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Bioreactor systems

Performance of a suspended biofilter as a new bioreactor for removal of toluene

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ABSTRACT

A suspended biofilter, as a new bioreactor, was constructed for removal of VOCs (volatile organic compounds). The biofilter bed (height of 30 cm, diameter 16 cm and working volume of 6.0 L) was formed by applying suspended carrier with porous surface and the carrier itself has a density slightly lower than water. According to the results, it was found that the suspended biofilter was suitable to treat the toluene-contaminated stream. Since it could startup quickly, tolerate great transient shock loadings, and possess average removal efficiency higher than 90.2% in a toluene loading range of 11.0–58.5 g m^{-3} h^{-1}. What is more, it also gained a maximum elimination capacity of 113.6 g m^{-3} h^{-1} at a toluene loading rate of 272.2 g m^{-3} h^{-1}. The remarkable performance could be contributed to the rich bacterial communities for toluene degradation. A following 16S rRNA gene sequence analysis reveals that the communities contain high efficient toluene-degrading bacteria, i.e., *Acinetobacter* sp. Tol 5, *Burkholderia*, and *Comamonadaceae*. In addition, after a long-term operation of 141 days, no clogging was observed although there was a high biomass concentration in the biofilter bed. It demonstrated that this novel suspended biofilter overcome clogging and accumulation of biomass, which are the drawback of fixed biofilter.

1. Introduction

Industrial and manufacturing operations discharge VOCs to the air on a large scale. For instance, the emission of VOCs reaches 19,406 kton per year in China. Many VOCs (e.g., benzene, toluene) pose risks to the environmental and human health, such as photochemical ozone creation potential, toxicity, carcinogenicity and other nuisance [1–3]. These facts led to stricter environmental regulations during the last decades. Correspondingly, numerous techniques have been developed to control the emissions of VOCs to meet severe environmental regulations.

Among these technologies, the suspended-growth bioreactors, which are easily kept in homogeneous state, have been evaluated to show dependable performance for purification of VOCs contaminated gas. [4,5]. However, both low concentration of active microorganisms over an extended period of bioreactor operation and weak resistance to shock loadings can still be the limiting factors for the treatment of VOCs in suspended-growth bioreactors [2,6,7].

Alternatively, biofilters and biotrickling filters have attracted much attention for air treatment. Compared with suspended-growth bioreactors, biofilters and biotrickling filters can remove VOCs more efficiently due to much more microorganisms adhered on the packed fillers [8]. 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. These problems become more prominent when they are operated under high VOC loading rates or a long-term operation [9–14]. For example, Ryu et al. found that the benzene removal efficiency of a well-designed biofilter decreased from higher than 90% to approximately 75% after 27 days operation, due to the clogging caused by the excess growth of biomass.

It was noticed that the clogging and gas channeling were mainly due to the fixation of the fillers, as other fixed-bed reactors [15,16]. If these fixed-fillers are replaced by suspended carriers with low densities, the light carriers will float on the upper part of a nutrient solution. Therefore, this kind of reactor is referenced as a suspended biofilter in this paper. 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. In this paper, this kind of reactor is referenced

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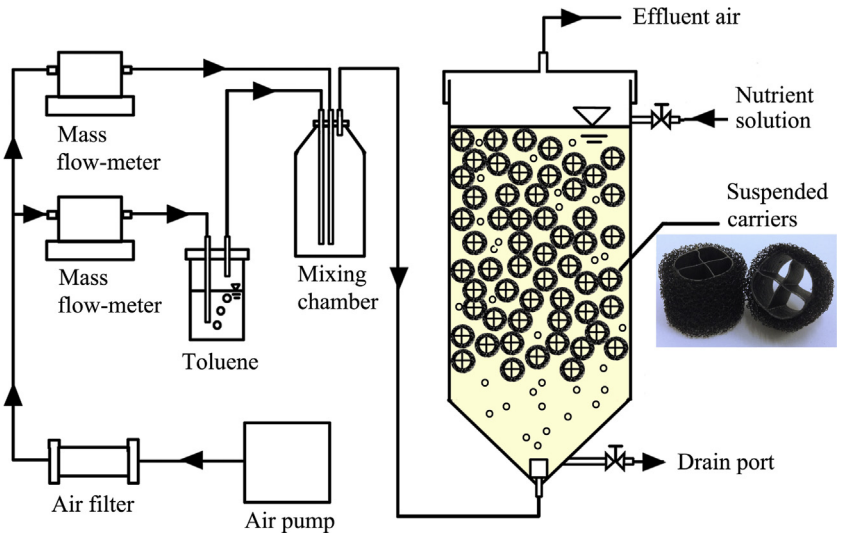

Fig. 1. Schematic diagram of suspended biofilm reactor.

as a suspended biofilter. In this study, a novel suspended biofilter reactor was constructed, in which the fillers are the suspended carriers with porous surfaces as shown in the insert of Fig. 1. This novel suspended biofilter was furthermore used to treat the simulated toluene containing gas. The performances of the suspended biofilter, including startup rate, potential of toluene removal under various operating conditions, and tolerance for transient shock loading were investigated. A special interest was paid to analyze the microbial community attached on these carriers. The aim of the paper is to develop a new bioreactor of VOCs removal with a high efficiency and easy operation.

2. Materials and methods

2.1. Inoculums and packing material

Fresh activated sludge was used as inoculums to culture the suspending biofilter, which was obtained from Datansha municipal wastewater treatment plant in Guangzhou, China.

The suspended carrier with porous surface was prepared by coating a sponge on the outside of a commercial carrier, as shown in the insert of Fig. 1. The sponge was made of polyurethane with open holed ratio of 90%, pore size of 45 ppi (pores per inch) and sponge thickness of 4 mm. It was supplied by Shanghai Yinke Co., Ltd., China. The commercial carrier is a polyethylene cylinder with a diameter of 20 mm, a height of 20 mm and density of 0.96–0.98 g cm^{-3}, having crisscross sheets inside it.

2.2. Setup and operation of suspended biofilter

The suspended biofilter consisted of an organic glass column, a nutrient solution and a suspended carrier, as showed in Fig. 1. The organic glass column has a height of 30 cm, an inner diameter of 16 cm and an effective volume of 6.0 L. The filling ratio of the carrier is 75% volume of the nutrient solution. The nutrient solution consisted of a minimal salts medium, contained (g L^{-1}): 1.64 KH_2PO_4, 2.74 K_2HPO_4, 0.6 $(NH_4)_2SO_4$, 0.24 $MgSO_4$; and a trace metal solution containing (mg L^{-1}): 0.3 $FeSO_4{\cdot}7H_2O$, 0.22 $MnCl_2{\cdot}4H_2O$, 0.024 $CuCl_2{\cdot}2H_2O$, 0.048 $ZnSO_4{\cdot}7H_2O$, 0.024 $CoCl_2{\cdot}6H_2O$, 0.024 $NiCl_2{\cdot}6H_2O$, 0.024 $Na_2MoO_4{\cdot}2H_2O$ and 0.024 $H_3BO_4{\cdot}Na_2CO_3$ and $NaHCO_3$ were used to control pH of the liquid medium between 6.0 and 7.5. Toluene waste gas was the only carbon source used in the experiment. During the entire operation period of the suspended biofilter, 500 mL of the liquid medium was drew off and renew with fresh nutrient solution everyday to control pH and provide necessary nutrients for microbial growth. The toluene waste gas was prepared by separating the air stream into two flows by a tee coupling. Before the tee coupling, there was an air filter, which could dry the air flow and protect the air mass flow-meter. A minor fraction of the stream was bubbled into a vessel filled with liquid toluene (analytical grade, purchased from Tianjin Damao Chemical Reagent Co., Ltd., China). The air containing contaminant vapor was then adequately mixed with the main fraction of clean airflow in a mixing chamber and conveyed the biofilter bed through an air distributor at the bottom of the reactor. The waste gas was biodegraded by microorganisms in the biofilter bed. Experiments were operated at ambient temperatures about 25 °C. Gas sampling valves and pressure meters were set on the inlet and outlet of the reactor to monitor relevant contaminant concentration and the pressure drops. The sludge settled to the bottom of the reactor was discharged every 10 days.

The pollutant concentration in the influent gas was varied by regulating the mass flow-meters. The operation of continuous

Table 1
Experimental scheme for continuous toluene degradation experiments.

Stage of experiment	Time (days)	Toluene concentration (g m^{-3})	Inlet loading (g m^{-3} h^{-1})	EBRT (min)
Start up	1–14	0.1–0.8	2.5–17.2	2.9
Phase I	15–45	0.6–2.7	11.0–58.5	2.9
Phase II	46–82	0.6–2.7	18.5–108.4	1.8
Phase III	83–117	0.6–2.4	26.8–133.0	1.2
Phase IV	118–123	3.0	230.2–289.8	0.7
Phase V	124–128	1.7	32.7–36.7	2.9
Phase VI	129–133	0	0	0
Phase VII	134–141	1.5	25.8–35.2	2.9