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Investigation of factors on a fungal biofilter to treat waste gas with ethyl mercaptan

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Abstract: The biofilter is cost-effective for the waste gases treatment. The bacterial is the main microorganism in the conventional biofilters. However, it faces some problems on the elimination of hydrophobic compounds. In order to overcome these problems, the biofilters with fungi were developed. The objective of this study is to investigate the factors affecting ethyl mercaptan(EM)-degradation using a fungal biofilter. A laboratory experiment was set up. The effects of loading rate, empty bed residence times(EBRT) and pH on EM degradation were investigated. Over 95% removals of EM could be achieved, under the condition of the influent loadings below 80 g/(m·h). Removal efficiencies improved to 98% with EM loading decreased to 45 g/(m·h). For long EBRT of 58 s corresponding to a flow rate of 0.3 m^3/h, the EM removal efficiencies of over 98% were observed. However, when EBRT was decreased to 14 s, the removal efficiencies fell under 80%. The pH range of 3—5 was feasible to fungi.

Keywords: off-gas treatment; odor; ethyl mercaptan; biofilter; fungi

Introduction

Off-gases containing VOC and odors may do great harm to environment and people's health. There are many methods for treating them, such as physical methods, chemical methods and biological methods. Biological methods are widely applied in the process of off-gases purification for their low investment and operational costs. Biofilter is an economic and efficient biological technology for treating off-gases. In the biofilter, the off-gases are forced to rise through a packed bed attached microorganisms. It is especially good for cases with a large volume and a low concentration(Lim, 2001). Bacteria and fungi are two dominant microorganisms groups in the biofilter. Bacteria have the advantage of rapid substrate uptake and growth, and they are dominant in a conventional biofilter, although fungi are also present (Devinny, 1999). However, the conventional biofilter, based on compost and bacteria activity, faces some problems to eliminate hydrophobic compounds. Because of the low solubility in water, the hydrophobic compounds are poorly absorbed by the bacterial biofilms. Besides that, the biofilter operational stability is often hampered by acidification and drying out of the filter bed(van Groenestijn, 2002).

To overcome these problems, a biofilter with fungi on inert packing material has been developed. Fungi are more resistant to acid and dry conditions than bacteria, which is a helpful property when operating biofilters. Moreover, it is hypothesised that the aerial mycelia of fungi, which are in direct contact with the gas, can take up hydrophobic compounds faster than flat aqueous bacterial biofilm surfaces. In principle the application of fungi in biofilters may offer two advantages: (1) Stringent control of the water activity and/or pH in the filter bed is less important, since fungi are generally tolerant to low water activity and low pH. (2) Reduction of the water activity in the filter bed may improve the mass transfer of poorly water soluble waste gas compounds (Cox, 1993).

Relatively better growth of fungi at low pH compared with the average bacterial species is a well known fact. A low pH is a prerequisite for fungal development in the biofilter, coinciding with a high VOC elimination capacity(van Groenestijn, 2001).

Mercaptans are important impurities distributed among petroleum products. They are toxic and produce odor. Ethyl mercaptan(EM) can cause odor nuisance at a concentration as low as about 0.001 ppm (Schafer, 1995). EM can be produced from proteins degradation, the petroleum industry, waste and wastewater(Cha, 1999). According to characteristic of EM, fungi are more efficient than bacteria to degrade EM. Therefore, it is important that enriches EM-degrading fungi in a biofilter and develops an EM-degrading biofilter with fungi, which are stable at low pH and low water activity.

The purpose of this experiment is to investigate the effects of loading rate, EBRT, and pH on the performance for treating EM in off-gas to determine the optimal operating conditions of the biofilter with fungi.

1 Materials and methods

1.1 Biofilter with fungi

For EM treatment, a laboratory-scale biofilter was used. The experimental set-up is presented in Fig. 1. The volume of the biofilter was 4.8 L, with 0.75 m of height. Air from a blower was bubbled through an EM solution in a water-bathed Erlenmeyer flask to make volatile EM. Concentrations of EM in the gas phase could be varied by adjusting the temperature of the water bath. The EM-rich air was then mixed with a main air stream, which then flowed through the packing material. The airflow rates were adjusted by mass flow controllers. The gas entered the biofilter continuously from the top. The relevant operating conditions used during the test period are collected in Table 1. During start-up the biofilter was operated with an EM inlet concentration of 0.10 g/m^3 and a gas flow rate of 0.15 m^3/h, resulting in a specific EM load rate of 3.125 $g/(m^3 \cdot h)$.

Table 1 Operating condition ranges of fungal biofilter

Operating condition	Units	Operating range
Load rates	$gEM/(m^3 \cdot h)$	3—80
EM concentration	g/m^3	0.10—0.40
Gas flow rate	m^3/h	0.15—1.2
EBRT	Second	14—115
Gas temperature	℃	20—35

1.2 Media

Since the 1980s, some organic materials such as compost, peat and wood bark have been used as biofilter media. These media were found to have high removal capability due to high physical adsorption capability and water holding capacity, but also to have some

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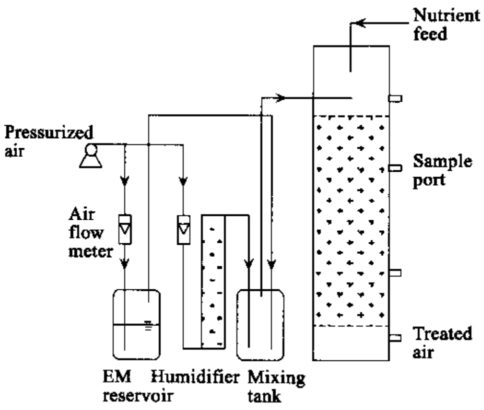

Fig.1 Schematic diagram of the fungal biofilter for off-gas treatment with EM

disadvantages, such as the media decomposition and compaction. Therefore, some media that can hold and maintain large amounts of active microbes, without degradation and distortion, were developed (Lim, 2001).

In order to overcome limitation of the conventional biofilter, a new biofilter medium, polyurethane foam was developed. The polyurethane foam was served as solid supports for microbial attachment(Golla, 1994; Kondo, 1992; Heidman, 1988; van Groenestijn , 2002). In the experimental system of Fig. 1, polyurethane foam cube with pore size 0.5 mm and weight 3.6 mg/cm^3 was used. The specific surface area of the polyurethane foam cubes was 320 m^2/m^3.

1.3 Nutrient

The nutrient solution was periodically added to the fungal biofilter to assure microbial activity. The composition of nutrient solution is shown in Table 2. There is no carbon and sulfur source in this nutrient.

Table 2 Nutrient medium provided to the fungal biofilter

Constituents	Unit	Concentration
$NaNO_3$	g/L	2.0
K_2HPO_4	g/L	1.0
KCl	mg/L	500
$MgCl_2$	mg/L	190
$Fe(NO_3)\cdot 9H_2O$	mg/L	15

1.4 Definitions and performance reporting

The performance of the experimental systems as elimination capacity(*EC*) or removal efficiency (*RE*) was expressed by Equation (1) and Equation (2). It is a function of the inlet and outlet gas concentrations($C_{g,in}$ and $C_{g,out}$), the air flow rate(Q) and the packed bed volume (V). The elimination capacity represents the amount of pollutant degraded per unit volume of fungal biofilter and time; it is often reported as a function of the pollutant loading(L) (Equation 3).

$$EC = \frac{(C_{g,in} - C_{g,out})Q}{V} \ (g/(m^3 \cdot h)), \quad (1)$$

$$RE = \frac{(C_{g,in} - C_{g,out})100}{C_{g,in}} \ (\%), \quad (2)$$

$$L = \frac{C_{g,in}Q}{V} \ (g/(m^3 \cdot h)). \quad (3)$$

2 Results and analysis

2.1 Experimental results

The flow rate of off-gas, EM concentrations and removal efficiency are shown in Fig.2 and Fig.3 respectively. The biofilter was operated with a low gas flow rate of 0.15 m^3/h to culture the fungi for degrading EM during start-up. The experimen was in steady state after an adaptation period of two months. The elimination capacity of EM in steady state was over 20 g/(m^3 · h), and the removal rates were over 90%. After 150 d of operation, *EC* was 26 g/(m^3 · h), and the removal rates of EM were over 99% (Fig.3). The experimental results showed that the fungal biofilter has a high elimination capacity to EM. The EM removal rates obtained in this study were significantly higher than that reported by other researchers using the bacteria biofilter(CWRTAICE, 1999).

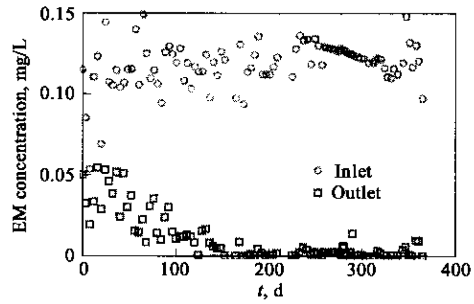

Fig.2 Ethyl mercaptan inlet and outlet concentrations during the fungal biofilter operation

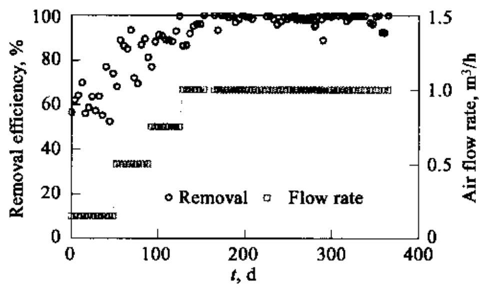

Fig.3 Evolution of the removal efficiency and the flow rate in the biofilter vs. time

2.2 Effect of loading rate on elimination capacity

The experimental results showed that maximum EM removal capacity of the biofilters was highly influenced by the concentration(or loading rate) of EM in the gas. In order to detect the highest capacity of the fungal biofilter, the relationship between inlet concentration and elimination capacity of EM was investigated(Fig. 4).

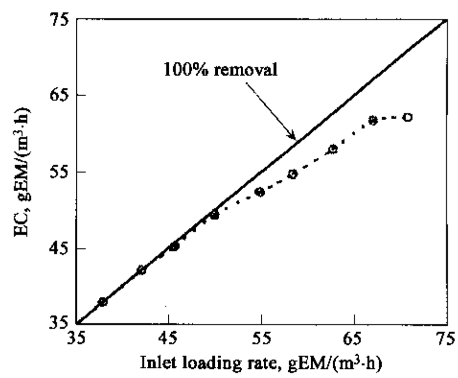

Fig.4 EM elimination capacity of the fungal biofilter as a function of inlet loading rate
Symbols represent the experimental data, while the solid line indicates 100% removal, and the dashed line depicts the regression results

The EM elimination capacity increased with increased inlet loading, but an opposite trend was observed for the removal efficiency. Greater than 95% removals could be achieved under inlet loadings below 50 gEM/(m^3 · h). Removal efficiencies improved to 98% with EM loading decreased to 45 g/(m · h). For higher inlet load, the EM removal is not complete and *EC* moves off the inlet load. *EC* then reaches the maximum value allowed to estimate the limits within which the biofilter functions. In this study, maximum elimination capacity (EC_{max}) of EM is 62 gEM/(m^3 · h). This reduction of removal efficiency of EM as a function of the load could be explained by the limitations of the microbial metabolisms (Aizpuru, 2001; Cook, 1999; McNevin, 2000). When loading rate (or inlet concentrations) preponderate over the maximum elimination capacity of the biofilter, the removal efficiency decreases.

2.3 Effect of EBRT on removal efficiency

In order to study the influence of airflow rate on the EM removal efficiency, the EM concentration in inlet gas was maintained at 0.40 g/m^3 and the airflow rate was changed to change EBRT. Fig.5 shows the impact of EBRT on the average removal efficiency of EM in the biofilter. It is to be noted that the removal efficiency increased with EBRT. Thus, for long EBRT of 58 s corresponding to a flow rate of 0.3 m^3/h, the EM removal efficiencies of over 98% were observed. A long EBRT was favorable for the EM degradation because the contact time between the microorganisms and EM was increased (Delhoménie, 2002). However, when EBRT was decreased to 14 s, the removal efficiencies of EM fell to under 80%. The reason of this result was that contacting time between the hypha and the EM was too short and microorganisms had insufficient time to perform the required degradation on the available amount of EM.

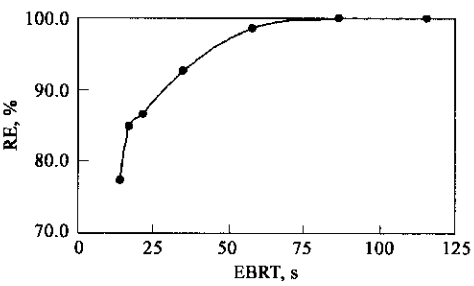

Fig.5 Influence of the EBRT on the removal efficiency of the biofilter

2.4 The effect of pH value

The pH value in the biofilter depending on the contaminant being treated and the characteristics of the microbial ecosystem. The optimal pH of the bacteria biofilter is in the 7—8 range. Changes of the pH value generally affect the microorganisms. Biodegradation of sulfur-containing organics lead to H_2SO_4 buildup. Process failure is the most dramatic result of acidic biofilters dominated by bacteria. Fungi grow relatively better at low pH compared with the average bacterial species (Lu, 2002; He, 2001).

The pH values of the nutrient feed and leachate were measured. It was found that the difference between the two pH values were within 0.1 pH units, which indicated that the pH of the environment within the fungal biofilter could be controlled by adjusting the pH of the nutrient feed. Fig.6 shows the removal efficiencies of EM as a function of pH of the nutrient feed. It was seen that EM removal efficiencies increased as the pH of the nutrient feed increased in the pH range of 2—4.

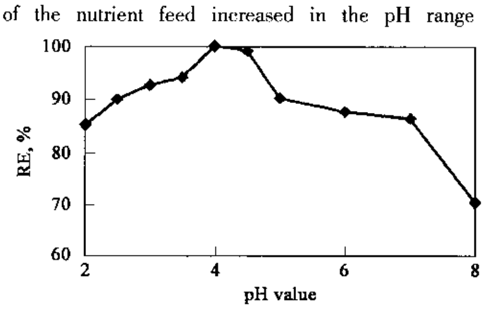

Fig.6 The relationship between the pH value and EM removal efficiency

However, an opposite trend was observed for pH between 4 and 8. This indicated that the most EM degraded fungi in the biofilter preferred a weak acidic environment. In the pH range of 3—5, the removal efficiencie of EM was over 90%.

3 Conclusions

The removal efficiency of EM in off-gas and some effect factors have been investigated using a bench-scale biofilter with fungi. The experiment carry on over one year, and the results are as follows:

The fungal biofilter can remove efficiently EM from off-gas. The elimination capacity of EM in steady state was over 26 g/(m^3·h), and the removal rates were over 99%.

The loading rate, EBRT and pH value have prominent effect on the elimination capacity of the fungal biofilter. In this study, the maximum elimination capacity of EM is 62 gEM/(m^3·h), however, corresponding removal efficiency is under 90%. If the loading rate of EM decreased to 45 g/(m·h), its removal efficiencies improved to 98%. In order to obtain a high removal efficiency of EM, about 1 min of EBRT and 3—5 of pH value are feasible.

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