

BIOFILTRATION TREATMENT of α -PINENE

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Abstract

This paper provides an overview of air biofiltration with experimental data on the performance of a synthetic media biofilter system. It is shown that use of high surface area per unit volume structured media results in higher contaminant treatment rates per unit biofilter volume. It is shown that use of specially designed synthetic media allows effective control of biomass buildup by continuous removal of biomass from the biofilter media and that the biomass removal rate depends on nutrient and biocatalyst flowrate.

Introduction

Remediation of contaminated air is needed to protect ecological and human health. Potentially cost-effective systems for remediating contaminated air use biological treatment to degrade or transform contaminants to innocuous residuals^{1,2}. The literature describes three major biological systems for treating contaminated air: bioscrubbers, biotrickling filters and biofilters. Bioscrubbers, which are not evaluated here, use counter current gas-liquid spray columns with microorganisms freely suspended in the aqueous phase. The contaminants, transferred to the recycling water during contact, have sufficient residence time in the system to be microbially degraded or transformed.

Biofilters and biotrickling filters use microbial populations immobilized on suitable support media to degrade or transform contaminants using biofilms. Filter media can be classified as: (1) fine or irregular particulates, such as soil, peat, compost or mixtures of these materials^{3,4}; (2) pelletized, which are randomly packed in a bed; and (3) structured, such as monoliths with defined passage size and geometry. The media can be made of sorbing materials, such as peat or activated carbon, or non-adsorbing, such as ceramic. The pelletized and structured media require recycled solution of nutrients and buffer for efficient microbial activity. Filters using recycled solution of nutrients and buffer are thus called bio-trickling filters; filters with fine particulates as media, referred to as biofilters, usually do not recycle solutions of nutrients and buffers to prevent media compaction and gas channeling and require pre-humidification of the contaminated air. To insure biofilter bed moisture, however, water may be intermittently sprayed at low flowrates. In addition, since biodegradation of contaminants may produce mineral acids, buffer solutions may also be sprayed intermittently to minimize acidification in the

biofilter. With overlapping operational methods, the term biofilter is used in this paper for filters with fine particulate, pelletized and structured media.

Biofiltration has been applied to remediate air contaminated with volatile organic compounds (VOCs) and other gases since the early sixties^{5,6,7,8}. Detailed studies of literature findings reveal that soil biofilters are relatively large compared to filters using other media, since soil pores are smaller and compounds have low permeability in soil^{7,8}. Soil biofilters also have limited depths due to problems associated with maintaining humidity in soil and minimizing pressure drop. Furthermore, soil sorption capacity is limited and residual contaminants are vented immediately to the atmosphere⁸.

Peat/compost biofilters are suitable for treating large volumes of air containing easily biodegradable VOCs at low concentrations^{9,10,11,12,13,14,15}. However, both soil and peat/compost biofilters are susceptible to channeling and maldistribution of the air stream. This leads to uneven biogrowth as well as drying of the bed. Both of these effects adversely impact biofilter performance. In soil and peat/compost biofilters, products of biomass decay cannot be washed out of the filters. Media replacement is required and the replacement interval has not been well established as a function of VOC loading. When VOCs contain organic chlorine, sulfur or nitrogen, the support media with solid buffers neutralize acidic degradation products.

To meet these needs, extensive work has been conducted by EPA's Risk Reduction Engineering Laboratory and the University of Cincinnati on biofilters with novel media and operational approaches^{16,17}. Support media used in these studies is a special high surface area, low bulk density, high void fraction, synthetic media, which is coated with a special surface layer which enables effective attachment of aerobic bacterial films. Control studies were also conducted to investigate adsorption/desorption of contaminants on the media in the absence of bioactivity.

The biofilters were operated continuously. The concentrations of the compounds and carbon dioxide in the inlet and the outlet streams (gas and liquid) were measured for each biofilter. The effluent nutrient solution was analyzed for pH, ammonia-nitrogen content and chloride ion concentration.

MATERIALS AND METHODS

Biofilter set-up

A typical experimental set-up of a biofilter bed packed with support media is shown in Figure 1. Experiments were run with gas flows in the range of 100 L/min to 500 L/min in an upflow mode, with the nutrients trickling downwards. Each biofilter consisted of a 4 inch ID cylindrical glass tube, with a Teflon grating for supporting the media. The biofilters received α -pinene in a concentration range from 1 – 500 ppmv in air. Air was contaminated with α -pinene by sparging it through a glass vessel containing

liquid α -pinene. Vapor concentrations of the contaminant were controlled by using gas proportioners.

Start-up procedure for the biofilters

Biomass from a pilot-scale activated sludge plant, treating hazardous waste, was suspended in an aerated aqueous phase bioreactor (column 100 mm diameter, 700 mm height). The bioreactor was fed daily with the VOC substrates. Nutrients, consisting of a mixture of mineral salts, yeast extract and trace elements were also added periodically. Biomass from the bioreactor was transferred to the biofilters by circulating the bioreactor suspension through the biofilter. Attachment of the biomass to the support was successful.

Nutrient composition

Constituents in deionized distilled water were: (1) mineral salts solution containing KH_2PO_4 , K_2HPO_4 , $\text{Na}_2\text{HPO}_4 \cdot 2\text{H}_2\text{O}$, NH_4Cl , $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, CaCl_2 and $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$; (2) trace salts solution containing $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, H_3BO_3 , $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ and $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$; (3) vitamin solution containing biotin, nicotinic acid, thiamine, p-aminobenzoic acid, pantothenic acid, cyanocobalamine and folic acid; or (4) yeast extract solution as a substitute for vitamin solution.

The nutrients also contained a specially formulated biocatalyst solution, which consisted of a mixture of enzymes, proteins, and fatty acids to accelerate the biological degradation of the contaminants.

Gas sampling Procedure and Analytical Method

Gas samples to characterize biofilter performance were collected from the inlet and outlet ports of the biofilter. Samples were collected in 250 mL glass sampling tubes by diverting the gas flow through the tubes for 1 hour. Each sampling tube had a side port septum for withdrawal of an analytical sample by gas tight syringe. The 250 microliter samples were injected into the gas chromatograph (Column: Restek 30 m, 0.32 mm i.d. column containing a 0.25 μm film of crossbonded 95% dimethyl-5% diphenyl polysiloxane). Pinene concentration was determined using a flame ionization detector (FID) at 275°C with an injection temperature of 225°C. All analyses were isothermal at an oven temperature of 125°C.

RESULTS AND DISCUSSION

Biofilter performances were expressed in terms of removal efficiencies of the compounds. Removal efficiency of the biofilter for each compound was calculated from the amount of compound removed per unit time in the biofilter, expressed as a percentage of the amount of that compound entering the biofilter per unit time. Biofilter design was not optimized for each operating condition, but rather a standard design was used in all our studies.

Abiotic adsorption studies with synthetic media did not exhibit any adsorption of α -pinene by the media material.

Biofilter Performance Studies

Table 1 shows the % Removal efficiency of the Biofilter as a function of superficial gas velocity through the biofilter column and inlet concentration of pinene in the gas-phase.

Table 1. % Removal Efficiency of α -Pinene as a function of Inlet Concentration (ppmv) and Superficial Gas Flowrate (Liters/minute).

Inlet Concentration (ppmv)	Gas Flowrate (Liters/minute)							
	100	120	200	250	300	350	400	500
50	99.8	100	99.8	99.7	100	99.6	99.5	99.2
100	100	99.8	99.4	99.0	99.2	99.1	98.2	98.0
200	99.3	100	99.1	99.0	98.3	98.5	90.4	95.7
300	100	99.4	99.0	99.2	96.4	95.2	91.0	93.6
400	92.1	94.5	93.6	90.3	92.5	90.1	88.4	85.2
500	97.1	94.5	92.1	90.4	86.2	80.1	76.3	72.6

It can be seen that at high concentrations and high gas flowrates, the removal efficiency declines lower than 95%. In small diameter columns, as in laboratory testing, bypassing of gas along the column walls can also lower removal efficiencies at higher flowrates. However, when the design is scaled-up, wall effects become negligible.

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Figure 1. Schematic of the experimental biofilter system.

