Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

Restaurant emissions removal by a biofilter with immobilized bacteria*

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Received Sept. 25, 2004; revision accepted Dec. 5, 2004

Abstract: *Pseudomonas* sp. ZD8 isolated from contaminated soil was immobilized with platane wood chips to produce packing materials for a novel biofilter system utilized to control restaurant emissions. The effects of operational parameters including retention time, temperature, and inlet gas concentration on the removal efficiency and elimination capacity were evaluated. Criteria necessary for a scale-up design of the biofilter was established. High and satisfactory level of rapeseed oil smoke removal efficiency was maintained during operation and the optimal retention time was found to be 18 s corresponding to smoke removal efficiency greater than 97%. The optimal inlet rapeseed oil smoke loading was 120 mg/(m^3·h) at the upper end of the linear correlation between inlet loading and elimination capacity.

Key words: Restaurant emission, Immobilized bacteria, Biofilter
doi:10.1631/jzus.2005.B0433 **Document code:** A **CLC number:** X7

INTRODUCTION

Restaurant emission is a pollutant to atmosphere and human body. Polycyclic aromatic hydrocarbon contained in oil smoke directly induces lung and bladder cancer (Chen and Ye, 1991; Gupta *et al*., 2001; Lutz, 1982). According to former researches (Kleinerman *et al*., 1999; Liu *et al*., 1987), oil smoke contains many harmful substances that can induce not only general diseases but also gene mutation, DNA damage and immune function impairment, and many ingredients such as fatty acid, alkyl, alkene, aldehyde, ketone, alcohol and ester (Zhang *et al*., 2002; Leson and Winer, 1991) that are harmful to atmosphere.

Biological gas cleaning is the most attractive technology from economic and environmental perspectives due to its low operating costs and low energy requirements (Koh *et al*., 2004). There is a continuing need for cost-effective technologies to control emissions of volatile organic compounds (VOCs) (Neal and Loehr, 2000). During the last decades, biofiltration for air pollution control has been established as a reliable, cost-effective technology for controlling low-concentration biodegradable waste gases (Bohn, 1992; Pedersen and Arvin, 1995; Lu *et al*., 2003). Biofiltration is not presently a well-recognized waste air treatment technique in China and can be applied in a wide range of industries and public sectors including restaurants in the near future. To treat gases emitting from a restaurant, other techniques like incineration often prove economically impossible. Adsorption on activated carbon or aqueous adsorption could be problematic because of the high moisture content of the gas and the low solubility of some compounds in it. Emissions from restaurant tend to contain a mixture of partially oxygenated hydrocarbons (i.e. carboxylic acid, aldehyde, ketone, alcohol and ester) whose composition and concentration vary with time. This poses a special challenge for a biofilter, as it has to work with intermittent loads and deal with changes in the concentration of indi-

* Project (No. 2003C23019) supported by the Major Scientific and Technological Project of Zhejiang Province, China

vidual contaminants. Little research has been carried out on the capacity of biofilters to deal with such effluents.

The idea behind a biofilter is to let microorganisms degrade pollutants from the air and use these substances as their primary carbon and energy source. The key to a successful biofilter operation is to create a health ecosystem in the filter, by controlling parameters like moisture content, pH, temperature, access to oxygen and nutrients. The choice of filter material is fundamental and in recent years various synthetic packing materials indeed do not contain microorganisms or nutrients, which therefore must be added. Wood seems to be a suitable biofilter medium since it is cheap, develops low pressure-drops, has good mechanical properties and offers a seemly habitat for microorganisms.

The objective of this study was to investigate the feasibility of using a wood biofilter for the treatment of restaurant emissions, in which rapeseed oil emissions would be the target.

MATERIALS AND METHODS

Microorganism

Pseudomonas sp. ZD8, used throughout the experiments was isolated from contaminated soil.

Medium and culture condition

An artificial medium was used for the cultivation of *Pseudomonas* sp. ZD8. The basal composition of the medium (g/L) was as follows: $(NH_4)_2SO_4$ 1, $CaCl_2$ 0.4, $MgSO_4 \cdot 7H_2O$ 0.5, KH_2PO_4 2, K_2HPO_4 1, $NaNO_3$ 0.25 and 3 ml rapeseed oil as the carbon source. The pH of the artificial medium was adjusted to 7.5. The culture was carried out at 30 °C for 24 h on a rotary shaker at 210 rpm.

Preparation of platane wood chip

The physical properties of porous platane wood chips (20 mm×20 mm×10 mm) were as follows: bulk density 0.8 g/cm^3 and porosity 58%. The platane wood chips were prepared by washing with distilled water, drying at 100 °C for 24 h and autoclaving at 121 °C for 20 min.

Immobilization onto platane wood chips

Pseudomonas sp. ZD8 cultured in the 5 L fresh artificial medium were harvested by centrifugation at 17000×g for 15 min and washed twice with distilled water. The harvested cells were resuspended in fresh artificial medium (1000 ml) and subjected to immobilization. The immobilization was performed according to the method described below. The cells were adhered and absorbed onto the platane wood chips (5000 g) by injecting the bottle evacuated by sucking with an aspirator. The cells adhered and absorbed onto the platane wood chips were subsequently transferred to a sterile breaker and covered with a thin foil. The cells were further incubated at 30 °C for 24 h. The moisture content of the platane wood chips was adjusted to 45% (v/w) by adding the basal medium. The initial cell number was approximately 108 cfu/g platane wood chips.

Scanning electron microscopy

Pseudomonas sp. ZD8 immobilized onto the platane wood chips was observed under scanning electron microscopy. The platane wood chips with immobilized cells were compared to those without cells. For scanning electron microscopy, the platane wood chips were fixed with 2% (v/v) glutaraldehyde and 1% (v/v) osmium acid for 1 h. Samples were dehydrated in a graded series of ethanol concentrations [20%~99.5% (v/v) ethanol from 15 min to 30 min, twice], and dried to critical point by using the Critical Point Dryer. Samples were coated with Pt-Pd using Ion Sputter and observed at an accelerating voltage of 100 kV with scanning electron microscope.

Biofilter construction

A laboratory-scale experimental biofilter is shown in Fig.1.

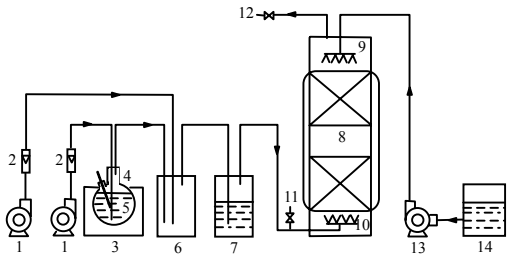

Fig.1 Flow chart of biofilter system

1: Air pump; 2: Flow meter; 3: Heating apparatus; 4: Lampblack reactor; 5: Thermometer; 6: Gas blender; 7: Humidifier; 8: Packing; 9: Spray thrower; 10: Gas distributor; 11: Inlet; 12: Outlet; 13: compressed water pump; 14: Reservior

The platane wood chips immobilized cells were packed into a glass column (250 mm×600 mm of working length). The basal medium contained in a humidification bottle was supplied to the immobilized cells by purging air through the humidification bottle. Relative humidity of 90% to 95% was routinely and continuously achieved during the operation. Rapeseed oil smoke at different concentrations was supplied to the column at varied flow rates. The experimental temperature was held at 30 °C.

Analysis of rapeseed oil smoke

Charcoal and XAD-2 tubes were used for the determination of rapeseed oil smoke, stored at −18 °C until analysis. Alkyl ester was dissolved into CCl_4 in tubes and analyzed by using a gas chromatography (HP 5890) coupled to a flame ionization detector (FID). A standard solution composed of eleven alkyl esters was used (Mixture FO 7, 90-1107, LOT NO: 6071:2, Larodan Fine Chemicals).

RESULTS AND DISCUSSION

Rapeseed oil smoke removal continuous operation

A long-term investigation into removal of different oil smoke concentrations was conducted at a flow rate of 1 m^3/h for 90 d. To evaluate the adaptability of *Pseudomonas* sp. ZD8 to this condition, the biofilter was supplied with 100 mg/m^3 rapeseed oil smoke for the first thirty days, and then a 600 mg/m^3 rapeseed oil smoke shock loading was fed for the remaining sixty days. The removal efficiency of rapeseed oil smoke is shown in Fig.2. After thirty days of start-up required, more than 97% removal efficiency was achieved at inlet with the concentration of 300 or 600 mg/m^3.

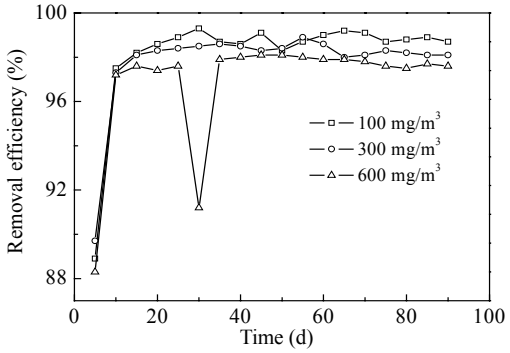

Fig.2 Rapeseed oil smoke removal efficiency of a biofilter at a rate of 1 m^3/h

However, when the concentration of rapeseed oil smoke supplied was increased from 100 mg/m^3 to 600 mg/m^3 during 30 d, a short-term decline in performance was observed. The biofilter required about 5 d for recovery of its microorganism oxidation ability.

Effect of retention time on rapeseed oil smoke removal

The effect of retention time in the biofilter on rapeseed oil smoke was studied by introducing 50 mg/m^3 rapeseed oil smoke to the biofilter at various flow rates, and the results are shown in Fig.3. The retention time of rapeseed oil smoke in the biofilter was calculated by the following equation:

$$RT=V/F$$

where RT is the retention time in seconds; V is the volume of platane wood chips (m^3); F is the flow rate (m^3/s).

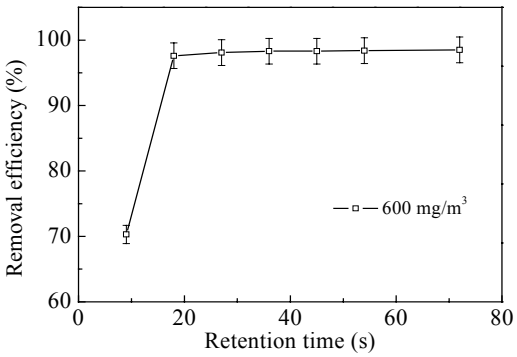

Fig.3 Effect of gas retention time on rapeseed oil smoke removal efficiency at 600 mg/m^3 of inlet gas. The removal efficiency required 15 d of operation to reach a steady state

High removal efficiency (≥90%) was achieved when the retention time was 9−72 s. When the retention time was shortened to 9 s, the removal efficiency decreased significantly.

Effect of temperature on rapeseed oil smoke removal

The effect of temperature on rapeseed oil removal efficiency was investigated from 15 °C to 50 °C and the results are shown in Fig.4. High removal efficiencies were consistently observed with little variation in range from 25 °C to 35 °C, regardless of whether inlet concentrations were high or low. However, the removal efficiencies dropped signifi-

cantly at the two extremes (15 °C or 50 °C) with greater reduction observed at 50 °C, which can be attributed to the sensitivity of the microorganism to high temperature. Based on removal efficiency, the optimum temperature for our system operation was 30 °C. This is near the optimum temperature for *Pseudomonas* sp. ZD8 cultivation in batch culture.

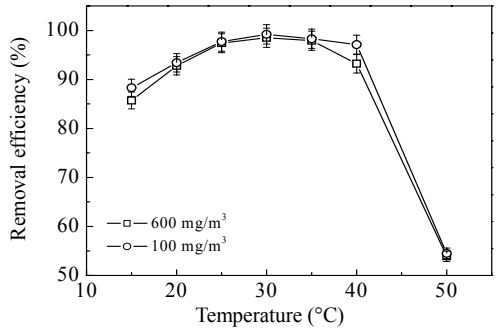

Fig.4 Effect of temperature on rapeseed oil smoke removal efficiency at a flow rate of 1 m^3/h

Effect of flow rate and inlet concentration on rapeseed oil smoke removal

The rapeseed oil smoke removal efficiency as functions of gas flow rates and rapeseed oil smoke concentrations are shown in Figs.5 and 6.

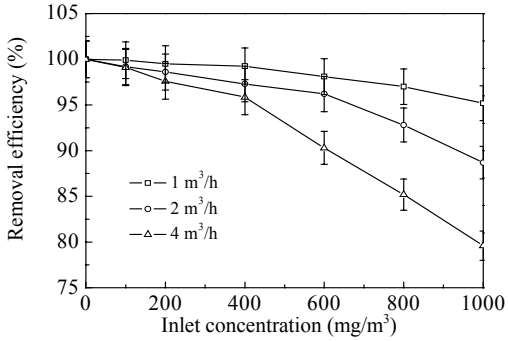

Fig.5 Rapeseed oil smoke removal efficiency versus inlet concentration at different flow rates

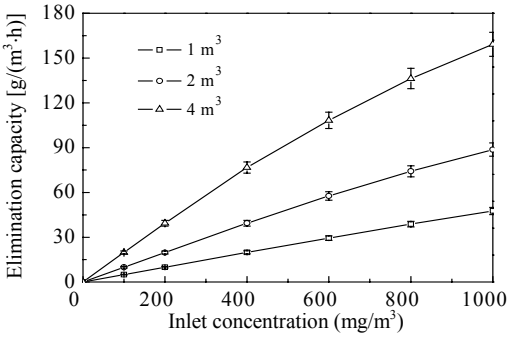

Fig.6 Elimination capacity versus inlet rapeseed oil smoke concentration at different flow rates

Removal efficiency decreased progressively with increasing gas flow rates and rapeseed oil smoke concentrations. Removal efficiencies of rapeseed oil smoke of 1 m^3/h to 2 m^3/h showed a little variation. Significant difference was noticed when the flow rate was increased to 4 m^3/h. Higher inlet concentration also had large effect on removal efficiency. The elimination capacity versus the inlet rapeseed oil smoke concentrations at different flow rates is shown in Fig.6. Note that an increase in gas flow rate from 1 m^3/h to 4 m^3/h resulted in almost doubled removal capacity, while increase from 1 m^3/h to 2 m^3/h resulted in increased improvement of removal capacity. Clearly, the gas flow rate strongly influenced both removal efficiency (Fig.5) and the removal capacity (Fig.6) when inlet concentrations were from 100 mg/m^3 to 1000 mg/m^3.

Criteria for designing a scale-up of biofilter

Complete rapeseed oil smoke removal can be only achieved below the threshold of a critical inlet loading. If beyond, rapeseed oil smoke will be detected at the outlet of the biofilter. Finding the optimal inlet loading is therefore important for the operation of the biofilter. The equation related to the inlet rapeseed oil smoke per unit time and volume of packing material [g/(m^3·h)] is expressed as follows:

$$Load=(F\times C)/V$$

where F is the flow rate (m^3/h), C is the inlet rapeseed oil smoke concentration (mg/m^3) and V is the volume of the platane wood chips (m^3).

Thus both gas flow rate and inlet gas concentration play important roles in designing a real scale-up biofilter if the volume of packing material is constant. The relationship between the inlet loading and the removal capacity for rapeseed oil smoke is shown in Fig.7.

It was obvious that the maximum inlet rapeseed oil smoke loading was approximately 160 mg/(m^3·h) and only 70% rapeseed oil smoke removal was achieved. If we considered the linear region between inlet loading and removal capacity, the optimal inlet loading should be 120 mg/(m^3·h). For example, when rapeseed oil smoke at high concentration is introduced into the biofilter, we must lower the flow rate of rapeseed oil smoke or increase the volume of packing materials to achieve optimal removal capacity. Conversely, we can increase the gas flow rate or

decrease the volume of packing materials in treating diluted concentration of inlet gas by using the scale-up criteria.

Microscopic observations

The platane wood chips without *Pseudomonas* sp. ZD8 immobilized on them were observed with electron microscopy (Fig.8). We can find that the platane wood chips had many intervals which were adaptive for microbe growth. After 30 d of the biofilter operation, the platane wood chips were covered with a layer of white biofilm, as shown in Fig.9. The thickness of the biofilm was 0.5 mm to 1.5 mm.

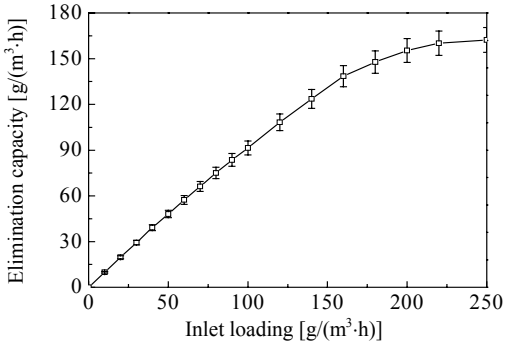

Fig.7 Relationship between the inlet loading and rapeseed oil smoke elimination capacity

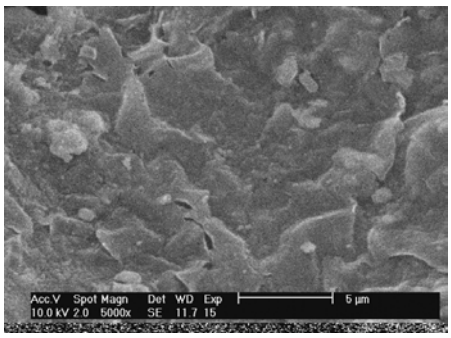

Fig.8 SEM of platane wood chips

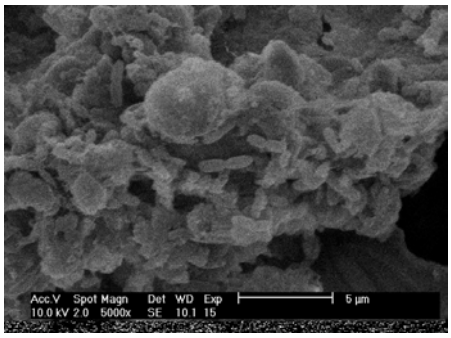

Fig.9 SEM of platane wood chips with immobilized *Pseudomonas* sp. ZD8 on them

CONCLUSION

Pseudomonas sp. ZD8, with rapeseed oil smoke removal capacity was isolated from contaminated soil. The experiment results showed that the biofilter has competent ability in eliminating rapeseed oil smoke over an extended period of time. Greater than 97% removal efficiency and excellent adaptability to adverse conditions have been demonstrated even at the level of a 6-fold shock loading. The optimal inlet rapeseed oil smoke loading for this biofilter is suggested to be 120 mg/(m^3·h).

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