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Performance of Fibrous Bed Bioreactor for Treating Odorous Gas

Scientific Note

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Abstract

A fibrous bed bioreactor was used for treatment of odorous volatile fatty acid (VFA). The effect of gaseous VFA (acetic, propionic, and butyric acids) mass loading on the bioreactor performance was investigated. The VFA degrading microbial culture was selected from activated sludge by the three VFAs using a shake-flask culture. The selected microorganisms were then immobilized in a biofilter using cotton fabric as packing material. In the biofiltration experiment, the inlet gas flow rates ranged from 1 to 4 L/min, the total VFA concentrations ranged from 0.10 to 0.43 g/m^3, and the resulting total mass loadings of VFA studied ranged from 9.7 to 104.3 g/m^3/h. At total mass loading of 104.3 g/m^3/h, the VFA removal efficiency was 87.7%. Higher removal efficiencies (>90%) were achieved at mass loadings below 50.3 g/m^3/h.

Index Entries: Biofiltration; odor control; VFA; fibrous bed bioreactor.

Introduction

Volatile fatty acids (VFA) are malodorous compounds that generate a rancid and pungent smell and have low odor thresholds *(1)*. They are produced by the livestock industry, especially in animal wastes stored under anaerobic conditions *(2)*, and are generated from composting facilities as intermediate products in the compost pile *(3)*. Such emissions cause malodorous air pollution and frequently give rise to odor nuisance.

Various deodorizing methods have been used for removal of odorous compounds from foul air, including physical and chemical methods, such

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as activated carbon adsorption, catalytic thermal oxidation, ozonation, and wet chemical scrubbing. However, biological methods are now attracting more attention. Compared with conventional physical and chemical methods, biological methods possess several advantages, such as low operation and maintenance cost, good stability, and no secondary waste production, since their resulting byproducts are carbon dioxide and water *(4,5)*.

Biofiltration is the most common biological-odor treatment method. Waste gases are passed through a biologically active porous medium using soil, peat, activated carbon, bark, and leaves as basic filter material, and are biodegraded by indigenous microbes. Biofiltration has been successfully applied for removal of odorous compounds, such as hydrogen sulfide, triethylamine, ammonia, and butanal *(6–8)*, from contaminated air, and currently is used to eliminate hazardous volatile organic compounds, such as the mixture of benzene, toluene, ethlybenzene, and xylene (BTEX), chlorinated hydrogen, and gasoline vapors, from gas streams *(4,9)*.

Although high odor-removal efficiency can be achieved with conventional biofilters, soil and compost as the biological attachment media have several drawbacks because of their low porosity and high compactness, causing high resistance and channeling flow. These biofilters are also subject to clogging and dehumidification over long-term operation *(5,9)*. Moreover, the large footprint of conventional biofilters limit their use in small and crowded city areas. On the other hand, a new type of biofilter that can overcome the aforementioned disadvantages has been developed for various bioprocessing purposes *(10–12)*. The bioreactor contains a packed bed of spiral-wound porous fibrous sheet materials with built-in vertical spaces between adjacent fibrous sheets to allow gas to flow upward freely through the packed bed. The fibrous bed with high porosity (>90%) and high surface area provides good multiphase contacts and an environment ideal for microbial growth and biochemical reactions to take place. In environmental application, the fibrous bed bioreactor has been studied for treatment of BTEX-contaminated ground water and waste streams *(13)*.

In this article, the fibrous bed bioreactor was used as a biofilter for treatment of odorous volatile fatty acids in gas streams. The performance of the bioreactor under different mass loadings was studied.

Materials and Methods

Odorous Volatile Fatty Acids

Acetic, propionic, and butyric acids were used as odorous gases for this study.

Microorganisms and Selection Culture Conditions

Activated sludge (Southerly Waste Water Treatment Plant, Columbus, OH) was used as the initial culture. The desired microorganisms were selected by the three VFAs using shake-flask cultures. The medium for

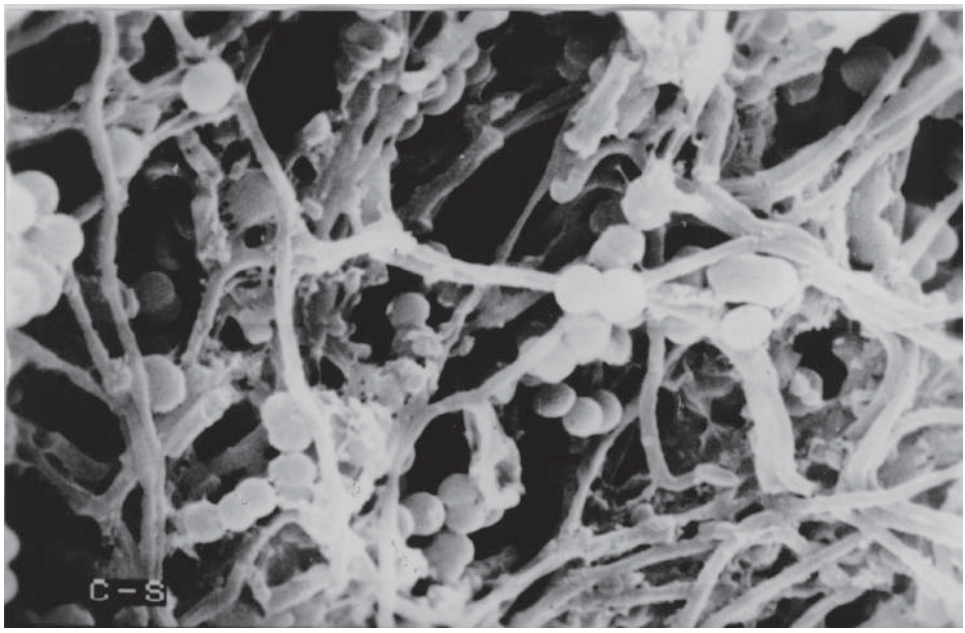

Fig. 1. Biofilm on fabric medium.

microbial selection contained 2.5 g/L $(NH_4)_2SO_4$, 1 g/L KH_2PO_4, 1 g/L $MgSO_4 \cdot 7H_2O$, 1 g/L yeast extract, 6.67 g/L acetic acid, 6.67 g/L propionic acid, and 6.67 g/L butyric acid. The total VFA concentration was 20 g/L.

Microbial Kinetics and Bioreactor Start Up

One milliliter of activated sludge was transferred to a 500-mL flask containing 100 mL culture media, incubated at 30°C and 200 rpm. After a 3-d growth period, the cell broth was used to inoculate a stirred tank using 4 L as the working volume. The growth condition was controlled at 30°C and pH between 7.5 and 8.0 by the stirred tank reactor.

After the cessation of microbial growth, the culture broth inside the stirred tank was trickled on top of the fibrous bed at 200 mL/min for immobilization of the starved microorganisms. The immobilized biofilm on the medium is shown in Fig. 1. After 15 d of liquid recirculation until the cell concentration in the stirred tank became steady (Fig. 2), gaseous VFA was introduced into the bioreactor.

Experimental Apparatus

An illustration of the experimental biofilter system is shown in Fig. 3. The reactor system consisted of a cylindrical glass column with an internal diameter of 5 cm and height of 73 cm. The cotton fabric packing material (52×30 cm) was spirally wound together with a stainless-steel wire cloth with the same dimensions. The empty bed volume was 1 L and void volume was 900 mL.

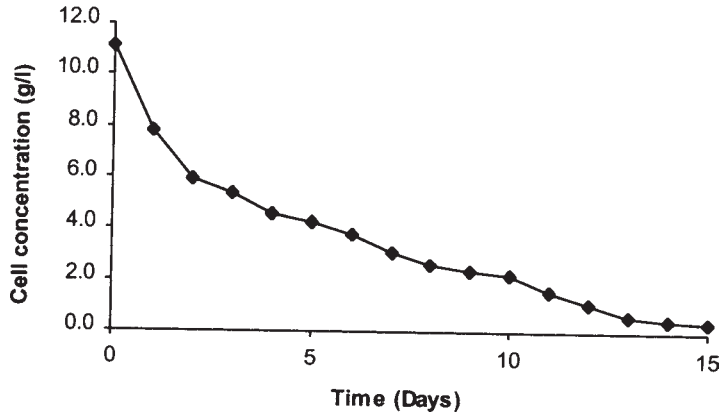

Fig. 2. Change of cell concentration in a stirred tank during immobilization.

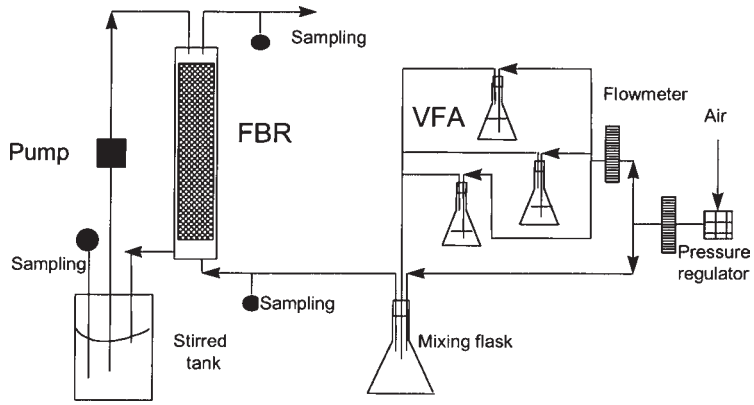

Fig. 3. The experimental setup.

The odorous VFA gas was generated by bubbling air through 25% (v/v) VFA solution. Different air flow rates were used to vary VFA concentrations in the gas inlet. The odorous gas was introduced at the bottom of the reactor and treated gas was exited from the top.

The stirred tank was used for culture selection and as a recirculation tank during microbial immobilization. After the completion of immobilization, it was disconnected from the column reactor. The fibrous bed packing was totally submerged in liquid, which provided a moist condition for microorganisms. Gas sampling ports were located at the inlet and outlet of the fibrous bed reactor. Liquid sampling ports were at the bottom of column and also at the stirred tank.

Biofiltration Experiment

The effects of VFA mass loading on the bioreactor performance were studied. The flow rate ranged from 1 to 4 L/min (empty bed retention time

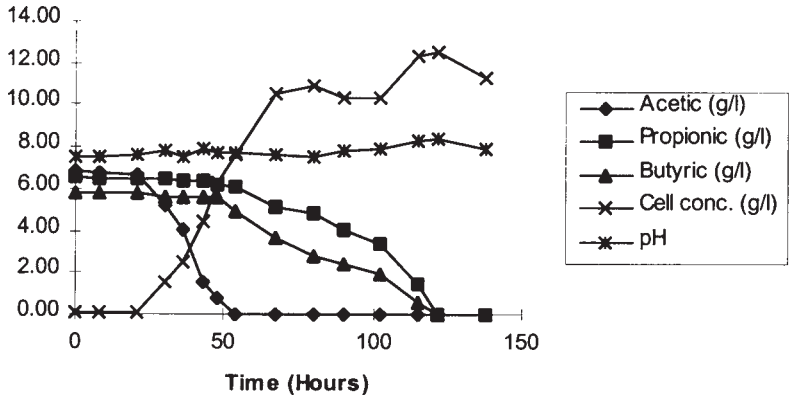

Fig. 4. Growth kinetics of microorganisms showing cell concentration and VFA concentration in selection culture from activated sludge using VFA as a carbon source.

[EBRT] 15–60 s). The total VFA concentration ranged from 0.10 to 0.43 g/m^3, and the total mass loading of VFA studied was between 9.7 and 104.3 g/m^3/h.

Analytical Methods

The gaseous VFA concentrations were determined using a Varian gas chromatography 3300 system equipped with a DB-WAX capillary column (J & W Scientific, 15 m × 0.53 mm id) detected by a flame ionization detector. Nitrogen was used as the carrier gas and the temperature of column, injector, and detector was 110, 110, and 160°C, respectively. Fifty milliliters of gas sample was taken from the sampling port by using a 60-mL syringe, which was then preconcentrated by injecting it into a 1.5-mL microcentrifuge tube containing 1 mL deminerialized distilled water, and 2 µL of this liquid was injected into the GC. The error of this preconcentration step was found to be below 10%. The VFA concentration from the liquid in the stirred tank and the FBR was analyzed with high-performance liquid chromatography (HPLC). The liquid sample was first centrifuged at 12,000 rpm for 3 min. Ten µL of cell-free sample was then injected into an organic-acid analysis column (Bio-Rad, Model PX-87). The eluant used was 0.01 *N* H_2SO_4 at a flow rate of 0.6 mL/min. The cell density was determined by optical density at 600 nm determined by a spectrophotometer (Model 340, Sequoia-Turner). It was found that 1 U of OD was equivalent to a cell density of 0.708 g/L.

Results and Discussion

Microbial Kinetics Study

The microbial growth in the stirred tank, the change in pH, and the change of VFA concentrations in the culture broth are shown in Fig. 4. The specific growth rate was found to be 0.05/h, the maximum cell concentration obtained was 12.6 g/L. The growth of microbes stopped at 100 h and

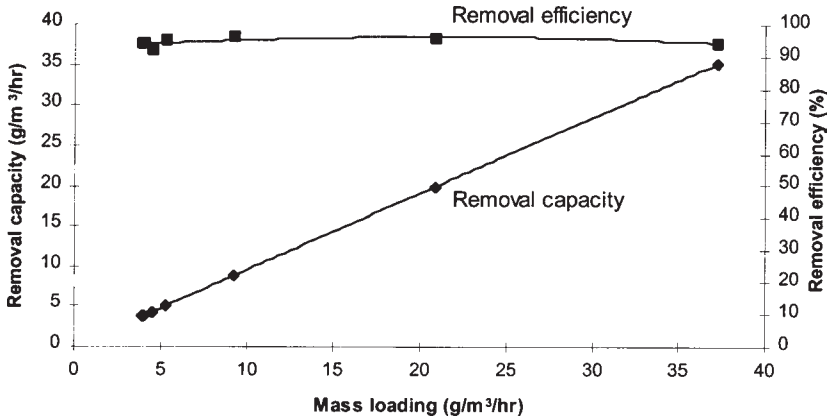

Fig. 5. Removal profile of acetic acid at increasing mass loading.

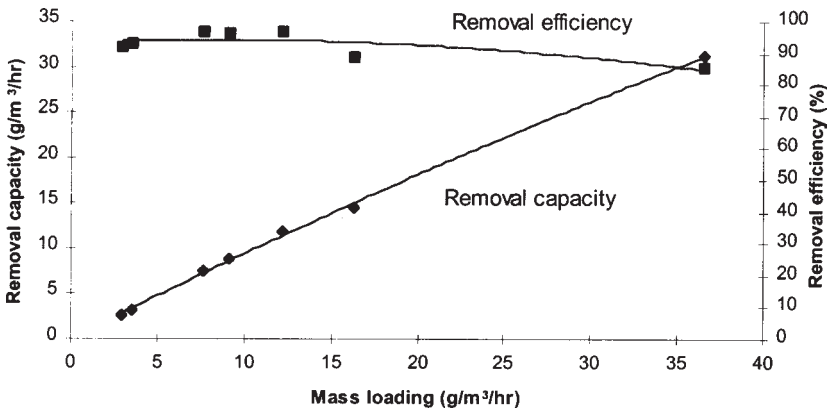

Fig. 6. Removal profile of propionic acid at increasing mass loading.

continued to grow after 1 g/L yeast extract was added. At 122 h, the growth ended because of exhaustion of VFA.

Acetic acid was the first VFA depleted in the culture broth. It was consumed at an average rate of 0.13 g/L/h, and was used up after 48 h. Propionic and butyric acids were consumed slowly in the presence of acetic acid, only at 0.007 and 0.005 g/L/h for propionic and butyric acids, respectively. The consumption rates of propionic and butyric acids, after the exhaustion of acetic acid, was increased sharply. Finally, both depleted at 122 h. The maximum VFA consumption rates were found to be 0.30, 0.05, and 0.06 g/L/h for acetic, propionic, and butyric acid respectively. It implied that during VFA treatment, acetic acid would be removed faster compared with propionic and butyric acids.

Performance of Bioreactor on Increasing Mass Loading

The removal capacities and removal efficiencies at different mass loadings are shown in Figs. 5–8. At VFA mass loading below 22.4 g/m^3/h, the

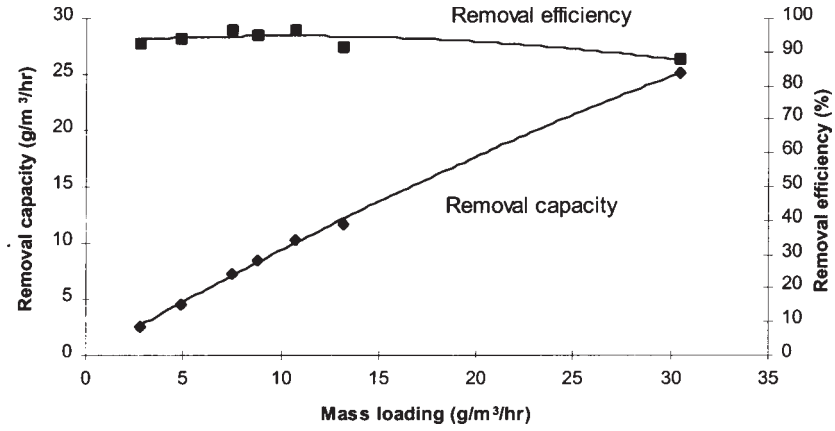

Fig. 7. Removal profile of butyric acid at increasing mass loading.

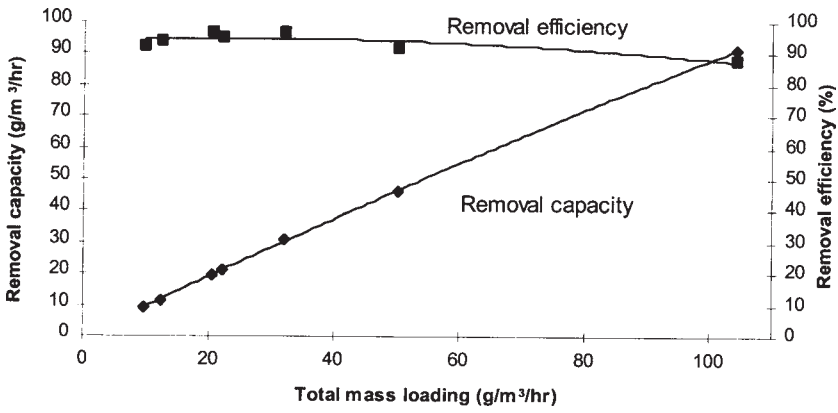

Fig. 8. Removal profile of total VFA at increasing mass loading.

VFA concentration from the gas outlet and in the liquid inside the bioreactor was always nondetectable, and a steady pH in the liquid phase was observed. Under this condition, there was no accumulation of VFA inside the bioreactor where the microorganisms were able to degrade all the VFA introduced.

When total mass loading was increased to 22.4 g/m^3/h, VFAs were still nondetectable in the gas outlet. However, propionic and butyric acids started to accumulate in the liquid phase (Table 1). The system was stabilized when the VFA concentration in the liquid phase reached 1.0 g/L. When total VFA mass loading was raised to 50.3 g/m^3/h, the outlet VFA concentration started to show, and the removal efficiency was reduced to 91.9%. The resulting removal capacity was 46.1 g/m^3/h.

The total VFA mass loading was further increased to 104.3 g/m^3/h, with 37.2, 36.6, and 30.5 g/m^3/h for acetic, propionic, and butyric acids, respectively. At semisteady state, the total VFA removal efficiency was lowered to 87.7%, with 94.4, 85.3, and 82.7% for acetic, propionic, and

Table 1
VFA Concentration (g/L) in the Liquid Phase at Different Mass Loadings

Mass loadings, $g/m^3/h$	Acetic	Propionic	Butyric	Total VFA
104.0	0.5	3.1	3.1	6.7
50.3	ND	2.8	2.7	5.5
22.4	ND	0.5	0.5	1.0

butyric acids respectively, and their respective concentration in the liquid phase was 0.5, 3.1, and 3.1 g/L (Table 1).

In the gas phase, the removal efficiency of acetic acid was highest among the three VFAs. While in the liquid phase, acetic acid was also at the lowest level compared with propionic and butyric acid (Table 1). There was no accumulation of acetic acid at VFA mass loadings of 22.4 and 50.3 $g/m^3/h$. At total mass loading of 104.3 $g/m^3/h$, acetic acid concentration was the lowest compared to other VFAs. This finding was consistent with the microbial kinetics study that acetic acid was preferentially degraded.

Conclusion

The performance of the fibrous bed bioreactor under different VFA mass loadings was investigated. The bioreactor was operated at total mass loadings up to 104.3 $g/m^3/h$ (37.2, 36.6, and 30.5 $g/m^3/h$ for acetic, propionic, and butyric acids respectively), and an overall removal efficiency of 87.7% was attained. At mass loadings below 50.3 $g/m^3/h$, higher removal efficiencies (>90%) were achieved. Among the three VFAs, acetic acid was the most preferably degraded in both gaseous and liquid phases, which was consistent with the microbial kinetics study.

Acknowledgment

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