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ORIGINAL ARTICLE

Performance of three pilot-scale immobilized-cell biotrickling filters for removal of hydrogen sulfide from a contaminated air steam

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Abstract Hydrogen sulfide (H_2S) is a major malodorous compound emitted from wastewater treatment plants. In this study, the performance of three pilot-scale immobilized-cell biotrickling filters (BTFs) spacked with combinations of bamboo charcoal and ceramsite in different ratios was investigated in terms of H_2S removal. Extensive tests were performed to determine the removal characteristics, pressure drops, metabolic products, and removal kinetics of the BTFs. The BTFs were operated in continuous mode at low loading rates varying from 0.59 to 5.00 g H_2S m^{-3} h^{-1} with an empty bed retention time (EBRT) of 25 s. The removal efficiency (RE) for each BTF was >99% in the steady-state period, and high standards were met for the exhaust gas. It was found that a multilayer BTF had a slight advantage over a perfectly mixed BTF for the removal of H_2S. Furthermore, an impressive amount >97% of the H_2S was eliminated by 10% of packing materials near the inlet of the BTF. The modified Michaelis–Menten equation was adopted to describe the characteristics of the BTF, and K_s and V_m values for the BTF with pure bamboo charcoal packing material were 3.68 ppmv and 4.26 g H_2S m^{-3} h^{-1}, respectively. Both bamboo charcoal and ceramsite demonstrated good performance as packing materials in BTFs for the removal of H_2S, and the results of this study could serve as a guide for further design and operation of industrial-scale systems.

1. Introduction

Hydrogen sulfide (H_2S), a highly toxic gas, is one of the major malodorous compounds emitted from wastewater treatment plants, composting plants, and food processing plants (Montebello et al., 2012; Rattanapan et al., 2009). Even though many well-established physicochemical processes are presently available for the removal of H_2S (Gabriel et al.,

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2004), they are relatively costly and ineffective in comparison with biological technologies. In contrast, biotrickling filtration has proved to be one of the most promising processes because of its low capital and operating costs, its high removal efficiency (RE), the absence of residual by-products requiring further disposal, and its public acceptance as an environmentally friendly technology (Gabriel and Deshusses, 2003; Hernández et al., 2012; Jin et al., 2005a, 2005b).

The three critical parameters for biotrickling filters (BTFs) are the packing material, operating conditions, and inoculated bacteria (Duan et al., 2007). The major function of the packing materials is to provide a biomass surface to which the active biological material can attach such that mass transfer of the gaseous effluents is enhanced. In recent years, several studies have reported the removal of H_2S from inlet gas with high H_2S concentrations using various carriers in BTFs. For instance, activated carbon is widely used as packing material for the removal of H_2S (Chung et al., 2004; Duan et al., 2006, 2007). In addition, polyurethane foam, rubber particles, wood chips, and compost are also widely used for the treatment of odorous gases from wastewater (Gabriel et al., 2004; Ma et al., 2006; Park et al., 2011; Hernández et al., 2013). Ramirez et al. (2009a) used a laboratory-scale BTFs spacked with polyurethane foam to remove H_2S and achieved a RE of almost 100% for 129 ppmv H_2S. The effects of the gas, liquid flow rate, and EBRT on the performance of a bioscrubber spacked with polypropylene pall rings for treating inlet gas with an H_2S concentration of 100 ppmv have also been investigated (Potivichayanon et al., 2006). Gabriel and Deshusses (2003) converted an existing full-scale chemical scrubber to a BTF for the removal of H_2S with gas contact times as low as 1.6 s.

Nevertheless, the removal of H_2S from inlet gases with low H_2S concentrations with a high throughput has not been studied extensively, although these conditions are closer to those encountered in practical applications. Furthermore, because of their capacity to adsorb odor pollutants and also supply nutrients for microorganisms, bamboo charcoal and ceramsite can be potentially used as high-performance packing materials. However, very few investigations of the use of bamboo charcoal for H_2S removal have been reported, and almost all previous studies have focused on single packing materials. In particular, the combination of bamboo charcoal and ceramsite has never been studied.

In this paper, the H_2S removal performance of three pilot-scale BTFs spacked with combinations of bamboo charcoal and ceramsite in different ratios was investigated. The present study focused on the operating factors and the metabolic pathways of elemental sulfur and evaluated the effectiveness of bamboo charcoal and ceramsite as packing materials for biological treatment of odor. In addition, a kinetic analysis of a BTF using immobilized bacteria was performed.

Table 1 Biomass test on the packing materials of different BTFs (number of bacteria per mass of packing materials, $\times 10^8$/g).

Location	BTF 1	BTF 2	BTF 3
Up region	49.8	49.9	51.6
Middle region	139.7	130.1	144.1
Bottom region	69.3	37.1	69.9
Average region	86.3	82.4	88.6

2. Materials and methods

2.1. Experimental apparatus and operating conditions

The experiments were performed using three pilot-scale BTFs (Fig. 1). Each BTF was made of polypropylene and had an inner diameter of 0.6 m and a height of 3 m (effective volume, 565 L). The three BTFs with different packing patterns contained (1) bamboo charcoal and ceramsite layers (BTF 1; 1:1 volume ratio; bamboo charcoal and ceramsite were placed layer-by-layer and the bottom layer is bamboo charcoal; each layer had a height of 25 cm), (2) a perfect mixture of bamboo charcoal and ceramsite (BTF 2; 1:1 volume ratio), and (3) pure bamboo charcoal packing material (BTF 3). The polluted air consisted of fresh and polluted air from a wastewater lift station and was supplied with an air compressor. The flow rates and inlet concentrations were automatically controlled via regulators on the pipes for fresh air and polluted air. The inlet gas was fed to the bottom of each BTF at a constant flow rate of 80 $m^3\,h^{-1}$, while the solution was sprayed downward for down flow-mode of operation. The system was operated at room temperature (20–25 °C) throughout the experimental period. The inlet and outlet H_2S concentrations were measured periodically, and percolate from the bottom of each BTF was evaluated to determine its pH and sulfate concentration. In addition, the outlet H_2S concentrations were determined at several sample points at different heights on BTF 3 to study the utilization rate of the packing materials.

2.2. Packing materials

The structures of bamboo charcoal and ceramsite were observed using a scanning electron microscope (SEM) (S-4800, Japan) to identify their potentials as high-performance packing materials. The densities of bamboo charcoal and ceramsite were 900 and 400 $kg\,m^{-3}$, and their specific areas (A_{sp}) were 4490 and 859 $m^2\,kg^{-1}$, respectively. Furthermore, the average pore sizes were 45 and 420 μm, respectively.

2.3. Enrichment of microbial consortium

Sulfide-oxidizing bacteria (SOB) were obtained from the activated sludge stream of a secondary sedimentation tank at a local wastewater treatment plant. In the experiments, 40 L/day of activated sludge was sprayed at the top of each BTF for 20 d. The medium prepared for the cultivation of the bacteria contained the following: 5 $g\,L^{-1}$ $Na_2S_2O_2{\cdot}5H_2O$, 1.5 $g\,L^{-1}$ KH_2PO_4, 1.5 $g\,L^{-1}$ K_2HPO_4, 0.4 $g\,L^{-1}$ NH_4Cl, 0.2 $g\,L^{-1}$ $MgCl_2{\cdot}6H_2O$, and 3.1 $g\,L^{-1}$ glucose. The nutrient solution was sprayed for 2 min from the top of the BTFs at a rate of 2 $m^3\,h^{-1}$ at intervals of 60 min, discharged from the bottom, and did not cycle.

2.4. Analytical methods

The inlet and outlet H_2S concentrations were determined by an online H_2S monitor (DR70C, China) and a portable H_2S