more biomass would accumulate in the inlet section. By carbon balance analysis, the variation of the biomass concentration in the biofilter was calculated. The variation of the biofilter performance and the biomass concentration demonstrated that 10,000 g C m^{-3} might be a critical biomass concentration for the biofilter to maintain a stable operation. An evaluation equation based on biomass growth kinetics was successfully established and used to estimate the stable-run time of a biofilter under different VOCs loadings. Bed mixing was found to be able to remove approximately 4000 g VSS m^{-3} of excess biomass and could also recover the performance of the biofilter.

Keywords: VOCs; Biofilters; Biomass accumulation; Toluene gas; Bed mixing

1. Introduction

Due to the regulation demands, waste gases treatment and control were paid more and more attention in these years. Among different waste gas treatment techniques, biofiltration were successfully applied to remove low-concentration volatile organic compounds (VOCs) or odorous pollutants in the gases emitted from different industrial or agricultural process [1]. Compared with other techniques, the advantages of biofilters are simple configuration, low capital and operation costs and minimum secondary pollution production [2].

By selecting an appropriate packing medium and optimizing the running conditions, a biofilter can gain a good performance for pollutants removal in the former operation time after startup. However, after a fairly long operation time, the pollutant removal capacity of the biofilter would sometimes decrease under constant operating conditions [3–6]. To overcome this problem and ensure a stable operation, the reasons and solutions for performance decline during long-term operation were studied by different researchers [7,8]. One reason for performance decline is nutrient limitation which often occurred when there was no enough supplementary nutrient added. Using a nutrient-rich packing medium like compost or directly supplying nutrient solutions into the filter bed by spraying could solve this problem [6]. Another reason for performance decline is bed compaction induced by deterioration of some natural organic packing media. Using inorganic packing media or adding some inorganic packing media into the organic filter bed could prevent bed compaction effectively [8]. Another possible reason for long-term performance decline is the variation of the pH values in the filter bed, which would inhibit the microbial biodegradation activity [9]. For example, the biofilters treating H_2S or chlorinated hydrocarbons would have the pH of the filter bed decrease if no buffer was added. Spraying buffer solutions to the filter bed periodically could control the pH value and overcome this problem.

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Excess biomass accumulation, which often occurred under high inlet pollutant loading, can also make a decrease in the pollutants removal capacity and an increase in higher pressure drops [7,10]. The characteristics of biomass accumulation and its effect on bed structure and biofilm property were studied by different researchers. Experimental investigation showed an uneven biomass distribution along the filter bed and more biomass would accumulate in the inlet section where most of substrate was removed. Theoretical and model analysis on bed structure demonstrated that the specific surface area and void fraction of the filter bed would decrease with increasing biofilm thickness [11,12], and channeling might occur due to non-uniform biomass growth [13]. In addition to variation in bed structures, the biofilm properties such as pollutant-degrading fraction of total microbes also changed with increasing biomass [14].

Several different methods have been developed to prevent excess biomass accumulation, which include reducing biomass production, removing produced excess biomass and optimizing biomass distribution [15,16]. Before applying the biomass control method, the effect of operating conditions on long-term performance of a biofilter should be well known and the stable-run time of a biofilter under different conditions should be estimated. Most of the experiments to date were operated under single conditions and the effects of operating conditions on biofilter's long-term performance were paid little attention. In this study, the long-term performance and the biomass accumulation process of a biofilter treating gaseous toluene were investigated under different inlet toluene concentrations and superficial velocities. Based on the experimental results, the effect of operating conditions on long-term performance of a biofilter was discussed and a simple method was developed to estimate the stable-run time of a biofilter under different VOCs loadings.

2. Materials and methods

2.1. Biofiltration systems

The diagram of the biofilter system used here was shown in Fig. 1. The biofilter column had an inner diameter of 0.12 m.

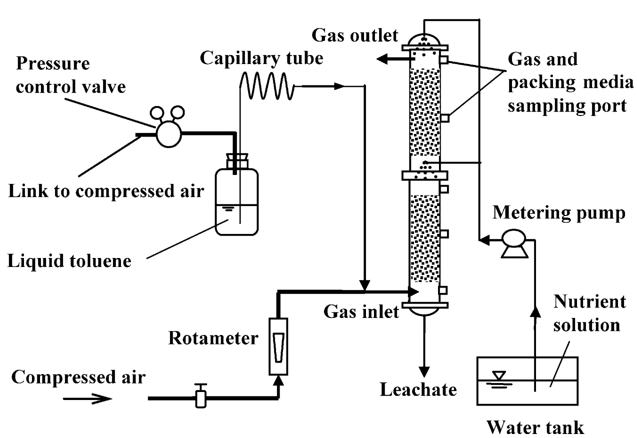

Fig. 1. The diagram of the biofilter system.

Table 1
Operating conditions of the biofilters

Operating conditions	Items	Parameter
Environmental condition	Temperature	20–25 °C
	Relative humidity	50–85%
Gaseous toluene feeding	Inlet toluene concentration	200–2000 mg m^{-3}
	Flow rate	0.27–0.54 m^3 h^{-1}, upflow
	Empty bed retention time	30–60 s
	Superficial velocity	25–48 m h^{-1}
	Loading rate	10–110 g C m^{-3} h^{-1}
Spraying	Spraying intervals	Once every 6 h, 1 min for each time
	Quantity sprayed	9–10 L m^{-2} min^{-1}

The filter bed had two layers and each layer had a height of 0.20 m. The overall volume of the filter bed was 4.5 L. Three liters of wood chips (10–40 mm length and 1–3 mm width) and 2 L propylene spheres (25 mm in diameter) were packed into the filter bed. The propylene spheres were proved to be very effective to prevent bed compaction for organic packing media in our previous study [8]. The void fraction of the filter bed was 0.60 at the beginning of the operation period.

A gas feeding apparatus was set up to produce a toluene gas with desired concentration and flow rate. The fundamental and control method of the gas feeding apparatus can be found in the literature [8]. A metering pump (Iwaki EHC-R220C, Japan) was used to send nutrient solution from a stock tank to the filter bed.

2.2. Operating conditions and experimental control

After being inoculated with 1.5 L activated sludge (MLSS = 12.5 g L^{-1}) taken from a wastewater treatment plant, the biofilter was operated continuously for more than 270 days. The operating conditions during this period are shown in Table 1. To avoid other factors except for biomass accumulation to influence the long-term performance, a nutrient solution, which contained 10.0 g L^{-1} of $NaNO_3$, 0.7 g L^{-1} of Na_2HPO_4, 0.5 g L^{-1} of KH_2PO_4 and other trace elements, was added into the filter bed from the top of the biofilter periodically to supply the microbes with enough nutrients. In addition to preventing nutrient limitation, the sprayed solution also functioned as a buffer with the existence of $HPO_4{}^{2-}$ and $H_2PO_4{}^{-}$. The leachate pH of the biofilter was kept between 6.0 and 8.5 during the operation period.

To investigate the impact of the inlet concentration and superficial velocity, the experimental period was divided into two phase. In Phase I (days 1–105), the superficial velocity remained unchanged at 27 m h^{-1} and the inlet toluene concentration varied from 200 to 2000 mg m^{-3}. In Phase II (days 106–270), the inlet toluene concentration remained between 400 and 500 mg m^{-3}, the superficial velocity varied from 25 to 48 m h^{-1}.

During the experimental period, the inlet and outlet toluene concentrations were monitored to evaluate the pollutant removal capacity of the biofilter. To investigate the biomass accumula-