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Comparative elimination of dimethyl disulfide by maifanite and ceramic-packed biotrickling filters and their response to microbial community

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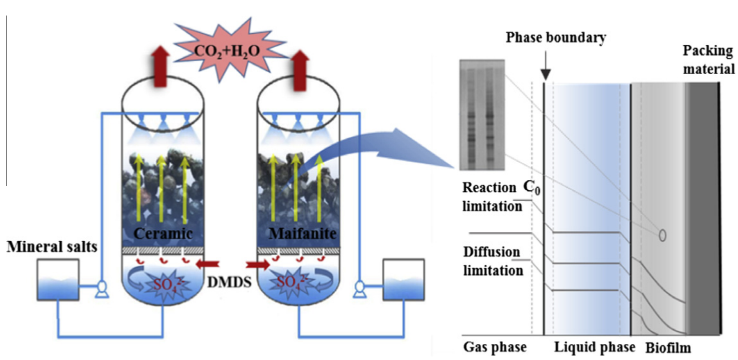
HIGHLIGHTS

- The seeded GIGAN2 became dominant species after 45 days accumulation in twin BTFs.
- Higher ECs and REs were achieved in maifanite-packed BTF than ceramic-packed BTF.
- Max EC in BTF with maifanite (19.0) is higher than ceramic (16.6 g m^{-3} h^{-1}).
- Higher abundance of GIGAN2 on maifanite proved its higher DMDS removal capability.

GRAPHICAL ABSTRACT



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ABSTRACT

Unpleasant odor emissions have traditionally occupied an important role in environmental concern. In this paper, twin biotrickling filters (BTFs) packed with different packing materials, seeded with *Bacillus cereus* GIGAN2, were successfully constructed to purify gaseous dimethyl disulfide (DMDS). The maifanite-packed BTF showed superior biodegradation capability to the ceramic-packed counterpart in terms of removal efficiency and elimination capacity under similar conditions. At an empty bed residence time of 123 s, 100% of DMDS could be removed by maifanite-packed BTF when DMDS inlet concentration was below 0.41 g m^{-3}. To achieve same effect, the inlet concentration must be lower than 0.25 g m^{-3} for ceramic-packed BTF. The bacterial communities analyses found higher relative abundance of GIGAN2 in the maifanite-packed BTF, suggesting that maifanite is more suitable for GIGAN2 immobilization and for subsequent DMDS removal. This work indicates maifanite is a promising packing material for real odorous gases purification.

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1. Introduction

Volatile organic sulfur compounds (VOSCs) are the primary irritants and one of the most offensive malodorous pollutants. They have attracted much attention in recent decades due to their adverse effects on human health (Wu et al., 2010) and their atmospheric chemistry activity relevant to the formation of sulfate aerosols (Andreae and Crutzen, 1997; Rumsey et al., 2014). The VOSCs mainly emitted from pulp and paper facilities, municipal sewage treatment plants, food industries and agricultural production processes can cause serious annoyance to

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adjacent residents even in trace-level concentrations due to very low sensory thresholds (Li et al., 2015; Luvsanjamba et al., 2008). As a typical VOSC, dimethyl disulfide (DMDS) possesses the lowest threshold value of 0.1 $\mu g\ m^{-3}$ among all odorous compounds and can cause fatigue, dyspnea, and upper respiratory tract irritation experiences at high concentration (Wan et al., 2011). In addition, it is also potentially related to the disturbance of human heme synthesis system (Klingberg et al., 1988). Thus, it is very meaningful and essential to develop safety and effective ways to remove this kind of compounds from waste gas effluents.

To eliminate the VOSCs threat, every relevant discharge should be subject to scrutiny and various treatment, and disposal technologies are also needed to be employed in industrial sites. Conventional control methods such as adsorption, condensation and thermal incineration are mainly based on physicochemical or chemical processes, which just simply transfer pollution sources from gas phase to liquid or solid phase, and need further processing (Ralebitso-Senior et al., 2012). Moreover, these traditional approaches show efficient and economical merits merely for the high-concentration pollutants. However, in the most cases, the VOSCs-contaminated gas was emitted with high-flow gas streams but at low concentrations, which are more preferred for the biological degrading processes (Jin et al., 2007). Biofiltration technologies have been attracting much attention definitely due to their cost-efficient, sustainable and environmentally friendly characters (He et al., 2009). Among them, biofilters and biotrickling filters (BTFs) are the most ubiquitously used and promising biotechnologies, while bioscrubbers are less popular since they require to dissolve gaseous pollutants in the short residence time and is less suitable for less water-soluble compounds. However, most of the target VOCs are volatile and less water-soluble (Shareefdeen and Singh, 2005). Generally, biofilters use organic materials as packing material with nutrient solution added periodically. Whereas, recirculated nutrient solution is trickled continuously in BTFs. More importantly, BTFs normally require inert packing material to avoid bed compaction and subsequent sharply elevated gas pressure drop, which frequently occur in biofilters during the operation processes (Ding et al., 2011). Furthermore, the continuous trickling model of BTFs can also prevent the packing bed from drying and enhance the renewal rate of biofilm. A great majority of BTFs are proved to be more efficient than conventional biofilters because of their higher maneuverability of operating conditions with respect to long-term operation, especially when the pollutants are degraded with acids released such as chlorine-based and sulfur-based volatile organic compounds (Cox et al., 2002).

Packing material and metabolic population are the key factors to determine the biodegradation performance in BTFs (Ralebitso-Senior et al., 2012). The major evaluation factor of packing material is its cost and mechanical strength. The most commonly used packing materials include activated carbon, lava rock, plastic ring, ceramic particle, polyurethane foam, molecular sieve and perlite (Delhomenie and Heitz, 2005). Maifanite is a kind of granitoid silicate produced from basic or acidic intrusive rocks by weathering and denudation, and is widely used in various fields, including medical care, food additives, antisepsis, and heavy metal decontamination in East Asia countries for its innocuous and neutral characteristics (Fu et al., 2013; Jiang et al., 2013). It also presents a great potential as packing material for BTFs due to its good mechanical properties to avoid the collapsing of fillings and cavernous porosity which is beneficial to microbial immobilization. Furthermore, various micro-nutrient elements such as Ca^{2+}, Na^{+}, K^{+}, Fe^{2+}, Cu^{2+}, Mg^{2+}, Zn^{2+} and Mn^{2+} can also be released into the liquid phase from maifanite as mineral nutrition source for bacterial growth (Gao et al., 2013). However, no study has been conducted to investigate the biodegradation promoting behavior of maifanite as the packing material in the BTFs yet.

Generally, the functional bacteria or consortium targeted to the specific pollutant should be inoculated on the inert packing material in BTFs. Previously, various VOSCs degradable strains were isolated and introduced into BTFs for VOSCs removal (An et al., 2010; de Bok et al., 2006; Giri et al., 2010; Hayes et al., 2010). Some reported functional species relative to the DMDS degradation with their main parameters and degradation performances in BTFs were listed in Table S1. After inoculation, the bacterial strain might experience a slow acclimation period and became the dominant species once the acclimation was achieved. Therefore, monitoring the dynamic of bacterial community is essential to understand the acclimation process. Nevertheless, few research was relative to the exploration of bacterial community dynamic in acclimation process, especially for the DMDS biodegradation.

Thus, in this study, twin BTFs were firstly designed and constructed. Considering its various merits and further application, maifanite was chosen as packing material in one column, and the most commonly used ceramic particle was packed in another column for comparison. *Bacillus cereus* GIGAN2, preciously isolated for degradation of odorous DMDS in aqueous medium by our research group (Liang et al., 2015), was inoculated into twin BTFs to purify gaseous DMDS. The effect of empty bed residence time (EBRT) and inlet DMDS concentration on the RE as well as elimination capacity (EC) were extensively compared. Further, the bacterial compositions were comparatively analyzed in the twin BTFs based on PCR-DGGE technology.

2. Methods

2.1. Metabolic strain, packing materials and mineral salts medium

A novel DMDS degrader *Bacillus cereus* GIGAN2 previously isolated from sludge of a river in Guangzhou city, China by our group was seeded in twin BTFs (Liang et al., 2015). Maifanite and ceramic particles were used as packing material respectively in the twin BTFs, and the physical characteristics of the packing materials are presented in detail at Table S2. The specific surface area of maifanite and ceramic particles were 3.882 and 3.182 $m^2\ g^{-1}$ and the porosity volume for the pile reached 49% and 44%, respectively. Overall, their physical characteristics presented above didn't show significant differences. The scanning electron microscope images show that the surface of both packing materials is rather rough (Fig. S1). DMDS (99.5%) purchased from J&K chemical Ltd. was employed as sole carbon source. All other chemicals were of analytical grade and obtained from Guangzhou Chemical Reagent Co., Inc., China. Mineral salts medium was used for trickling the packed materials from top of BTFs, and the recipe was provided in supporting information. After each 30-day operation, half volume of mineral medium was replaced with isovolumetric fresh mineral medium to avoid adverse effect on microbial growth by the produced intermediates.

2.2. Description and operation of biotrickling filter

As Fig. 1 shows, a twin custom laboratory-scale BTF unit was employed in the experiment which comprised a couple of layers with the same configurations to ensure their comparability. The twin BTFs were made of high-transparent plexiglass and fixed to a horizontal steel frame. The external diameter and height of each filtration column was of 60 and 1200 mm, respectively. Maifanite and ceramic particles were divided into six equal layers and were packed into the BTFs respectively with a total volume of 1.37 L in each column. The packing height of each layer was approximately 100 mm. Sampling ports were opened in each layer. All the air tubes were made of polytetrafluoroethylene. Ambient air purified

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