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Biological treatment of H_2S using pellet activated carbon as a carrier of microorganisms in a biofilter

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ABSTRACT

Biological treatment is an emerging technology for treating off-gases from wastewater treatment plants. The most commonly reported odourous compound in off-gases is hydrogen sulfide (H_2S), which has a very low odor threshold. This study aims to evaluate the feasibility of using a biological activated carbon as a novel packing material, to achieve a performance-enhanced biofiltration processes in treating H_2S through an optimum balance and combination of the adsorption capacity with the biodegradation of H_2S by the bacteria immobilized on the material. The biofilm was mostly developed through culturing the bacteria in the presence of carbon pellets in mineral media. Scanning electron microscopy (SEM) was used to identify the biofilm development on carbon surface. Two identical laboratory scale biofilters, one was operated with biological activated carbon (BAC) and another with virgin carbon without bacteria immobilization. Various concentrations of H_2S (up to 125 ppmv) were used to determine the optimum column performance. A rapid startup (a few days) was observed for H_2S removal in the biofilter. At a volumetric loading of 1600 $m^3 m^{-3} h^{-1}$ (at 87 ppmv H_2S inlet concentration), elimination capacity of the BAC (181 $gH_2S\, m^{-3} h^{-1}$) at removal efficiency (RE) of 94% was achieved. If the inlet concentration was kept at below 30 ppmv, high H_2S removal (over 99%) was achieved at a gas retention time (GRT) as low as 2 s, a value, which is shorter than most previously reported for biofilter operations. The bacteria population in the acidic biofilter demonstrated capacity for removal of H_2S in a broad pH range (pH 1–7). There are experimental evidences showing that the spent BAC could be re-used as packing material in a biofilter based on BAC. Overall, the results indicated that an unprecedented performance could be achieved by using BAC as the supporting media for H_2S biofiltration.

1. Introduction

Biological treatment processes are promising techniques and have wide applications in odourous air pollution control. The selection of an appropriate packing media is essential to the overall odor removal performance of a bioreactor system, which is generally believed to depend primarily on the type of packing medium (Luo, 2001). Packing medium should have a high surface area, high air and water permeability, and provide a good surface of microbial growth (Elias et al., 2002). It also plays an important role in air and water distribution, as well as mass transfer (Yang et al., 2000). So

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far, few examples were methodically reported about the relationship between the characteristics of packing material and bioreactor performance (Higuchi et al., 2000).

Packing materials used up to date include either natural materials (Cho et al., 2000; Smet et al., 1996; Yang and Allen, 1994a) such as soil, compost, peat, wood chips, and lava rock, or synthetic materials (Gabriel and Deshusses, 2003a; Kinney et al., 1996; Koe et al., 2001; Sorial et al., 1998) such as ceramic saddles, polyethylene pall rings, polyurethane foam, activated carbon, and extruded diatomaceous earth pellets. Natural materials such as compost and wood chips could be used but the surface-to-volume ratios are low which results in low volumetric reaction rate (Cho et al., 2000). Large footprint is generally required for natural materials and upgrading is difficult if flows increase due to the process expansion. For a long-term operation, settling of media might cause channeling thus reducing performance over time. Organic media also need to be replaced after 3–5 years, and they are difficult to be regenerated (Gabriel and Deshusses, 2003a). On the other hand, although humidified air must be used and nutrients must be supplied, the use of synthetic packing media has advantages, such as low head losses due to larger interstices between packing granules or pieces, larger specific surface areas, and solid phase adsorption of contaminants (Martin et al., 2002).

Among synthetic packing media, activated carbon has been the most extensively used material for physical adsorption of odor. However, its limited capacity and high cost prevents carbon from being a broader application. Biological systems that employ biological activated carbon (BAC) for the treatment of organic pollutants in water, wastewater, or air have been known to exhibit superior performances (Ehrhardt and Rehm, 1985; Li et al., 2002a; Liu and Barkley, 1994). The major function of activated carbon is to support the microorganisms and act as a buffer for fluctuating loading though biofilm might hinder the carbon adsorption. The enhanced performance may be manifest in higher removal efficiency compared to conventional biological systems, shorter acclimation periods of the microorganisms in the system, and lower pollutant concentration in the effluent during step increases in the influent pollutant concentration (Voice et al., 1992). Activated carbon as a filter material mixed with other materials (mostly compost) performed successfully in some biofilter applications (Abumaizar et al., 1998; Mohseni et al., 1998). Although some studies on organic pollutants treatment using BAC have been reported, further investigation is still needed using carbon as packing media for bacteria immobilization, particularly for the application of BAC in biological deodourisation processes. BAC should provide a more efficient odor treatment compared to other conventional media, but supporting data for this assumption is not sufficient yet.

In this research, a laboratory-scale cylindrical biofilter system was set up to investigate the performance of BAC (e.g., elimination capacity, removal efficiency). Various operating parameters were studied including H_2S inlet concentration, gas retention time (GRT), gas flow rate, and frequency of system irrigation, etc. Spent activated carbon (SAC; saturated with H_2S) was also investigated, targeting at the potential re-use or bio-regeneration. Scanning electron microscopy (SEM) was used to observe the biofilm development on the activated carbon.

2. Materials and methods

2.1. Activated sludge acclimation

An acclimated activated sludge was used in this work rather than the activated sludge itself for a quick system set up. It was prepared using a normal activated sludge acclimated to Thiosulphate (TS) medium for 5 days, and transferred to a fresh medium after the 5-day acclimation. The composition of TS medium is as follows: $Na_2S_2O_2 \cdot 5H_2O$, $10\,g\,L^{-1}$; KH_2PO_4, $1.5\,g\,L^{-1}$; K_2HPO_4, $1.5\,g\,L^{-1}$; NH_4Cl, 0.4 g; $MgCl_2 \cdot 6H_2O$, $0.8\,g\,L^{-1}$; $CaCl_2 \cdot 2H_2O$; $0.05\,g\,L^{-1}$; cycloheximide (anti-fungus reagent), $0.05\,g\,L^{-1}$ (pH = 6.8 ±0.2). Sulfide oxidizing bacteria were obtained from a return activated sludge stream at the secondary sedimentation tank at a local wastewater treatment plant. After acclimatization for about 15 days (2 transfers), the bacteria seeds were ready for inoculating onto the activated carbon bed.

2.2. Biofilter system

A laboratory-scale biofilter system was designed and constructed. It consisted of parallel dual vertical columns, which could be operated simultaneously and controlled separately (Fig. 1). The packing material (Calgon AP460) was placed in a transparent and rigid Perspex tubing, which has an inner diameter of 3.6 cm and a height of 30 cm. The carbon bed was packed inside the tubing to a height of 20 cm and yielded 0.2 L of packing volume. The packed material was supported by a plastic sieve plate to ensure a homogeneous distribution of the inlet gas across the bed. In this work, columns A and B are distinguished by whether the carbon bed is immobilized with bacteria or not. The composition and physical properties of the columns are summarized in Table 1.

Sampling ports are located along the column for gas sampling and pressure measurements. The individual sampling ports are identified based on their locations along the biofilter column as inlet, 5, 10, 15 cm and outlet ports. In this study, most of samplings were conducted at outlet, except for several points where 10 cm sampling port was used dealing with short GRTs (at 1 s). The humidified air stream was prepared by blowing air through a gas wash bottle that contains water (the humidification chamber). Moreover, the bed was irrigated twice a day by submerging the bed in culture medium for 10 min and then releasing the solution. The desired H_2S inlet concentration was adjusted by the needle valve at the outlet of the 5% H_2S gas cylinder (balanced in N_2, Linde Gas Singapore Pte Ltd). Foul gas (containing various concentrations of H_2S) flow rates were controlled and measured using AALBORG (Orangeburg NY, USA) flow meters with units of $L\,min^{-1}$ located at the inlet of the wash bottle, blowing upward from the bottom inlet into the biofilter. Two additional pressure ports were installed at the top and bottom of the column in order to