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Performance of a new suspended filler biofilter for removal of nitrogen oxides under thermophilic conditions and microbial community analysis

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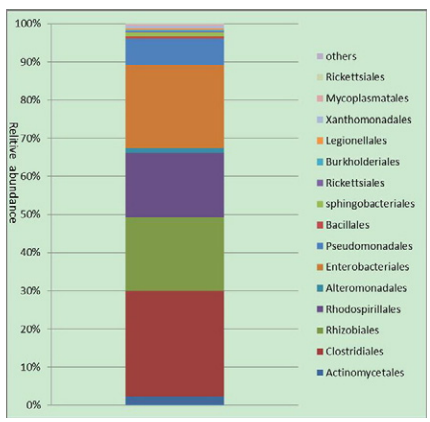
HIGHLIGHTS

- A suspended biofilter was firstly constructed for the removal of nitrogen oxides.
- The biofilter could remove NO efficiently with great elimination capacity.
- No clogging was observed in the suspended biofilter during the running period.
- The biofilm bacteria community was analyzed by the newest Illumina MiSeq platform.
- The dominant species in the biofilm were all common denitrifying bacteria.

GRAPHICAL ABSTRACT



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ABSTRACT

A suspended biofilter, as a new bioreactor, was constructed for the removal of nitrogen oxides (NO_X) from simulated flue gas under thermophilic conditions. The suspended biofilter could be quickly started up by inoculating the thermophilic denitrifying bacterium *Chelatococcus daeguensis* TAD1. The NO concentration in the inlet stream ranged from 200 mg/m^3 to 2000 mg/m^3 during the operation, and inlet loading ranged from 8.2–164 g/(m^3·h). The whole operation period was divided into four phases according to the EBRT. The EBRT of phases I, II, III and IV were 88 s (9–43 d), 44 s (44–61 d), 66 s (62–79 d) and 132 s (80–97 d), respectively. An average NO removal efficiency of 90% was achieved during the whole operation period, and the elimination capacity increased linearly with the increase in NO inlet loading and the maximum elimination capacity reached 146.9 g/(m^3·h). No clogging was observed, although there was a high biomass concentration in the biofilter bed. The remarkable performance in terms of NO removal could be attributed to the rich bacterial communities. The microbial community structure in the biofilm was investigated by high throughput sequencing analysis (16S rRNA MiSeq sequencing). The experimental results showed that the microbial community structure of the biofilm was very rich in diversity, with the most abundant bacterial class of the Alphaproteobacteria, which accounted for 36.5% of the total bacteria, followed by Gammaproteobacteria (30.7%) and Clostridia (27.5%). It was worthwhile to mention that the dominant species in the suspended biofilter biofilm were all common denitrifying bacteria including

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Rhizobiales (inoculated microbe), Rhodospirillales, Enterobacteriales and Pseudomonadales, which accounted for 19.4%, 17%, 21.6% and 7%, respectively. The inoculated strain TAD1 belonged to Alphaproteobacteria class. Because high-throughput 16S rRNA gene paired-end sequencing has improved resolution of bacterial community analysis, 16S rRNA gene sequencing of these bacteria could provide more functional and phylogenetic information about the bacterial communities.

1. Introduction

Anthropogenic emissions of nitrogen oxides (NO_X, mainly including NO and NO_2), which are mainly produced during the burning of fossil fuels, have negative effects on ecosystems and human health (Jin et al., 2005). Increasing emissions of nitrogen oxides (NO_X) from various industrial processes and transportation activities, especially coal-fired power plants, are widely regarded as risks to the global environment and human health (Gao et al., 2011). Nitric oxide (NO) is the primary composition of NO_X, particularly to flue gas. Flue gas from a power plant consists of CO_2, SO_X, NO_X and O_2, and the primary pollutants are SO_X and NO_X with NO being about 90% (Yang et al., 2012a; Skalska et al., 2010). NO is a precursor for tropospheric ozone depletion and the main constituent in photochemical smog. It may also react with moisture in the air to form nitrous acid, which has been implicated in acid rain (Parvulescu et al., 1998). Although the production of NO_X can be significantly reduced by combustion process control, post-combustion flue gas treatment is required to satisfy the current regulatory air standards. Bioprocesses including biotrickling filter and biofilter are emerging post-combustion control technologies that can be used as potential alternatives for purification of NO_X containing dilute gases (de Morais and Vieira Costa, 2008).

In general, biofiltration techniques are limited to operate under mild temperature conditions (25–35 °C) because mesophilic and oxidizing microbial populations form biofilms (Morales et al., 2012). However, it is noted that many industrial emission gas are very high in temperature. For example, in coal-fired power plants, the influent flue gas stream for a NO_X removal reactor is the emission from a sulfur dioxide scrubber, and the temperature of the gas exiting from the scrubbers of the effluent is still between 50 and 60 °C (Chen et al., 2015b; Lee et al., 2001). Precooling the gas stream to appropriate temperatures is an effective preprocessing method that increases the investment and operational costs of the treatment (Shanchayan et al., 2006). An alternative technique that does not require precooling treatment is thermophilic biofiltration, which utilizes the metabolic activity of thermophilic organisms (Bruns, 2013). Thermophilic biofilters have advantages such as low cost and high microbial metabolism rates. Elimination capacity can be increased by using thermophilic bacteria instead of mesophilic bacteria (Mohammad et al., 2007). A thermophilic biofilter for ethylacetate removal has shown a higher removal efficiency (>100 $g/m^3 \cdot h$) than a mesophilic biofilter at 45–50 °C volatile compounds, including methanol and other organics, have been successfully treated through thermophilic biofiltration (Deshusses et al., 1999). However, only a few studies have described the use of thermophilic biotreatment for effective NO_X removal (Chen et al., 2015a, b; Yang et al., 2013).

However, both biofilters and biotrickling filters are confronted with some operation problems caused by excess biomass accumulation, such as bed clogging, gas channeling and pressure drops (Littlejohns et al., 2010). These problems become more prominent when they are operated under high inlet load or in a long-term operation (Clarke et al., 2009; Iliuta and Larachi, 2004; Lebrero et al., 2012; Okkerse et al., 1999). It was noticed that the clogging and gas channeling were mainly due to the fixation of the fillers, similar to other fixed-bed reactors (Littlejohns et al., 2010; Nielsen et al., 2007). If these fixed-fillers are replaced by suspended carriers with low densities, it is expected that the free movement of these suspended carriers could lead to self-agitation and continuous backwashing. Hence, it may avoid the bed clogging and gas channeling. This type of reactor is referenced as a suspended biofilter.

Table 1
Experimental scheme for continuous NO_X degradation experiments.

Stage of experiment	Time (days)	NO_X concentration (g/m^3)	EBRT (s)
Startup	1–8	0	0
Phase I	9–43	0.2–2	88
Phase II	44–61	0.4–2	44
Phase III	62–79	0.4–2	66
Phase IV	80–97	0.4–2	132

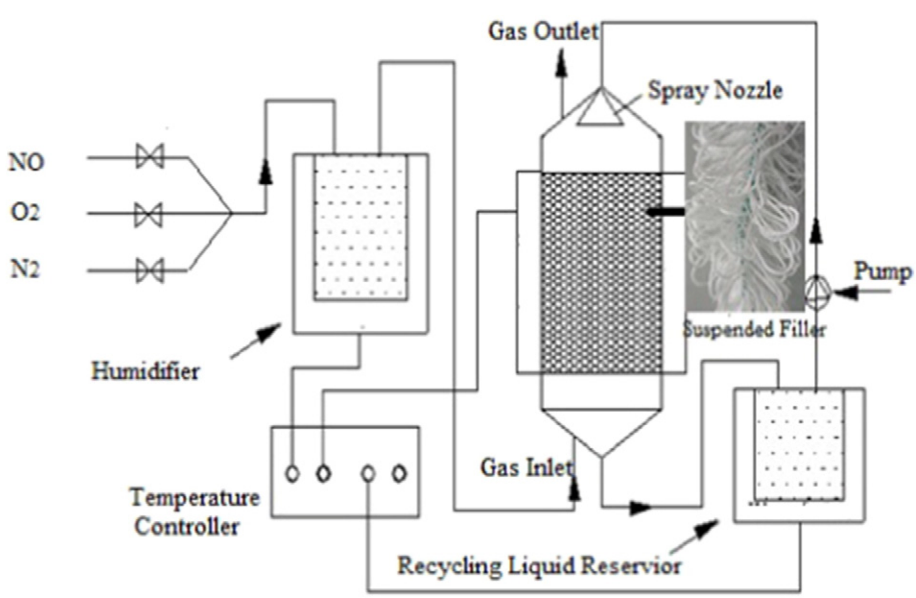

Fig. 1. Schematic diagram of the suspended biofilter reactor.