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Odorous composting gas abatement and microbial community diversity in a biotrickling filter

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ABSTRACT

This study aimed to remove complex odorous gas produced from composting using a biotrickling filter and to observe the temporal and special distributions of bacteria, fungi, and actinomycetes. The removal efficiencies of the total volatile organic compounds (TVOC) were 26.1% and 81.5% before and after inoculation of volatile organic compounds (VOC)-degrading microbes, respectively. Especially trimethylamine was 100% degraded. In the first and second composting period, the odor reduction efficiencies showed average values of 86.2% and 94.5%, respectively. The total average of the bacteria in the biofilm was 2.06×10^9 CFU/g TS, which was 22.2% higher than that of the control (the culture of microbes prior to the inoculation of VOC-degrading microbes). The bacteria may have played a predominant role in odor removal. The total average of the fungi in the biofilm was 9.64×10^6 CFU/g TS, which was only 6.40% of the control. The total average of the actinomycetes in the biofilm was 5.10×10^5 CFU/g TS, which was 5.63 times higher than that of the control. Findings from this study showed that usage of a biotrickling filter is a promising process for the treatment of complex odorous gas.

1. Introduction

Odorous gas emitted from composting facilities has complicated components, which necessitate efficient, environment-friendly, and cost-effective treatments. The main components (i.e., pollutants) of the odorous gas are (1) nitrogen-containing compounds, such as NH_3 (Komilis and Ham, 2006) and N_2O (Fukumoto et al., 2003); (2) sulfur-containing compounds, such as H_2S; (3) volatile organic compounds (VOC) (Akdeniz et al., 2010); and (4) bioaerosols (i.e., principally airborne microorganisms and microbial constituents released from composting processes where movement of material is involved) (Sanchez-Monedero et al., 2003). In addition, the components and their concentrations exhibit significant changes at different composting stages.

The physicochemical properties of odorous gas are diversified. Easily and adversely biodegradable matters coexist, and some are either hydrophilic or hydrophobic. Hydrophilic substances have diverse solubilities in water. Hydrophobic substances are not readily available to microorganisms, and thus inadequate for use in biological treatments (Hassan and Sorial, 2010). These properties demonstrate that effective treatment of odorous gas is difficult.

In the last few decades, emission control of VOC and other odorous pollutants has become a crucial issue owing to their adverse effects to humans, animals, and the environment. Most VOC are toxic and carcinogenic substances; thus, loss of these substances to the ambient air may have an adverse impact on air quality and endanger public health (Yoon and Park, 2002). Anthropogenic activities will influence the conversion of natural VOC into condensable vapors to generate natural aerosols and thus, further affect climate (O'Dowd et al., 2002). Therefore, it is very important to develop effective technologies to remove these compounds to preserve human health and the environment.

Trimethylamine (TMA), one of VOC is a malodorous aliphatic amine frequently identified in gaseous emissions of multiple industrial and agricultural processes. Compared with ammonia, TMA can be perceived and detected at greater distances because of its characteristics, including persistent intensive odor and very low odor detection thresholds (Goldstein, 2002). TMA poses serious

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ecological and environmental issues and is a strong environmental pollutant. Health effects associated with inhalation of TMA include irritation of the respiratory tract, eyes, and skin. Consequently, the sensitive determination of TMA in atmospheric and human work environments is of great importance (Cháfer-Pericás et al., 2004). Thus, TMA and other VOC disposal through usage of a biotrickling filter (BTF) was studied in this paper.

Biological processes for odor treatment, including bioscrubbers, biofilters, and biotrickling filters, are promising odor abatement technologies that take advantage of the ability of microorganisms to remove substrates from odorous organic compounds (Canovai et al., 2004). Their development owes its increasing popularity to two of its advantages: (1) It is operated at ambient temperatures (15–30 °C); (2) It does not produce toxic by-products (Delhoménie et al., 2002). In a biotrickling filter, waste air streams pass through a packed bed of synthetic inert material where particular microbes are immobilized to form a thin aqueous layer (biofilm) (Zilli et al., 2007). Biofilters are more popular than biotrickling filters in the treatment of odorous composting gas. The latter are more complex and more expensive than biofilters but are usually more effective, especially in the treatment of compounds that are difficult to degrade or those that generate acidic by-products, such as H_2S (Cox and Deshusses, 2000).

Biotrickling filters have seldom been used to treat waste-composting gas. The reason biotrickling filters are preferred over biofilters is that they contain trickling liquid which helps avoid dryness of the packing material and allows removal of metabolites produced during degradation which can then be recycled. Smits et al. (1995) applied a biotrickling filter to treat ammonia and odor from a composting facility. The biological elimination capacity was 4 g $NH_3/(m^3 \cdot h)$, and the odor removal efficiency was 50% for odor loads as high as 5 o.u./$(m^3 \cdot s)$. Pei et al. (2008) revealed that a constant TVOC removal efficiency, an odor concentration above 70% and a maximum elimination capacity of 130 g/$(m^3 \cdot h)$ can be achieved. Mao et al. (2006) found that biotrickling filters have better deodorization capability for odor from food waste-composting plants than the biofilter and the chemical scrubber with deodorization efficiencies measured according to odor concentrations of 82%, 59%, and 45%. It is expected to improve biotrickling filter removal efficiency of the odor concentration.

Although the performance of biotrickling filters depends on the type of microorganisms present, reports on the microbial community in biotrickling filters remain scarce. Inside the biofilm of biotrickling filters or biofilters, biodegradation is mediated by mixed cultures of bacteria, fungi, actinomycetes, and algae, all thriving in a complex ecosystem. Secondary pollutant degraders and predators, such as protozoa, metazoan, and other higher organisms, are also included. Investigating changes in the microbes in biotrickling filter will promote research on the microbial degradation mechanism, optimization of design and operation of biotrickling filters.

This study aims: (1) to gain an insight into how a biotrickling filter effectively eliminates complicated composting gas; (2) to determine the removal efficiency of biotrickling filter for odor concentration; and (3) to find out the spatial and temporal distribution of microbial community in biotrickling filter.

2. Materials and methods

2.1. Equipment

The composting reactor schematic representation and the biotrickling filter setup are shown in Fig. 1. The upper part of the filter was the biotrickling section, with a working volume of 5.0 L. A perforated plexiglass plate, which served as gas and liquid distributor, was placed at the bottom of the biotrickling section. Packing material was supported on the plexiglass plate. About 1.8 L of trickling liquid in the holding tank was fed by a pump to the top of the BTF. It trickled through the packing material to the liquid distributor. The inlet gas pipe of the biotrickling filter was placed under the trickling liquid, which formed the scrubber section, to employ the absorption capacity of trickling liquid. The properties of the packing material, the operation of the composting bioreactor, and other specifications were given by Xue et al. (2010).

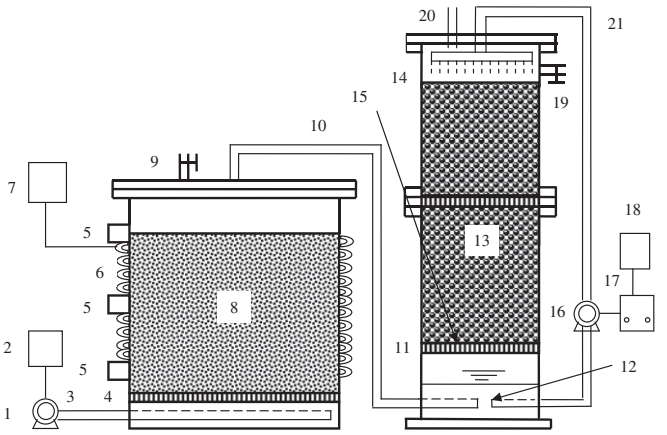

Fig. 1. Composting reactor schematic representation and the biotrickling filter setup. (1) Air compressor; (2) time relay; (3) composting air inlet pipe; (4) perforated plate; (5) composting sampling port; (6) heating belt; (7) automatic temperature controller; (8) composting reactor; (9) composting exhaust gas sampling port; (10) BTF air inlet pipe; (11) perforated plate; (12) trickling liquid holding tank used as scrubber section; (13) biotrickling section of BTF with packing; (14) BTF; (15) liquid distributor; (16) micro pump; (17) voltage- and current-steady power supply; (18) time relay; (19) gas sampling port; (20) air exhaust; (21) trickling liquid pipe.

2.2. Gas sampling and analysis

Sampling ports were set on top of the composting bioreactor and on each section of the biotrickling filter. Gas samples were collected from the inlet and outlet streams using a gas sampler (Model QS-1S, Beijing Municipal Institute of Labor Protection, China). Trimethylamine was transferred into an aqueous solution and then analyzed using the picric acid spectrophotometric method (SBPCI, 1999). Hydrogen sulfide was determined using gas-detection tubes made by the Beijing Municipal Institute of Labor Protection, China. TVOC was analyzed using gas chromatography (Perkin Elmer clarus600Gc-Turbomatrix ATD650, column: Elite-624 30 m*320 μm, detector: FID) at the Center for Test of Environmental Quality, Tsinghua University, China (EBSEPA, 2003). Odor concentration (without unit) was measured through olfactometry, in accordance with the triangle odor bag method (SEPA, 1993). Ammonia was determined according to Nessler's reagent colorimetric method (SEPA, 1993) (SEPA etc. are abbreviations of corresponding organisms who issue the methods).

2.3. Enrichment and screening of VOC-degrading microbes

The selective inorganic salt medium consisted of the following (per liter): NaCl 1.0 g, $MgSO_4 \cdot 7H_2O$ 0.7 g, NH_4C1 1.0 g, KCl 0.7 g, KH_2PO_4 2.0 g, Na_2HPO_4 3.0 g, and pH 7.0. A trace element solution was added after autoclaving. The trace element consisted of the following (per liter): $CaCl_2$ 0.2 mg, $FeCl_3 \cdot 6H_2O$ 0.5 mg, $CuSO_4$ 0.005 mg, $MnCl_2 \cdot 4H_2O$ 0.005 mg, and $ZnSO_4 \cdot 7H_2O$, 0.1 mg (Wang and Shao, 2006).

The microbial enrichment medium consisted of 1 g of peptone +1 L of selective inorganic salt medium.