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Microbial populations analysis and field application of biofilter for the removal of volatile-sulfur compounds from swine wastewater treatment system

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Abstract

A biofilter packed with granular activated carbon (GAC) was applied to eliminate volatile-sulfur compounds (VSC) emitted from solid–liquid separation tank in swine wastewater treatment system. Hydrogen sulfide, methanethiol, dimethyl disulfide, and dimethyl sulfide were effectively reduced to 96–100% at gas residence times of 13–30 s. Elemental sulfur and sulfate are their primary oxidation metabolites. Regarding odor, an average of 86% reduction was achieved at short residence time (13 s). In addition, bioaerosol emissions could also be effectively reduced by 90% with the biofilter. Advantages of the system include low moisture demand, low pressure drop, and high biofilm stability. Further characterization of bacterial populations of the activated carbon samples using the fluorescent in situ hybridization (FISH) technique revealed that *Pseudomonas* sp. remained the predominant community (56–70%) after long-term evaluation of 415 days.

Keywords: Hydrogen sulfide; Methanethiol; Dimethyl sulfide; Dimethyl disulfide; FISH

1. Introduction

During the last decades, three-step piggery wastewater treatment (TPWT) system, which consists of solid/liquid separation, anaerobic and aerobic procedures, has been successfully introduced to treat swine wastewater [1]. However, malodorous gases are most usually emitted from solid–liquid separation tank in swine wastewater treatment system. The most frequently studied odorants are ammonia (NH_3) and volatile-sulfur compounds (VSC) containing hydrogen sulfide (H_2S), methanethiol (MT), dimethyl sulfide (DMS), and dimethyl disulfide (DMDS) because of their toxicities and lower odor thresholds [2,3].

In recent years, biofiltration in treating low concentration air pollutants has been extensively investigated because of their low capital and operating costs. The field application of biofilters in reducing NH_3 gas has also been investigated, and NH_3 emission has been successfully treated [4,5]. In contrast, most reports regarding the reduction of these VSC have only been undertaken in laboratory-scale biofilters under constant operating conditions [6,7]. Until now, little research have been carried out on the field application of biofilters to treat complicated and mixed VSC since it is hindered by high complexity and instability.

The previous reports have shown that H_2S is easily biodegraded due to its high solubility [8]. For other relatively insoluble and slowly biodegradable VSC, longer gas residence times (>120 s) were required to obtain high removal efficiency (>90%) [9]. Although several types of packing media such as compost [10] and peat [11] in biofilters have been used for VSC reduction in the laboratory and optimal performances (∼90%) have been achieved, the major constraint on biofilter application is frequent media replacements as a result of aging or deterioration [12].

In the last decade, GAC has been used successfully as a good packing material because of the advantage of rapid pollutant adsorption followed by slow release for biodegradation by microorganisms, and a higher removal capacity was achieved in our previous studies [13,14]. However, the GAC system lacked a long-term evaluation in the field applications for VSC reduction. Therefore, the objective of this study is to examine the performance of the biofilter using GAC with immobilized *Pseudomonas* sp. to treat VSC emission from solid–liquid separation

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tank in swine wastewater treatment system at gas residence times of 13–30 s. The FISH method was used to further characterize bacterial populations and bioaerosol reductions. Operational parameters such as gas residence time and inlet concentration of VSC were conducted because the fluctuations of VSC concentration were usually associated with the nature of field operation. Other measured parameters such as pH, metabolites, pressure drop, and moisture content were monitored. The results of FISH study could enhance our understanding of bacterial diversity of biofilms in the biofilter and provide a better basis for understanding the performance and stability of VSC, odor or bioaerosol reduction after long-term evaluation of 415 days.

2. Materials and methods

2.1. Microbial culture and medium

Pseudomonas sp. was isolated from piggery wastewater and enriched in nutrient broth at 26 °C. *Pseudomonas* sp. could be a potential microorganism to utilize some VSC from the laboratory experiments (data not shown). Because a better VSC removal efficiency was obtained when *Pseudomonas* sp. grew on glucose medium compared with other carbon sources (sucrose, fructose, and molasses), glucose was used as a carbon source for microbial growth and VSC removals in this study. In all experiments, an inflow medium containing glucose 10.0 g/L, KH_2PO_4 4.08 g/L, K_2HPO_4 5.22 g/L, NH_4Cl 0.4 g/L, $MgCl_2{\cdot}6H_2O$ 0.2 g/L, and Fe(III)-citrate 0.01 g/L was supplied and stored in the nutrient tank. The final pH was adjusted to 7.0 by using 0.1 N NaOH or HCl.

2.2. Immobilization procedure

GAC with a particle size of 4.5 mm was used as the packing material, and its detailed characteristics were described by Chung et al. [13]. *Pseudomonas* sp. was grown in 10-L nutrient broth for 2 days and was harvested by centrifugation ($8000 \times g$ for 10 min). The pellets were resuspended with 100-L nutrient broth and mixed with about 70-kg of GAC in a 200-L PVC tank. Fresh broth was added once every 3 days until the bacterial count reached nearly 10^8–10^9 CFU/g dry GAC, and then the cell-laden GAC was packed into the biofilter. In addition, all materials and equipments were maintained in aseptic conditions during the above experimental period.

2.3. Experimental setup and operation

The design of the biofilter is shown in Fig. 1. It was installed on a swine farm in the Miaoli County of Taiwan. Two PVC columns (diameter 0.48 m, height 0.5 m) connected in series were packed with GAC immobilized *Pseudomonas* sp. and supported by a perforated sieve at the bottom of each column. The packed volume and weight of GAC in each column was 72.3 L and 34.7 kg, respectively. The column wall contained two types of sampling ports namely GAC and gas samplers. Malodorous gases was exhausted by a fan from solid–liquid separation tank in swine wastewater treatment system and then flowed downward

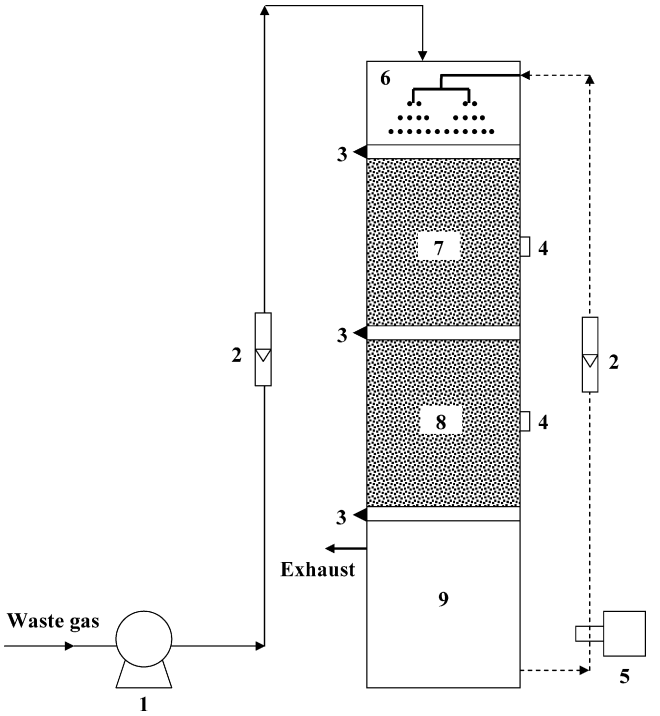

Fig. 1. A schematic diagram of the biofilter: (1) exhaust fan; (2) flow meter; (3) gas sampler; (4) GAC sampler; (5) peristaltic pump; (6) sprinkler zone; (7 and 8) column 1 and column 2 of the biofilter inoculated with *Pseudomonas* sp.; (9) nutrient tank.

through the top of the biofilter; gas flow rate was controlled by a flow meter. The inflow medium stored in a nutrient tank (diameter 0.48 m, height 0.6 m) located at the bottom of the biofilter was recycled by a peristaltic pump at 5 L/min for 10 min, six times a day. The peristaltic pump was connected to a spray nozzle located at the top of the biofilter to spray the medium uniformly on the GAC surface. The solution volume was periodically maintained at 70 L by adding distilled water and fresh inflow medium, and 0.1% of glucose was supplied once weekly. To estimate the operating performance of the biofilter for VSC removals, waste gases were supplied to the system at various empty bed gas residence times (EBRTs) in the range of 13–30 s. The EBRT was defined as the volume of the packed bed section divided by the gas flow rate.

2.4. Analytical methods

Hydrogen sulfide and methanethiol concentrations were analyzed by using a gas chromatograph (GC) coupled to a flame photometric detector (FPD) and a 30-m HP-1 column (Hewlett Packard, USA) with detection limit of 20 ppb [15]. Dimethyl sulfide and dimethyl disulfide concentrations were measured by GC coupled to a flame ionization detector (FID) and a 50-m Ultra-2 column (Hewlett Packard, USA) with detection limit of 50 ppb [16]. To avoid a superposition by a temporal effect, the measurements of pressure drop and moisture content of GAC were performed 2 h after liquid recirculation had occurred. The pressure drop across the biofilter was measured using a U-tube water manometer in mm-H_2O/m-filter height. GAC moisture